Changes in mountain birch forests and reindeer management: Comparing different knowledge systems in Sápmi, northern Fennoscandia

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Abstract

Mountain birch forests in the northern areas of Sápmi, the Saami homeland, serve as pastures for semi-domesticated reindeer. Recent reindeer management of the area has, to date, proceeded with little involvement of reindeer herders or their knowledge. To get more in-depth understanding of recent changes, we present together herders’ knowledge and scientific knowledge concerning the impacts of herbivory and climate change on mountain birch forests in three Saami communities in Norway and in Finland. Most of the herders interviewed reported changes in weather during the preceding decades. Herders agreed that the canopy and understorey of mountain birch forests have changed. The observed transformations in the quality of pastures have increased the financial costs of reindeer husbandry. Our study demonstrates that herders have practical knowledge of the present state and recent changes of birch forests, and of the responses of reindeer caused by these. This knowledge generally coincides with scientific knowledge. We call for better integration of knowledge systems and a better protocol for co-production of knowledge as it relates to more adaptive future reindeer management regimes. Such integration will facilitate understanding of cultural adaptation within rapidly changing social-ecological systems in which sustainable reindeer husbandry continues to be an important livelihood.

Introduction

Mountain birch (Betula pubescens spp. czerepanovii) is the predominant tree within the sub-arctic forest zone of northern Fennoscandia, which is situated between treeless upland fells and the coniferous forest zone at lower elevations (Fig. 1). As such, the mountain birch forest ecosystems are the most important source of primary production in the northern areas of Sápmi, the Saami homeland that encompasses much of northern Fennoscandia, including parts of Kola Peninsula (Lehtola, 2002; Wielgolaski, 2002).

Indigenous Saami have used mountain birch forests for several centuries in various ways: as a pasture for semi-domesticated reindeer (Rangifer tarandus tarandus) and for hunting, trapping, fishing, food and fuel gathering, raw material for handicrafts and construction, and also for spiritual purposes (Aikio & Müller-Wille, 2002; Crate, Forbes, King, & Kruse, 2010; Itkonen, 2008; Tømmervik et al., 2004; Wielgolaski, 2002). Reindeer themselves affect soil properties and the parastorey vegetation (ground lichen, graminoids and shrubs) is crucial when considering mountain birch forests as reindeer pastures. Mountain birch forests are cultural landscapes; intensity and spatial distribution of land uses, specifically reindeer grazing, has been shaped by cultural activities and socio-political processes for centuries (Bernes, Bråthen, Forbes, Speed, & Moen, 2015; Uboni et al., 2016).

Mountain birch forests in the northern areas of Sápmi, the Saami homeland, serve as pastures for semi-domesticated reindeer. Recent reindeer management of the area has, to date, proceeded with little involvement of reindeer herders or their knowledge. To get more in-depth understanding of recent changes, we present together herders’ knowledge and scientific knowledge concerning the impacts of herbivory and climate change on mountain birch forests in three Saami communities in Norway and in Finland. Most of the herders interviewed reported changes in weather during the preceding decades. Herders agreed that the canopy and understorey of mountain birch forests have changed. The observed transformations in the quality of pastures have increased the financial costs of reindeer husbandry. Our study demonstrates that herders have practical knowledge of the present state and recent changes of birch forests, and of the responses of reindeer caused by these. This knowledge generally coincides with scientific knowledge. We call for better integration of knowledge systems and a better protocol for co-production of knowledge as it relates to more adaptive future reindeer management regimes. Such integration will facilitate understanding of cultural adaptation within rapidly changing social-ecological systems in which sustainable reindeer husbandry continues to be an important livelihood.

Mountain birch is an important source of summer forage for reindeer; during winter reindeer feed mainly on the terricolic lichens, as well as dwarf shrubs, that grow on the forest floor. Access to winter forage is often difficult and energy expenditure of moving and foraging is increased, due to snow conditions (Kitti, Gunslay, & Forbes, 2006; Riseth et al., 2011). Deep or icy snow during the winter or late snow melt during the following spring may lead to high winter mortality of reindeer as well as to low calf survival (Eira, 2012; Kitti et al., 2006; Turunen, Rasmus, Bavay, Ruosteenoja, & Heiskanen, 2016). When the snow cover is deep or icy, reindeer look for the arboreal lichens that grow on the upper trunks and branches of birch (Sonesson, 2001).

In addition to accessibility of forage, the state of the understorey vegetation (ground lichen, graminoids and shrubs) is crucial when considering mountain birch forests as reindeer pastures. Herbivory and climate are considered as main factors affecting the mountain birch forests ecosystems of the region (Cairns, Lafon, Moen, & Young, 2007; Moen, Cairns, & Lafon, 2008; Tømmervik et al., 2004; Wielgolaski, 2002). Reindeer themselves affect soil properties
and microbial processes, plant species and vegetation diversity by grazing, trampling and through excrements (Bernes et al., 2015; Väisänen et al., 2014). Geometrid moths including autumnal (Epirrita autumnata) and winter moths (Operophtera brumata) have periodically great effect on the mountain birch (Helle, 2001; Neuvonen, Bylund, & Tømmervik, 2005; Fig. 2). Other herbivores (voles, lemmings and some invertebrates) (Anschlag, Broll, & Holtmeier, 2008), fire (Stocks et al., 1998), forest cutting (Veijola, 1998) and tourism (Forbes, Tolvanen, Wielgolaski, & Laine, 2005) also affect these ecosystems.

Autumnal moths appear episodically at approximately 10-year intervals (Tenow & Nilssen, 1990). A severe autumnal moth outbreak was experienced in our research area in 1965–66; significant outbreaks have been documented also in 1927 and 1955 (Kallio & Lehtonen, 1973). In the 1960s, autumnal moths defoliated sizeable areas of mountain birch forest in Ohcejohka commune in northernmost Finland; these areas have regenerated extremely slowly over the intervening five decades and are presently mostly treeless tundra (Neuvonen et al., 2005). During the years 2002–2008, both autumnal and winter moths caused spatially variable defoliation within the region (Jepsen, Hagen, Ins, & Yoccoz, 2008; Klemola, Andersson, & Ruohomäki, 2016). Studies in Arctic North America and northwest Eurasia have indicated an increase in tall deciduous shrub cover and abundance in response to climate change (Forbes, Macias-Fauria, & Zetterberg, 2010; Macias-Fauria, Forbes, Zetterberg, & Kumpula, 2012; Myers-Smith et al., 2011; Tape, Sturm, & Racine, 2006; Temmervik et al 2004). Higher temperature and increased precipitation are favourable for seed production of birch trees near the tree line (Wielgolaski, 2002). In the past, the tree line has migrated further north and to higher elevations when air temperatures have been high enough (Kullman, 2002). The effects of climate change on the mountain birch tree line can be difficult to isolate from other factors that affect it simultaneously (Emanuelsson, 1987; Hoegaard, 1997). For example, in northern Sweden, reindeer grazing keeps landscapes open and controls the deciduous tree line (Cairns & Moen, 2004).

In this work we relate two different knowledge systems, scientific knowledge and practitioners’ knowledge of local herders, to gain more in-depth understanding of the recent changes in the mountain birch forests of our research area. Scientific knowledge is accumulated through a formalised process and is most often explicit (written) and quantitative. Ecological and meteorological research is based on measurements (observations, monitoring, remote sensing), retrospective analyses, experimental manipulation of environment or on mathematical modelling. It aims at generalisations, replicability and objectivity (Huntington, Callaghan, Fox, & Krupnik, 2004; Raymond et al., 2010). In recent decades, a large and fast-growing body of literature has addressed the cultures carrying Indigenous Knowledge, Traditional Knowledge and Traditional Ecological Knowledge (TEK) (e.g. Agrawal, 1995; Alexander et al., 2011). The commonly used term TEK can be defined as “knowledge, practice and beliefs about the dynamic relationship of living beings with one another, and with their environment, which has evolved by adaptive processes, and has been handed down from generation to generation” (Berkes, 2008). In our case TEK can be understood as local, practitioners’ knowledge possessed by herders. Local knowledge is a wide term including several knowledge systems, also those classified as traditional and indigenous. It is thought to be developed by societies with long histories of interaction with their natural surroundings but it is not confined to certain inhabitant groups of the area (FAO, 2017; UNESCO, 2017). Also practitioners’ knowledge widens the scope of TEK to acknowledge the non-ethnic nature of knowledge gained in certain livelihoods by spending time on the land and evolving knowledge through practice and experience (Ingold, 2000). This knowledge has been gained over decades, most often
since childhood, and reflected in local practices (Forbes, 2006; Helander-Renvall, 2014; Vuojala-Magga, Turunen, Ryyppö, & Tennberg, 2011).

Practitioners’ knowledge of local herders has only relatively recently been integrated into studies on the status and management of mountain birch forests. Themes covered range from mountain birch forests as reindeer pastures (Aikio & Müller-Wille, 2002; Inga, 2007; Kitti et al., 2006; Vuojala-Magga & Turunen, 2015) to vegetation dynamics within the area (Horstkotte et al., 2017; Huntington et al., 2004). Also, the roles of extreme weather events (Vuojala-Magga et al., 2011) and snow conditions (Eira et al., 2013; Riseth et al., 2011) in herding have been discussed.

The understanding gained through relating different knowledge systems is especially needed in the planning of the northern land use and the management of reindeer herds. The post-WWII management regimes of reindeer herds within the respective Nordic countries have adhered to increasingly strict agricultural norms geared to maximise meat production, and while sustaining ground lichen reserves within winter pastures (Forbes, 2006; Forbes & Stammler, 2009). This approach has, to date, proceeded with little to no involvement of herders or their knowledge (Heikkinen, Sarkki, & Nuttall, 2012; Sarkki, Heikkinen, Herva, & Saarinen, 2018). This contrasts with the situation in Arctic North America, where co-management of renewable resources has been legally codified since the 1970s (Forbes & Stammler, 2009). Participatory action research, in which stakeholders and scientists collaborate and reflect on research implementation and interpretation, is relatively new in Nordic reindeer management (Hukkinen et al., 2006). As recently as 15 years ago, research directly involving reindeer herders was deemed too “political” in Finland (Kitti, 2004), and the admission of access to an area of science by “primitive and illiterate reindeer herders” (Magga, 2006) was dis-approved. Since then, however, participatory approaches to connect science, policy and society have become increasingly common (Armitage, Berkes, Dale, Kocho-Schellenberg, & Patton, 2011; Nilsson et al., 2019). New types of participatory methods are developing into a new norm in Nordic Arctic renewable resource management (Adenskog, 2018; Huntington et al., 2019; Jäske, 2018); participatory decision-making is believed to lead to more long-term, deliberate, inclusive and sustainable governance solutions. Emphasis on participation has been established as a general frame also in research funding (Armitage et al., 2011). Both national and EU Arctic strategies (European Commission, 2016; Prime Minister’s Office, 2013) have been developed to explicitly engage local stakeholders in research projects and land use planning processes. All of these developments call for research that is participatory, acknowledging the characteristics and potential of different knowledge systems.

This study is intended as a contribution towards the integration of distinct knowledge systems in Nordic mountain birch forests in the service of developing a better protocol for co-production of knowledge as it relates to more adaptive future reindeer management regimes. Our overall aim is to understand how the mountain birch forests dynamics are perceived, respectively, in reindeer herders’ and scientific knowledge systems. Specifically, we concentrate on knowledge pertaining to potential pathways from relatively closed mountain birch forest to open tundra, following massive herbivorous moth outbreaks in three localities within the Saami reindeer management region. To do so, we have collected the scientific and practitioners’ “ways of knowing” (sensu Kendrick, 2003) relevant to such moth outbreaks and describe the processes underlying the disappearance and regeneration, where relevant, of mountain birch forests, which function as reindeer rangelands. The main objectives are therefore to:

(1) assess herders’ perceptions of the key ecological drivers of birch forest rangeland dynamics following massive herbivorous moth outbreaks;
(2) present together herders’ perceptions of change and relevant findings within the scientific literature; and
(3) discuss the potential for future integration of practitioners’ knowledge in reindeer management regimes of Sápmi.

Fig. 2. Mountain birch forest before an autumnal moth outbreak without (a) and with (b) intensive reindeer herbivory, and after the outbreak (c). Photos: Otso Suominen.
Material and methods

Research area

The research area included the Saami communities of Máze (Masi) and Guovdageaidnu (Kautokeino) in Norway and Gáregasnjárja (Karigasniemi) in Finland. Ten herders were interviewed in Gáregasnjárja, nine in Máze and three in Guovdageaidnu. These communities are all situated within the sub-arctic zone; seasonal snow cover forms in the area typically in October and melts in May. The dominant tree in the area is mountain birch. The villages of Máze and Guovdageaidnu are located in the district Guovdajohtolat herding district, and in Guovdageaidnu (Kautokeino) municipality in Finnmark county; it is the largest municipality in Norway. Máze has approximately 400 inhabitants and about 1300 people live in Guovdageaidnu. Gáregasnjárja is located in the district Báisduottar herding district, and in Ohcejohka (Utsjoki) municipality; it has about 300 inhabitants. In the municipality of Ohcejohka, more than half of the inhabitants speak Saami as their native tongue and in the Guovdageaidnu municipality over 90% of the inhabitants speak Saami as their native tongue and in the Guovdageaidnu municipality over 90%

In each village, reindeer husbandry is an important livelihood; the surrounding territories serve as reindeer pastures, and 8–25% of the inhabitants of the Ohcejohka and Guovdageaidnu municipalities are reindeer herders (see Table 1). There are also other land users, for example, tourism, which of the most important form is moose (Alces alces L.) hunting. Herding practices of the area are based on Saami tradition. In this tradition (compared to small-scale herding combined with other livelihoods, practised in more southern, forested herding districts of Finland) herds are bigger, herding is more often based on pastoralism, and intensive supplementary winter feeding, especially feeding in enclosures, is seldom used (Helle and Jaakkola, 2008; Kitti et al., 2006). Herding work is organised through herding groups, súidas (Vuojala-Magga, 2012). Differences nevertheless exist between the practices of the herding communities. In northern Norway, reindeer generally move long distances between their summer and winter pastures. In Guovdageaidnu and Máze the winter pasture areas are situated inland, where lichen heaths dominate and summer pastures are by the sea, where vegetation consists of herbs and shrubs and there are also fewer biting insects compared to more heavily forested inland pastures. This represents a natural seasonal pasture rotation for reindeer. In difficult years (deep snow, icing of the ground), reindeer are given supplemental winter feed. The vicinities of the villages of Guovdageaidnu and Máze are utilised as transitional autumn/spring pastures. In Gáregasnjárja, Finland, reindeer graze more or less on the same areas year-round, even though some areas are protected from summer trampling. Annual slaughtering is nowadays conducted in autumn; this practice protects lichens pastures since fewer animals remain alive to forage throughout the winter. The reindeer have been herded with the aid of supplemental feeding (i.e. provided with forage along the way from one pasture area to another) in late winter since the 1990s. This practice is intended to reduce natural mortality, especially of pregnant females, during winters with deep or icy snow and maintain relatively consistent calf birth rates and weights from year to year. Detailed descriptions of the mountain birch forests of the research area are found in Neuvonen et al. (2005) and in Vuojala-Magga & Turunen (2015), of meteorological conditions in Vikhamar-Schuler, Hansen-Bauer, & Forland (2010) and in Rasmus et al. (2014), and of reindeer population dynamics in Uboni et al. (2016).

Knowledge systems on the impacts of herbivory and climate change on mountain birch forests

Interview methods

Semi-directed interviews were conducted with altogether 22 reindeer herders during 2007–2008. This comprises approximately 2.6 % of the herders of the Báisduottar and Guovdajohtolat herding districts (Table 1). Ten herders were interviewed in Gáregasnjárja, nine in Máze and three in Guovdageaidnu. We knew most of the herders beforehand in Gáregasnjárja, but not in Máze and Guovdageaidnu. One of us lived in two different families altogether one month. The interactions between the researchers and informants were thus not only based on interviews but on a mutual trust due to shared living experience. Participant observation transitioned to thematic interviews. Informants were found through the “snowball-method”
meaning that we asked each informant whom we should interview next. For interviews, we adhered to the research principles of the International Arctic Social Sciences Association (IASSA, 1998). The informants, all adults, consented to be interviewed and have approved the information and the sharing of it publicly, albeit anonymously. Sixteen of the herders were men and six were women. Their ages varied between 30 and 75 years, but most of them were 60–70 years old. People from different age groups were interviewed to obtain a broad sample set among the active and retired herders. The interviews were conducted either in Saami or in Finnish by two biologists and an anthropologist. It was an advantage that most of the participant observation and interviews could be conducted in Saami as this was the native language of most of the informants. In this paper, we present some Saami terms related to phenomena discussed when appropriate, but we do not present comprehensive analogues for all terminologies used. Saami terminology is designated via the use of italics throughout the text. The interviews were thematic, enabling the discussion of matters that the herders found interesting and important. As starting questions the herders were asked about the main characteristics of their pastures (e.g. topography, vegetation and the significance of mountain birch forests), their management practices, effects of geometrid moths, reindeer foraging and variation in weather on the amount and accessibility of forage on the pastures, and effects of these on reindeer husbandry. Subsequent to this step, discussions were left unstructured, but followed the themes which came naturally up. The temporal perspective of the processes discussed varied according to the theme: variation of weather was most often considered during the last 10–20 years, but for moth outbreaks and other rare events the time perspective was approximately 50 years.

The interview material was gone through and analysed thematically using a qualitative content analysis approach (Krippendorf, 1980). We sought to gain an interpretive understanding of the material, making comparison with scientific knowledge possible. From the material arose two central themes: changes in winter weather during recent decades, and changes in vegetation and effects of herbivory on reindeer pastures. Subthemes were: implications of changes in winter weather for reindeer husbandry; changes in birch forests; changes in understorey vegetation; effects of the moth outbreaks; and effects of reindeer grazing. Material related to these compiles the practitioners’ knowledge set used in this study. To protect the privacy of the informants, each person was assigned a code. Informants in Gárgaunjirga have codes G1–G10, in Máze the codes are M1–M9 and in Guovdageaidnu the codes are GG1–GG3. Letters without numbers (G, M, GG) refer to the reindeer herders of each village in general. Excerpts from 13 interviews are quoted in the text.

**Literature review methods**

Results of a complete meta-analysis of all studies on drivers of reindeer rangeland dynamics in northern Fennoscandia would not be commensurate with the practitioners’ knowledge described above and would not allow relevant comparison. Scientific knowledge concerning the central themes of the interviews was therefore compiled through a targeted literature review. A standard internet search using Google Scholar was performed from the recent literature starting with the broadest possible search terms. The main search terms were *Betula pubescens* spp. *czerepanovii* (or simply *Betula pubescens*) and mountain birch forest (or simply mountain birch). The approach was therefore comparable to the “snowball-method” utilised in the herders’ interviews (see Interview methods above), in that if a publication’s bibliography contained seemingly relevant citations, then those older publications would be checked as well. The time frame was eventually selected as the 1970s, when the outcomes of major moth outbreaks relevant for our study were first reported, up to the present. After the first step, publications were discarded if they were based on *B. pubescens* woodlands outside the geographical area of the study (e.g. Greenland, Iceland or central Norway). Similarly, if the study did not address central themes of the interviews (see Interview methods above), it was excluded. The publication types included in our review were peer-reviewed papers, book chapters and scientific reports. The literature search was performed both in English and Finnish. Approximately 200 references were screened, and about 80 cited. Of these, altogether 40 locally relevant references comprise the core of the scientific knowledge used in this study. The main results of these publications are collected in Tables 2 and 4, together with herders’ knowledge on central themes of the interviews. We compared the different knowledge systems both according to consideration of certain phenomena or process (has the issue been discussed?), and also according to the considered substance (i.e. coincidence of the knowledge systems; Huntington et al., 2004). Knowledge gaps and inconsistencies between the knowledge systems were also mapped.

**Results**

In this section, we go through the themes of the study, beginning by presenting herders’ experiences, based on interviews. These results are then discussed in the light of previous studies. See Tables 2 and 4 for summaries comparing herders’ knowledge and scientific knowledge concerning the changes in winter weather, and the changes in the vegetation cover in the research area, respectively.

**Changes in winter weather during recent decades**

Most of the herders reported specific changes in winter weather during the last 10–20 years (Table 2). Herders said that forecasting weather has become increasingly difficult and that weather changes more quickly. It has become more common even in midwinter that first it is raining and the next day the temperature is below 0°C. There are more often episodes of thawing (*njáhcu*) in midwinter, as well as extended periods of mild weather with a concomitant reduction in long periods of freezing temperatures (GG2). “For example, we were herding reindeer during Christmas 2007 and it was incomplete snow cover (girjehieda)” (GG2). Herders observe the quality and quantity of snow to estimate the conditions for moving, access to forage and herding (Eira et al., 2013). The Saami snow concept *goavi* relates to extremely poor grazing conditions due to deep or icy snow. According to herders, icing of the ground (*bodneskárta*) has become more frequent, as well as ice layers (*geartnit*) within the snow column. Herders have observed delayed snow cover formation in the autumn and earlier snowmelt in the spring.

Herders’ observations about warmer winters and shortened periods below 0°C coincide with the measurements of long-term climate trends for the Guovdageaidnu area (Vikhamar-Schuler et al., 2010, 2016) and northern Finland (Lépy & Pasanen, 2017; Vuojala-Magga et al., 2011). Delayed snow cover formation has been observed in some meteorological stations of the area by Rasmussen (2014), but Vikhamar-Schuler et al. (2010) observed
References to scientific literature have been sorted according to the local relevance, ** meaning high relevance (studies conducted in the same locations than our interviews) and * meaning low relevance (studies conducted in different locations than the interviews).

Snow depth of the area (Rasmus et al., 2014; Lépy and Pasanen 2017; Rasmus, Kumpula, & Jylhä, 2014; Vikhamar-Schuler et al., 2010) have not observed significant changes in the maximum annual snow cover depth. No significant change in the first day of the snow season. Studies have not observed significant changes in the maximum annual snow depth of the area (Rasmus et al., 2014; Lépy and Pasanen 2017; Rasmus, Kumpula, & Jylhä, 2014; Vikhamar-Schuler et al., 2010). Herders observations about earlier snowmelt agree with the meteorological records (Lépy and Pasanen 2017; Rasmus, Kumpula, & Jylhä, 2014; Vikhamar-Schuler et al., 2010).

Kivinen, Rasmus, Jylhä, and Laapas (2017) found that extremely cold weather events have significantly declined in all seasons during the past 100 years and extremely warm weather events increased particularly in spring and autumn. Vikhamar-Schuler et al. (2016) concentrated on exceptionally warm winter periods during the past century, often associated with rainfall and subsequent ground ice formation. These warm events have been frequent during 2000s, increasing in frequency during the study period.

### Implications of changes in winter weather for reindeer husbandry

The general consensus among interviewed herders was that the changes in the quality of pastures, particularly decreased access to forage and the amount of forage, have increased the number of working hours and altered herding practices (Table 3). Changes in snow conditions have negatively affected access to forage such that herding has become more difficult overall as a result (Table 3). There is a sense that pastures are becoming “locked” more often, meaning conditions which prevent reindeer reaching forage beneath the snow (heajos guohtun). “Locking” can be caused by (i) icing of the ground layer, which results from rain followed by freezing temperatures before there is adequate snow cover, or if the snow cover has melted completely during the winter; (ii) ice layers (geardni), which are caused by winter rain-on-snow or thaw events followed by freezing temperatures (one herder said that three discrete ice layers could effectively “lock” the pastures (GG3)); and (iii) snow drifts resulting from high snowfall in late winter, increased winds and high density of birch stems (Table 3). Two reindeer herders noted, “When there are more [shrub and mountain] birch, there will be more snow drifts” (GG1, GG2). Enhanced formation of snow drifts means that access to ground lichens can locally decrease, even if lichen cover remains undiminished.

Another finding reported by herders concerns the amount and consistency of snow. Animals keep busy and remain in one place when digging for forage below the snow (fieski). Adequate snow depth is needed for this, and as the timing of a complete snow cover has more frequently been delayed until late autumn, conditions for fieski tend to occur later than previously (GG2). One result is that herders are forced to manage their reindeer more intensively (GG2) (Table 3). When a complete snow cover was present earlier, the winter flocks used to be tamer and easier to handle since reindeer tended not to move outside of the fieski zone but turned

### Table 2. Comparison of herders’ knowledge and scientific knowledge concerning the changes in weather during the last decades in the research area

| Herders’ observations                     | Scientific knowledge                                           | Reference                                |
|-------------------------------------------|----------------------------------------------------------------|-----------------------------------------|
| More variable weather                     | No data                                                        |                                        |
| Warmer winters, long periods of freezing  | Number of days $<-15^\circ$C decreased, no change in mean winter | Vikhamar-Schuler et al. (2010)**        |
| temperatures reduced, thaw in midwinter   | temperature.                                                   |                                        |
| more common (GG)                          | Number of days $<-35^\circ$C decreased.                        | Vuojala-Magga et al. (2011)**          |
|                                          | Exceptionally warm winter periods more common.                 | Vikhamar-Schuler et al. (2010)**        |
|                                          | Shorter season with below 0°C temperatures, decline in extremely | Kivinen et al. (2017)**                |
|                                          | cold days.                                                    |                                        |
|                                          | Winters less severe (negative sum of degree days decreased).   | Lépy and Pasanen (2017)**              |
| Ice-crusted snow layers more common      | No change in number of rain-on-snow events after a cold period. | Vikhamar-Schuler et al. (2010)**        |
| (GG)                                     | More frequent ice formation in the snow cover.                 | Eira (2012)**                         |
|                                          | Exceptionally warm winter periods with melt or precipitation more | Vikhamar-Schuler et al. (2016)**       |
|                                          | common.                                                       |                                        |
|                                          | Number of freeze-thaw cycles increased.                        | Lépy and Pasanen (2017)*               |
| Ground ice more common (GG)              | No change in number of black frost days¹.                      | Vikhamar-Schuler et al. (2010)**        |
|                                          | More frequent ice formation in the snow cover.                 | Eira (2012)**                         |
|                                          | Exceptionally warm winter periods with melt or precipitation more | Vikhamar-Schuler et al. (2016)**       |
|                                          | common.                                                       |                                        |
|                                          | Increase in extremely warm events during autumn, leading to higher| Kivinen et al. (2017)**                |
|                                          | risk of ground ice.                                           |                                        |
| Thinner early winter snow covers (GG)    | Snow season duration shorter, no change in the first day of snow| Vikhamar-Schuler et al. (2010)**        |
|                                          | season.                                                        |                                        |
|                                          | Later snow formation.                                         | Rasmus et al. (2014)**                 |
|                                          | Snow cover duration shorter.                                  | Lépy and Pasanen (2017)*               |
| Deep snow cover forms later during the    | No change in max annual snow cover.                            | Vikhamar-Schuler et al. (2010)**        |
| winter (GG)                              | No significant change in max annual snow cover.                | Rasmus et al. (2014)**                 |
|                                          | No significant change in snow cover depth.                     | Lépy and Pasanen (2017)*               |
| Snow melts earlier (G)                   | Higher mean spring temperatures, earlier snow melt.            | Vikhamar-Schuler et al. (2010)**        |
|                                          | Earlier snow melt.                                            | Vuojala-Magga et al. (2011)**          |
|                                          | Snow cover duration shorter.                                  | Kivinen et al. (2017)**                |

¹Periods with snow-free ground and air temperature below 0°C during 1 September–31 August.

References to scientific literature have been sorted according to the local relevance, ** meaning high relevance (studies conducted in the same locations than our interviews) and * meaning low relevance (studies conducted in the northern Fennoscandian mountain birch region).
back by themselves. Now herders have to make temporary enclosures to keep reindeer within the designated areas (Table 3). At the same time, the aforementioned icing of the ground requires more effort, as herders need to move animals to unaffected areas or furnish animals with supplemental forage.

Interviewed herders have noted that the prolonged snow-free periods in both spring and fall have improved the availability of forage for reindeer and contributed to good condition of reindeer. “Snow melts here [in Gáregasnjárga] normally during Mother’s Day (11st May), but in the 2000’s it has not been the case, snow has melted earlier, but it has then snowed sometimes afterwards. Early snowmelt, mild weather and early start of the grass growth would be ideal for reindeer, it does not matter if it was cold in early summer, so long as snow melted, ponds of the mires dried, no insects developed” (G).

The effects of snow conditions reported by herders are congruent with scientific studies on this subject. Research has shown that deep or icy snow or late snow melt may lead to high winter mortality of reindeer as well as to low calf survival during the following spring (Helle & Kojola, 2008; Kumpula & Colpaert, 2003; Lee, et al., 2000). Satellite imagery from the Guovdageaidnu and johka areas (Tømmervik et al., 2004) parallels herders’ observations of increase in the abundance of mountain birch; birch grows faster and at higher elevations than previously (GG1, GG2). This has been observed particularly in coastal areas, but also further inland (Table 4). Willow does not spread as quickly as birch, but it is still expanding by increasing rapidly in height and cover (GG1). Herders generally felt that graminoids had become more abundant than before (Table 4). According to one herder, there are more mushrooms now than before, “reindeer are behaving crazier about them than in the past” (GG2).

At certain places within valleys, the mountain birch forest has become so dense that it is not possible for reindeer to utilise the areas (GG2). Within inland lichen heaths, the increase in birch forests and certain vascular understory plants affect reindeer husbandry and pasture quality negatively by reducing the amount of ground lichen cover. One mechanism is that the dense cover of fallen leaves in autumn within relatively closed forest canopies suppresses the growth of ground lichens. A positive effect of the increase in the birch forest is that the availability of fresh green forage in early summer during the lactation period is improved for the reindeer and their newly born calves.

Herders’ observations of decrease in lichens while birch and some graminoids (Deschampsia cespitosa, D. flexuosa) increase are consistent with research (Myers-Smith et al., 2011; Walker et al., 2006). Satellite imagery from the Guovdageaidnu and Kirájohka areas (Tømmervik et al., 2004) parallels herders’ observations on increases in the abundance of mountain birch. Abundance and height of woody plants are also increasing in other Arctic regions (Kääskö & Horskotte 2017; Myers-Smith et al., 2011; Normand et al., 2017; Tape et al., 2006).

Climate variability and change affect the growth conditions for mountain birch forests: temperature, precipitation and atmospheric nitrogen (Tømmervik et al., 2004). In recent decades, both forest and understory vegetation of Finnmark have developed in ways that reflect more oceanic conditions. For example, lichens have decreased and according to Tømmervik et al. (2004) one reason for this is that lichens grow slowly and some vascular plant species (like Cornus suecica, Vaccinium myrtillus) are better competitors under moist conditions. The documented increase in precipitation in the Finnmark area during the last century (Vikhamar-Schuler et al., 2010) is believed to be favourable for seed germination and growth of birch near the tree line (Kullman, 2002; Wielgolaski, 2002). Research on the abundance of mushrooms is scarce. Some results suggest that belowground fungal communities could be controlled by herbivory, and moth outbreaks could have a cascading effect on root-associated fungi (Saravesi et al., 2015).

### Table 3. The effects of climate change during the year on the quality of the pastures and working conditions of herders as revealed by the interviews

| Herders’ observations | PASTURE QUALITY | WORKING HOURS |
|-----------------------|----------------|---------------|
|                       | Amount of forage | Access to forage | Feeding | Herding | Making fences |
| More snow drifts      | ↓               | ↑              |          |
| More ice-crusted snow layers | ↓           | ↑              |          |
| More frequent icing of ground | ↓   | ↑              |          |
| Thin or non-existing early winter snow cover | ↓   | ↑           |          |
| Deep late winter snow cover | ↓   | ↑       |          |
| Earlier snow melt      | ↑(↑)           | ↓              |          |
| Decrease in lichen cover | ↓             | ↑              |          |
| Increase in birch      | ↓(↑)           | ↑              |          |
| Increase in oceanic plant species | (↑) | ↑         |          |

↑ increasing effect, ↓ reducing effect, (↑) increasing effect on summer forage.

**Changes in vegetation and effects of herbivory on reindeer pastures**

**Changes in vegetation cover**

Herders reported changes in vegetation cover, for example, an increase in the abundance of mountain birch; birch grows faster and at higher elevations than previously (GG1, GG2). This has been observed particularly in coastal areas, but also further inland (Table 4). Willow does not spread as quickly as birch, but it is still expanding by increasing rapidly in height and cover (GG1). Herders generally felt that graminoids had become more abundant than before (Table 4). According to one herder, there are more mushrooms now than before, “reindeer are behaving crazier about them than in the past” (GG2).

At certain places within valleys, the mountain birch forest has become so dense that it is not possible for reindeer to utilise the areas (GG2). Within inland lichen heaths, the increase in birch forests and certain vascular understory plants affect reindeer husbandry and pasture quality negatively by reducing the amount of ground lichen cover. One mechanism is that the dense cover of fallen leaves in autumn within relatively closed forest canopies suppresses the growth of ground lichens. A positive effect of the increase in the birch forest is that the availability of fresh green forage in early summer during the lactation period is improved for the reindeer and their newly born calves.

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Changes in vegetation caused by moth outbreaks

Despite herders’ observation about more abundant mountain birch within wooded areas, the effects of mass outbreaks of moths can overshadow this trend locally. Herders had noticed that there have been moth outbreaks more often than earlier (Table 4). This has had significant effects on the use of mountain birch forests as reindeer pastures. In areas affected by extensive outbreaks in Gáregasnjárga, herders observed that the vegetation composition and cover have changed, with important implications for reindeer husbandry. Defoliation and mortality of birch trees have impacts not only on the availability of winter forage, but also on the availability of summer forage. As one of the herders said: “Defoliation of birch forests by moth is significant for our [summer pasture] areas in Ohcejohka municipality and northern parts of Anár . . . one just cannot understand it . . . the summer of 2008 was saved for example because there was plenty of mushrooms, so that it was not possible to see the effect of birch defoliation by moths on calf slaughter weights [in autumn], it saved the calves, because there was so many mushrooms, it was a good time for reindeer” (G). Ohcejohka and Gáregasnjárga herders reported that both ground and arboreal lichens and birch have decreased and the abundance of graminoids has increased. They largely link these changes to the large autumnal moth outbreak in the 1960s, which affected upland mountain birch forest and fell areas. For reindeer husbandry, the net result was that winter pasture quality has declined because lichens constitute important winter forage (Table 3). The negative effects for reindeer husbandry are increased expenses and working hours because animals require more frequent movements in search of lichens and require costly supplemental feeding. A potential positive effect of the decrease in mountain birch forest is that when the areas have become treeless, there is less snow cover than earlier and the area can be used longer in late winter. Currently, these areas can serve as calving grounds (G).

Table 4. Comparison of herders’ knowledge and scientific knowledge concerning the changes in the vegetation cover in the research area

| Herders’ observations | Scientific knowledge | Reference |
|-----------------------|----------------------|-----------|
| Increase in birch (GG)| Increased birch growth favoured by prolonged growing season and increased precipitation. Establishment of birch facilitated by reindeer. | Tømmervik et al. (2004)** |
|                       |                      | Vikhamar-Schuler et al. (2010)** |
|                       |                      | Helle (2001)* |
|                       |                      | Wielgolaski (2002)* |
|                       |                      | Lempa et al. (2005)* |
|                       |                      | Tømmervik et al. (2009)** |
| Increase in shrubs (GG)| Increase in shrub cover due to climate warming | Kullman (2002)* |
|                       |                      | den Herder et al. (2004)* |
| Increase in graminoids (G, GG)| Increased graminoids as a result of moth outbreaks in defoliated forests. Increase in graminoids due to warming. Graminoids benefit from the significant grazing pressure. | Lempa et al. (2005)* |
|                       |                      | Walker et al. (2006)* |
|                       |                      | Bråthen and Oksanen (2001)* |
|                       |                      | Eskelinen and Oksanen (2006)* |
| Increase in vascular plants (GG)| Warmer and moister conditions favour vascular plants. | Tømmervik et al. (2004)** |
| Decrease in lichen cover (G, GG)| Lichen cover decreased due to reindeer grazing and trampling. | Moen and Danell (2003)* |
|                       |                      | Lempa et al. (2005)* |
|                       |                      | Bråthen et al. (2007)** |
|                       |                      | Tømmervik et al. (2009)** |
|                       |                      | Cohen et al. (2013)** |
|                       |                      | Reinert and Benjaminsen (2015)* |
|                       |                      | Tømmervik et al. (2009)** |
|                       |                      | Walker et al. (2006)* |
|                       |                      | Virtanen (2000)* |
| Decrease in arboreal lichen (G)| No data | See references on decrease in birch. |

References to scientific literature have been sorted according to the local relevance, ** meaning high relevance (studies conducted in the same locations than our interviews) and * meaning some relevance (studies conducted in the northern Fennoscandian mountain birch region).
Herders in Gáregasnjárga state that due to attacks by autumnal moths, most old birch trees died; in some areas, nearly all trees have disappeared and the ground vegetation cover has changed. “Defoliated forests are still visible, in 1968 from Gáregasnjárga to Inari for over 10–15 km, there used to be a birch forest, then green larvae came, there were 2–3 larvae on each leaf. There used to be a lichen pasture, a couple of years after autumnal moth came, grass started to grow, wavy hairgrass, which killed the lichen, reindeer were fat due to grass which grew there for several years, when grass was finished, mosses came, soil became nutrient-poor, trees were decayed . . .” (G). In Guovdageaidnu and Máze, there have not been severe autumnal moth attacks, though in recent years moth damages have increased (GG, M). Herders reported outbreaks of winter moth during the 2000s in these areas; even the leaves of cloudberries were eaten by moths in summer 2008 (GG2).

The greatest change is the increased amount of graminoids and a decrease in ground lichens, in particular fruiticose forms (Table 4). This has had a clear effect on the forage quality of winter pastures. In the herders’ words, “Grasses destroyed the pastures” (G). One of the herders (G6) noted that the quality of pastures has decreased because the amount of star-tipped reindeer lichen (Cladina stellaris) has declined. Herders claim that the forage value of winter pastures has declined because lichens, which form the basis of the winter diet of reindeer, have decreased though animals also consume some graminoids and shrubs in winter. Herders say that the decline in old birch trees means that arboreal lichens growing on the stems have also disappeared (Table 4). In earlier times, during late winter after the snow cover had hardened, reindeer would walk from tree to tree feeding on arboreal lichens, when available. Regeneration of the birch forest has been spatially variable in the Gáregasnjárga area. According to herders, forests have not recovered from previous autumnal moth outbreaks in fell areas, although at lower elevations there has been noticeable regeneration.

Scientific knowledge parallels herders’ observations that autum nal moth has a clear effect on birch forests and tree line. Severe out breaks are known to have a long-term influence on mountain birch ecosystems (Tenow, Bylund, Nilsen, & Karlsson, 2005). Herders in Gáregasnjárga and the scientific literature have both linked the loss of birch forest to major outbreaks of the autumnal moth, which in 1965–66 defoliated about 60% (1350 km²) of forested area in the vicinity of the community (Tenow et al., 2005). Herders’ observation that more birches died in fell areas than in the lowlands is congruent with research done in Ocejohka commune (Lehtonen, 1987). Especially in the vicinity of Geavvu (Kevo), birch grew very slowly and the area has long ago become treeless (Kallio & Lehtonen, 1973). Regeneration has been unsuccessful partly due to root rot that developed in the aftermath of the moth outbreak, the consensus among herders is that reindeer themselves inhibit the regeneration of birch forests. Some contend that damages could have been prevented: “All the adult birch should have been cut when the moon is growing (when evaporation is strongest), then the shoots would have grown back. Now the birch died along the roots” (G7). Herders also had a concrete suggestion for renewal of the area: “Defoliated areas should be left in peace even for a couple of years, so that seedlings could be growing in peace” (G).

As a key reason for the long-term loss of lichens, at least in Gáregasnjárga, herders see soil erosion related to the retreating forest due to moth outbreaks. One informant said: “Earlier birch protected the earth; now wind and water erode the soil” (G4). Nevertheless, some herders said that the large number of generally unsupervised reindeer in the 1980s also had an effect on the decrease in ground lichen. Reindeer were both from Finland and Norway, as the fence between Norway and Finland was not complete (G). In the vicinity of Gáregasnjárga, there is also a certain amount of overlap in the territories where reindeer graze and trample year-round.

Based on scientific knowledge, healthy mountain birch forests tolerate moderate grazing and may benefit from it and grow faster (Helle, 2001). Reindeer grazing can also facilitate the establishment of birch because trampling creates gaps in the vegetation for seedlings to grow on the fell areas, thus affecting the growth of birch up to 300 m in elevation (Lempa, Neuvonen, & Tömmervik, 2005; Tömmervik et al., 2009; Wielgolaski, 2002). However, strong grazing and trampling pressure are known to negatively affect the birch forests, and death of seedlings is a
common phenomenon in intensively grazed birch forests (Helle, Kajala, Niva, & Särkelä, 1998; den Herder, Kytöviita, & Niemelä, 2003; Lehtonen and Heikkinen 1995). Herders’ observations agree with the scientific literature that damaged (autumnal moth) or limited areas (enclosures, islands) affected by heavy grazing and trampling regenerate very slowly if grazing is continuous (Vuojala-Magga & Turunen, 2015). Herders stated that regeneration of mountain birch forests has not succeeded near Gáregasnjårga because reindeer trample the areas and eat seedlings. This is in agreement with many published scientific studies (Biuw et al., 2014; Bråthen et al., 2007; Kallo & Lehtonen, 1973; Lehtonen & Heikkinen, 1995; Moen & Danell, 2003; Tenow et al., 2005). Reindeer browsing has also been shown to be an important mortality factor for saplings in mountain birch forests defoliated by the outbreaks (Lehtonen & Heikkinen 1995).

The decrease in lichens in places where graminoids increase has been both observed by herders and also reported in the scientific literature (Table 4), but the explanations differ somewhat. There is agreement within the scientific literature that high reindeer density has negative effects on lichen cover. A decrease in lichen biomass due to reindeer grazing has been shown in several studies (Bråthen et al., 2007; Lempa et al., 2005; Moen & Danell, 2003; Reinert & Benjaminsen, 2015), and significant grazing pressure seems to also benefit graminoids to the detriment of lichens (Bråthen & Oksanen, 2001; Eskelinen & Oksanen, 2006). Especially, detrimental is year-round grazing with no pasture rotation, as dry lichens are easily crushed and the shattered fragments are susceptible to wind and water erosion (Forbes & Kumpula, 2009; Kumpula, Kurkilahti, Helle, & Colpaert, 2014; Kumpula, Stark, & Holand, 2011). In some experiments, increases in vascular plant biomass due to decreased reindeer grazing have caused lichen biomass to decrease (Virtanen, 2000). After grazing pressure has decreased, regeneration of lichen pastures can be relatively rapid (Pajunen, Virtanen, & Roininen, 2008; Tonnervik, Bjerke, Gaare, Johansen, & Thunnheiser, 2012).

Discussion

All of the interviewed herders had observed that both the canopy and understory of mountain birch forests in Guovdageaidnu–Máze and Gáregasnjårga areas have changed during the past 50 years. The changes in weather conditions and vegetation have significantly affected reindeer husbandry by transforming herding practices and increasing expenses.

Even though we do not aim at validation of either of the two “ways of knowing” presented here, such general comparisons enrich our understanding of recent changes and clarifies the useful features of the respective knowledge systems. The knowledge of herders concerning Nordic mountain birch forest dynamics in large part coincides with the existing scientific knowledge base. Active and retired herders possess practitioners’ knowledge that is clearly grounded in, and related to, specific events and processes. This extends back several decades, so within the lifespan of retired herders. Yet knowledge pertaining to extreme events may also be handed down for several generations (Forbes et al., 2016; Huntington et al., 2004). There were also interesting inconsistencies between the knowledge systems, as well as knowledge gaps. Scientific and practitioners’ knowledge may have relevance at different temporal or spatial scales. In climate research, the most common temporal depth is approximately 30 years, whereas ecological research (apart from long-term ecological monitoring) often concentrates on certain short periods (e.g. part of the growing season) within a long continuum. Quantitative measurements are often spatially limited, especially in sparsely populated areas. They may also be seasonally biased. Herders’ memories, on the other hand, may emphasise recent and extreme conditions, and to seasons and phenomena which are most relevant to reindeer herding. Emphasis on extreme events, and paying most attention to variables and changes which are most relevant to herding, such as “locked” winter pastures, are very useful for understanding what adaptive strategies have been deployed in different times and places and how they may be deployed in the future as the Arctic climate most likely continues to warm (Forbes et al., 2016; IPCC, 2019). It has been suggested that public debate, for example, on climate change impacts may influence herders’ perceptions on this topic. However, according to a global analysis by Marin and Berkes (2013), herders, hunters and fishers are well aware of the mainstream public climate change narrative, yet the media discourse does not override the knowledge gained through practice and direct experience.

Some phenomena observed by herders have not been reported within the scientific literature. These include, for example, changes in abundances of mushrooms. Beyond our study, the increase in weather variability has been reported by several northern or Arctic communities (ACIA, 2004; Huntington et al., 2004; Krupnik and Jolly 2002; Meredith et al., 2019). Scientific knowledge on the subject is scarce, regarding our research area, and results can be contradictory, partly due to incomplete understanding of the scales involved and measures of variability (e.g. Fischer and Knutti, 2014). In our interpretation, our informants were most often considering the rapid, intermittent changes in daily weather. In meteorological terms, this would mean a perceived decrease in weather persistence from one day to the next. To our knowledge, weather persistence of sub-Arctic Fennoscandia has not been explicitly studied.

On the other hand, not all processes or events reported by scientists were mentioned by our informants. The combined effects of herbivory and climate change on northern ecosystems have been recently studied (Biuw et al., 2014; Cairns & Moen, 2004; den Herder et al., 2004; Vorwes, Lovehav, Molau, & Björk, 2017), as well as combined effects of historical human activities and climate change (Normand et al., 2017) and potential feedbacks of herbivory on climate. Examples of these feedbacks include the reduction in deciduous shrub cover and height (cf. Kitti et al., 2009; Kolari et al., 2019), and the loss of fruticose lichen (Forbes & Kumpula, 2009; Helle & Jaakkola, 2008; Kumpula et al., 2014). The former increases albedo, especially during the snow-covered period, meaning decreased absorption of heat at the ground level or snow cover surface (stabilising feedback); the latter decreases albedo during the snow-free period, resulting in increased absorption of heat (reinforcing feedback) (Cohen et al., 2013; Olofsson et al., 2009). Although important, our analysis does not encompass these complex issues as they did not explicitly stand out from our interview material. In previous studies, the effect of summer temperature and insect harassment during hot summers on reindeer condition and reindeer husbandry has been seen as significant (e.g. Weladji, Holand, & Almøy, 2003). This did not appear as a central theme in our interviews.

Another example of contrasting views arose in the discussion of lichen pasture deterioration, erosion and potential overgrowing by reindeer herds. Herders openly acknowledge the keystone role of reindeer, especially regarding how heavy trampling and grazing of seedlings impeded regeneration of mountain birch forests following massive moth outbreaks. The role of herbivorous moths...
is nevertheless seen as highly significant in terms of triggering a sequence of events in the transition from mountain birch forest to treeless tundra, and the well-documented retreat of the forest after massive moth outbreaks is considered to be the overriding driver in this transition. In the scientific literature, and in the media (Ruuikki 2016), reindeer trampling is often seen as a main explanatory factor of erosion (e.g. Uhlig & Zink 2006; Helle & Jaakkola 2008).

The scientific observations reviewed had varying relevance across scales (Tables 2 and 4). Most of the scientific literature on weather changes (Table 2) had high local relevance (conducted in the same locations as our interviews) and coincided with local practitioners’ knowledge. Scientific knowledge on changes in the vegetation cover (Table 4) is, in some cases, based on literature with lower local relevance (conducted in the northern Fennoscandian mountain birch region, but not in the same locations as our interviews). This was the case with research on increases in shrubs and graminoids. Several studies concentrating on decreases in lichen cover and increases in birch and vascular plants had high local relevance. In addition, literature on decreases in mountain birch due to moth outbreaks and inhibited regeneration due to reindeer grazing included several locally relevant studies.

Our results confirm the conclusions of recent studies in which local or practitioners’ knowledge on northern ecosystems have been related with scientific findings (e.g. Riseth et al., 2011; Eira et al., 2013; Helander-Renwall, 2014; Horstkotte et al., 2017).

There is a need to better understand and relate herders’ knowledge of past and ongoing changes with scientific studies in order to more sustainably manage reindeer rangelands in the contemporary milieu of multiple users (Bernes et al., 2015; Horstkotte et al., 2017). As national and international research funding calls and Arctic strategies demand more inclusive stakeholder involvement (European Commission, 2016; Prime Minister’s Office, 2013), it is critical to see where scientific and practitioners’ knowledge both converge and diverge, so that future research and decision-making can better incorporate different “ways of knowing” (sensu Kendrick, 2003). Especially, important is that practitioners can put observed events and processes into a locally relevant perspective, and enrich the meteorological and ecological data with aspects like experiences, impacts and coping. Also, local herding practices leading to measurable outcomes (e.g. vegetation changes, cf. Cohen et al., 2013; Horstkotte et al., 2017; Kolari et al., 2019) can be afforded their proper social-ecological context. Practitioners’ view can also bring forth new research questions.

The herders interviewed have applied their knowledge to comprehend remarkably detailed patterns of pasture extent, conditions and forage dynamics in space and time. Reindeer husbandry has functioned within the region for centuries, while simultaneously altering mountain birch forests (Horstkotte et al., 2017). The determining role of scientific knowledge in the management regime of reindeer herds of our research area has still been indisputable during the past decades (Hukkinen et al., 2006), as has been the low local decision-making power (Heikkinen et al., 2012; Sarkki et al., 2018). Herders have seldom been seen as “local managers”, making the actual management decisions based on their practitioners’ knowledge.

An example of the very recent emphasis on participation, and approaches that connect science, policy and society, is the process of setting the maximum reindeer numbers in Finland. Reindeer management in Finland belongs under the jurisdiction of the Ministry of Agriculture and Forestry (MAF). Every 10 years, MAF sets the maximum number of reindeer for each herding district. Already 30 years ago (MAF, 1989), it was suggested to allow more decision-making power to herding districts. However, maximum numbers have continuously been set according to the ecological carrying capacity of winter pastures, as estimated by the state-funded and mandated processes aimed at minimising conflicts with forestry and agriculture (MAF, 1989, 1999). The most recent process, setting the maximum numbers for the period of 2020–2030, generally succeeded in involving several stakeholders, including local herding communities, and recommendations were at least partly based on the scientific and practitioners’ knowledge (MAF, 2019). It is noteworthy that researchers involved in the process considered co-planning and local participation as central methods in the northern land use management (Kumpula et al., 2019a, 2019b).

Reindeer husbandry shares the same operational space with several other land users in northern Fennoscandia, encompassing the Sápmi region. Intensifying land use such as forestry, mining industry and tourism has contributed to decreased, fragmentation and degradation of the pastures (Kumpula et al., 2014; Pape & Löfler, 2012). Unlike in North America, where Arctic indigenous people have a legal right to participate in the co-management of living resources, access to reindeer rangelands in Sápmi depends on usufruct rights (Forbes and Stammler, 2009). Decades of top-down reindeer management have led to distrust of governance institutions (Forbes et al., 2006). A central question in future land use planning is how different actors can use the natural resources without significantly degrading the resources and reducing the range of options for use by others. Co-production of knowledge where both scientific findings and local information are combined facilitates the incorporation of qualitative aspects into the discussion (Markkula, Turunen, & Kantola, 2019). It provides locally valid information concerning how to prepare for the future (Huntington et al., 2004; UNESCO, 2017) and facilitates integrated understanding and in land use planning processes (Horstkotte et al., 2017; Raymond et al., 2010; Sandström et al., 2003).

All knowledge systems involved need to participate in a mutually respectful dialogue to determine which approach is the most desirable, and to what outcome. True integration in fact is the crux of the interactions among knowledge systems (cf. Gratani et al., 2011). As the de facto practitioners of reindeer management over generations in the mountain birch forest and adjoining fell tundra zones, a meaningful role for Sámi reindeer herders would be justifiable in the process. Viable reindeer rangelands should meet not only the biological needs of the reindeer itself, but also suit the herders’ sociocultural imperatives, such as passing on their particular ways of knowing in variable geographical and social-ecological contexts, to the next generation (Forbes et al., 2006; Laakso 2008; Ostrom, 2011).

Conclusions
Our results show that through a participatory research approach a rich body of knowledge can be assembled, and that the different knowledge systems, or “ways of knowing”, can coalesce from distinct yet complementary bases. It is nevertheless anticipated that further integration of these knowledge systems and better protocols for co-production of knowledge are critically needed in the near future. Learning on “how to relate knowledge from different systems for the purpose of improved decisions and solutions” is called for by IPCC (2019), as well.
This study has demonstrated that reindeer herders have relevant and practical knowledge of the present state and recent historic changes of the mountain birch forest ecosystem in northern Fennoscandia. In northern Canada and Alaska, the value of practitioners' knowledge has been recognized legally through land claims and has become progressively integrated into research and administration (Forbes & Stammel 2009). At present, ecosys-

tem management of Fennoscandia is based primarily on scientific knowledge when it comes to state administrative and regulatory regimes. Practitioners' knowledge does not have the same status and has not been properly accounted for in laws and regulations. As such, the acceptance of practitioners' knowledge is generally much more contested and conflicted in the policy arena, than as an academic inevitability (cf. Sara 2011; Turi and Keskitalo 2014; Benjaminsen, Reinert, Sjaastad, & Sara, 2015). We conclude that better integration of practitioners' knowledge with scientific knowledge will improve critical understanding of cultural land use patterns, cultural adaptation to local ecosystems and sustainable development of local communities where reindeer husbandry remains an important livelihood.

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References

ACIA. (2004). Impacts of a Warming Arctic: Arctic Climate Impact Assessment (ACIA) overview report. Cambridge: Cambridge University Press.

Adenskog, M. (1995). Dismantling the divide between indigenous and scientific knowledge. Development and Change, 26(3), 413-439.

Aikio, M. S., & Müller-Wille, I. (2002). Living at the timberline: The Sámi and the mountain birch forests in northernmost Europe. In S. Kankaanpää, L. Bernes, C., Bråthen, K., Forbes, B., Speed, J., & Moen, J. (2015). What are the impacts of reindeer/caribou (Rangifer tarandus) on arctic and alpine vegetation? A systematic review. Environmental Evidence, 4(1), 1-26.

Anschlag, K., Broll, G., & Holtmeier, F.-K. (2008). Mountain birch seedlings in the mountain birch forests in northernmost Europe. In S. Kankaanpää, L. Bernes, C., Bråthen, K., Forbes, B., Speed, J., & Moen, J. (2015). What are the impacts of reindeer/caribou (Rangifer tarandus) on arctic and alpine vegetation? A systematic review. Environmental Evidence, 4(1), 1-26.

Barrio, L., Lindén, E., To Beest, M., Olofsson, J., Rocha, A., Soininven, E., . . . Kozlov, M. (2017). Background invertebrate herbivory on dwarf birch (Betula glandulosa-nana complex) increases with temperature and precipitation across the tundra biome. Polar Biology, 40(11), 2265–2278. doi: 10.1007/s00300-017-2139-7

Benjaminsen, T. A., Reinert, H., Sjaastad, E., & Sara, M. N. (2015). Misreading the Arctic landscape: A political ecology of reindeer, carrying capacities, and overstocking in Finnmark, Norway. Norsk Geografisk Tidskrift-Norwegian Journal of Geography, 69(4), 219–229.

Berkes, F. (2008). Sacred Ecology. New York: Routledge.

Bernes, C., Bråthen, K., Forbes, B., Speed, J., & Moen, J. (2015). What are the impacts of reindeer/caribou (Rangifer tarandus) on arctic and alpine vegetation? A systematic review. Environmental Evidence, 4(1), 1-26.

Biup, M., Jepsen, J., Cohen, J., Ahonen, S., Tejevi, M., Aikio, S., . . . Ims, R. A. (2014). Long-term impacts of contrasting management of large ungulates in the arctic tundra-forest ecotone: Ecosystem structure and climate feedback. Ecosystems, 17, 890-905.

Bråthen, K. A., Ims, R., Yoccoz, N., Fauchald, P., Tveraa, T., & Hausner, N. (2007). Induced shift in ecosystem productivity? Extensive scale effects of abundant large herbivores. Ecosystems, 10(5), 773-89.

Cairns, K. A., & Oksanen, J. (2001). Reindeer reduce biomass of preferred plant species. Journal of Vegetation Science, 12(4), 473-480.

Cairns, D. M., Lafon, C., Moen, J., & Young, A. (2007). Influences of animal activity on treeline position and pattern: implications for treeline responses to climate change. Physical Geography, 28, 419-433.

Cairns, D. M., & Moen, J. (2004). Herbivory influences tree lines. Journal of Ecology, 92, 1019–1024.

Cohen, J., Pulliainen, J., Ménard, C.B., Johansen, B., Oksanen, L., Luojus, K., & Ikonen, J. (2013). Effect of reindeer grazing on snowmelt, albedo and energy balance based on satellite data analyses. Remote Sensing of Environment, 135, 107–117.

Crée S. A., Forbes, B. C., King, L., & Kruse, L. (2010). Contact with nature. In I. N. Larsen, P. Schweitzer, & G. Fondahl (Eds.), Arctic Social Indicators: A Follow-up to the Arctic Human Development Report (TemaNord 519) (pp. 109–127). Copenhagen: Nordic Council of Ministers.

den Herder, M., Kyttöviita, M.-M., & Niemellé, P. (2003). Growth of reindeer lichens and effects of reindeer grazing on ground cover vegetation in a Scots pine forest and a subarctic heathland in Finnish Lapland. Ecography, 26, 3–12.

den Herder, M., Virtanen, R., & Roininen, H. (2004). Effects of reindeer browsing on tundra willow and its associated insect herbivores. Journal of Applied Ecology, 41, 870–879.

Eira, I. M. G. (2012). The silent language of snow: Sámi traditional knowledge of snow in times of climate change. PhD dissertation. Tromso: University of Tromso.

Eira, I. M. G., Jaedicke, C., Magga, O. H., Maynard, N. G., Vikhamar-Schuler, D., & Mathiessen, S. D. (2013). Traditional Sami snow terminology and physical snow classification – Two ways of knowing. Cold Regions Science and Technology, 85, 117–130. doi: 10.1016/j.coldregions.2012.09.004

Emanuelsson, U. (1987). Human influence on vegetation in the Torneträsk area during the last three centuries. Ecological Bulletins, 38, 95–111.

Eskelinen, A., & Oksanen, J. (2006). Changes in the abundance, composition and species richness of mountain vegetation in relation to summer grazing by reindeer. Journal of Vegetation Science, 17(2), 245–254.

European Commission. (2016). An integrated European Union policy for the Arctic. URL: https://eeas.europa.eu/arctic-policy/eu-arctic-policy_en (assessed 20 November 2019).

FAO (Food and Agriculture Organization of United the Nations). (2017). What is local knowledge? URL: http://www.fao.org/docrep/007/y5610e/y561001.htm (assessed 24 October 2018).

Fischer, E., & Knutti, R. (2014). Impacts: Heated debate on cold weather. Nature Climate Change, 4, 537–538. doi: 10.1038/nclimate2386

Forbes, B. C. (2006). The challenges of modernity for reindeer management in northernmost Europe. In B. C. Forbes, M. Böltör, L. Müller-Wille, J. Hukkanen, F. Müller, N. Gunsay, & Y. Konstantinov (Eds.), Reindeer Management in Northernmost Europe: Linking Practical and Scientific
ground lichens (Cladonia spp.) in pastures grazed by semi-domesticated reindeer in Finland. Regional Environmental Change, 14(2), 541–559.

Kumpula, J., Siitari, J., Siitari, S., Kurkilähtii, M., Heikkinen, J., & Oinonen, K. (2019a). Reindeer herding area winter pasture inventory 2016–2018: Changes in winter pasture status and reasons for changes. Natural Resources and Bioeconomy Research 33/2019. Helsinki: Natural Resources Centre. 86 pp. (in Finnish)

Kumpula, J., Stark, S., & Holand, O. (2011). Seasonal grazing effects by semi-domesticated reindeer on subarctic mountain birch forests. Polar Biology, 34, 441–453.

Laakso, A. M. (2008). The shadow field of reindeer management: a case study from Finland. Acta Boracuelae, 25(2), 138–159. doi: 10.1080/080083 830802496763

Landbruksdepartementet. (2016). Ressursregnskapet for reindriftsrinnen 2015–2016 (Report of reindeer herding 2015–2016). Landbruksdepartementet Rapport 24/2016.

Lee, S. E., Press, M. C., Lee, J. A., Ingold, T., & Kurttila, T. (2016). Ressursregnskapet for reindritsnæringen i Norge (Statistics of Reindeer Numbers, 2015–2016). Boliger og områdeutbytte need for reindeer herding in northern Sweden. Ambio, 45(4), 398–414. doi: 10.1007/s13280-015-0762-5

Rasmus, S., Kivinen, M., & Irnanneshad, M. (2018). Basal ice formation in Northern Finland snow covers during 1948–2016. Environmental Research Letters, 13, 114009. doi: 10.1088/1748-9326/aaae541

Rasmus, S., Kumpula, J., & Jylhä, K. (2014). Suomen poronhoitoaikuaan muut- tuvat talviset sää ja lumiosoluheitteet (Changing winter conditions in the Finnish reindeer herding area). Tierra, 126(4), 169–185.

Raymond, C., Fazey, I., Reed, M., Stringer, L., Robinson, G., & Evely, A. (2010). Integrating local and scientific knowledge for environmental management. Journal of Environmental Management, 91, 1766–1777. doi: 10.1016/j.jenvman.2010.03.023

Reinert, H., & Benjaminsen, T. (2015). Conceptualizing resilience in Norwegian Sámi reindeer pastoralism. Resilience, 3(2), 95–112.

RHA (Reindeer Herders Association). (2017). Statistics of Reindeer Numbers, 2015–2016. Rovaniemi: RHA.

Riista- ja kalatalouden tutkimuslaitos. (2013). (2011). Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. Polar Record, 47(3), 202–217. doi: 10.1017/S0032040710000434

Ruukki, J. (2016). Reindeer factory farming is an environmental risk. Helsingin Sanomat, 19.09.2016. (in Finnish)

Sandström, P., Pahlén, T. G., Edestus, I., Tommervik, H., Hagner, O., Hemberg, L., … Mäkiä, E. (2003). Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. Ambio, 32, 557–567.

Sara, M. N. (2011). Land usage and sida autonomy. Arctic Review, 2(2).

Sarasvai, K., Aikio, S., Walli, P. R., Ruotsalainen, A. L., Kaukonen, M., Huusko, K., … Markkola, A. (2015). Moth outbreaks alter root-associated fungal communities in subarctic mountain birch forests. Microbial Ecology, 69(4), 788–797. doi: 10.1002/micr.00577-8

Saravesi, K., Aikio, S., Walli, P. R., Ruotsalainen, A. L., Kaukonen, M., Huusko, K., … Markkola, A. (2015). Moth outbreaks alter root-associated fungal communities in subarctic mountain birch forests. Microbial Ecology, 69(4), 788–797. doi: 10.1002/micr.00577-8

Saravesi, K., Aikio, S., Walli, P. R., Ruotsalainen, A. L., Kaukonen, M., Huusko, K., … Markkola, A. (2015). Moth outbreaks alter root-associated fungal communities in subarctic mountain birch forests. Microbial Ecology, 69(4), 788–797. doi: 10.1002/micr.00577-8
Sarkki, S., Heikkilä, H. I., Horva, V. P., & Saarinen, J. (2018). Myths on local use of natural resources and social equity of land use governance: Reindeer herding in Finland. *Land Use Policy, 77*, 322–331. doi: 10.1016/j.landusepol.2018.05.055

Sonesson, M. (2001). Ecology of some epiphytic lichens on the mountain birch. In F. E. Wielgolaski (Ed.), *Nordic Mountain Birch Ecosystems* (pp. 63–76). Paris and Parthenon, New York and London: UNESCO.

Stock, B. J., Forsberg, M. A., Lihnam, T. J., Mears, L., Wotton, B. M., Yang, Q., … McKinney, D. W. (1998). Climate change and forest fire potential in Russian and Canadian boreal forests. *Climatic Change, 38*, 1–13.

Tape, K., Sturm, M., & Racine, C. H. (2006). The evidence for shrub expansion in northern Alaska and the Pan-Arctic. *Global Change Biology, 12*, 686–702.

Tenow, O., Bylund, H., Nilsen, A. C., & Karlsson, P. S. (2005). Long-term influence of herbivores on northern birch forests. In F. E. Wielgolaski (Ed.), *Plant Ecology, Herbivory and Human Impact in Nordic Mountain Birch Forests* (pp. 165–181). Berlin: Springer.

Tenow, O., & Nilsen, A. (1990). Egg cold hardiness and topoclimatic limitations to outbreaks of *Epirrita autumnata* in northern Fennoscandia. *Journal of Applied Ecology, 27*, 723–734.

Tømmervik, H., Bjerke, J., Gaare, E., Johansen, B., & Thanhnheiser, D. (2012). Rapid recovery of recently overexploited winter grazing pastures for reindeer in northern Norway. *Fungal Ecology, 5*(1), 3–15.

Tømmervik, H., Johansen, B., Riseth, J. A., Karlsen, S. R., Solberg, B., & Hegda, K. A. (2009). Above ground biomass changes in the mountain birch forest: the influence of grazing and climate change. *Arctic, Antarctic and Alpine Research, 36*, 323–332.

Turi, E. I., & Keskitalo, E. C. H. (2014). Governing reindeer husbandry in western Finland: Barriers for incorporating traditional knowledge in local-level policy implementation. *Polar Geography, 37*(3), 234–251.

Turunen, M., Rasmus, S., Baray, M., Ruosteenoja, K., & Heiskanen, J. (2016). Coping with increasingly difficult weather and snow conditions: Reindeer herders’ views on climate change impacts and coping strategies. *Climate Risk Management, 11*, 15–36.

Uboni, A., Horstkotte, T., Kaarlejärvi, E., Sévéque, A., Stammler, F., Olofsson, J., … Moen, J. (2016). Long-Term trends and role of climate in the population dynamics of Eurasian Reindeer. *PLoS ONE, 11*(6), e0158359. doi: 10.1371/journal.pone.0158359

Uhlig, C., & Zink, A. (2006). Changes in organic horizon soil properties due to reindeer herding and changing management. In B. C. Forbes, M. Bölter, L. Müller-Wille, J. Hukkinen, F. Müller, N. Gunsay, & Y. Konstantinov (Eds.), *Reindeer Management in Northernmost Europe: Linking Practical and Scientific Knowledge in Social-Ecological Systems* (Ecological Studies 184) (pp. 245–264). Berlin: Springer.

UNESCO. (2017). Local and indigenous knowledge systems. URL: http://www.unesco.org/new/en/natural-sciences/priority-areas/links/related-information/what-is-local-and-indigenous-knowledge/ (assessed 24 October 2018).

Väisänen, M., Ylänne, H., Kaarlejärvi, E., Sjögersten, S., Olofsson, J., Crout, N., … Stark, S. (2014). Consequences of warming on tundra carbon balance determined by reindeer grazing history. *Nature Climate Change, 4*, 384–388. doi: 10.1038/NCLIMATE2147

Veijola, P. (1998). Suomen metsärajametsien käyttö ja suojele (Use and conservation of the tree line forests in Finland). Finnish Forest Research Institute, Research Papers 692, Helsinki, Finland.

Vikhamar-Schuler, D., Hansen-Bauer, I., & Forland, E. (2010). Long-term climate trends of Finnmarksvidda, Northern-Norway. Norwegian Meteorological Institute, Report 6, Oslo, Norway.

Vikhamar-Schuler, D., Isaksen, K., Haugen, J. E., Tømmervik, H., Luks, B., Schuler, T. V., & Bjerke, J. W. (2016). Changes in winter warming events in the Nordic Arctic Region. *Journal of Climate, 29*, 6223–6244.

Virtanen, R. (2000). Effects of grazing on above-ground biomass on a mountain snowbed, NW Finland. *Okos, 90*(2), 295–300.

Vowles, T., Lovehav, C., Mola, U., & Björk, R. (2017). Contrasting impacts of reindeer grazing in two tundra grasslands. *Environmental Research Letters, 12*(3), 34018.

Vuojala-Magga, T. (2012). Adaptation of Sámi reindeer herding: EU regulation and climate change. In Tennenberg M. (Eds.), *Governing the Uncertain: Adaptation and Climate Change in Russia and Finland* (pp. 101–122). Dortrecht, Hedelberg, London, NY: Springer.

Vuojala-Magga, T., & Turunen, M. (2015). Sámi reindeer herders’ perspective on herbivory of subarctic mountain birch forests by geometrid moths and reindeer: a case study from northernmost Finland. *SpringerPlus, 4*, 134. doi: 10.1186/s40064-015-0921-y

Vuojala-Magga, T., Turunen, M., Ryypö, T., & Tennenberg, M. (2011). Resonance strategies of Sami reindeer herding during climatically extreme years in northernmost Finland in 1970–2007. *Arctic, 64*(2), 227–241.

Walker, M. D., Wahren, C. H., Hollister, R. D., Henry, G. H. R., Ahlquist, L. E., Weladji, R. B., Holand, Ø., & Almøy, T. (2011). *Climate Trends of Finnmarksvidda, Northern-Norway*. Helsinki: Finnish Forest Research Institute.

Wielgolaski, F. E. (2002). Nordic mountain birch forest. In S. Kankaanpää, L. Walker, M. D., Wahren, C. H., Hollister, R. D., Henry, G. H. R., Ahlquist, L. E., Weladji, R. B., Holand, Ø., & Almøy, T. (2011). *Climate Trends of Finnmarksvidda, Northern-Norway*. Helsinki: Finnish Forest Research Institute.