Reindeer husbandry and climate change

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5 Reindeer husbandry and climate change

Challenges for adaptation

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Introduction

Observed climate change in the Arctic

In recent decades, the polar regions have warmed faster than the global average. Several processes contribute to this (see, e.g., Serreze & Barry 2011), the most obvious being the ice–albedo feedback, where warming leads to reduced sea ice, and the emerging open water surface contributes to further warming due to increased absorption of solar radiation (Koenigk et al. 2020). Warming has been rapid in northern Fennoscandia (Figure 5.1) during all seasons over the past three decades, but particularly between December and February (e.g., Berglöv et al. 2015).

Changes in precipitation patterns show strong spatial variation. An increase in winter precipitation has been recorded in northern Sweden and Norway during the past 30 years compared to the reference period 1961–1990 (Vikhamar-Schuler et al. 2016). For example, winter precipitation increased by 30% and snowpack thickness varied up to 50% between years in several herding districts in Sweden (Rosqvist et al., unpublished). In contrast, trends in precipitation are not clear within the RHA of Finland (Maliniemi et al. 2018), and no significant changes in snow cover thickness have been observed (Rasmus et al. 2014; Lépy & Pasanen 2017). However, more frequent and more intense rainy periods in winter have been reported (Vikhamar-Schuler et al. 2016; Luomaranta et al. 2019).

The timing of spring snowmelt in reindeer calving areas differs significantly between years. Generally, later formation and earlier melt of the snow cover have been observed in Finland (Lépy & Pasanen 2017; Luomaranta et al. 2019). The growing season degree day (GDD) sum has significantly increased throughout the RHA (Park et al. 2016; Rasmus et al. 2020).

Expected future climate change

Warming is expected to continue at a faster rate in the Arctic and elsewhere in high northern latitudes relative to the rest of the world. In addition, precipitation

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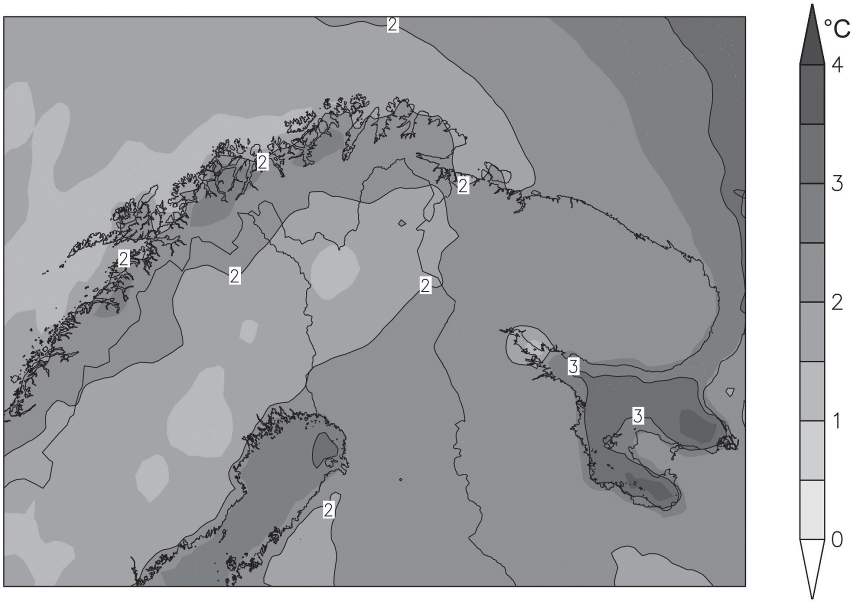

Figure 5.1 Linear trend in annual two-meter air temperature calculated from the ERA5 reanalysis data (Hersbach et al. 2020) between 1979 and 2019. The increasing trend is statistically significant at the 1% risk level across the whole area.

levels are projected to continue to increase in northern Fennoscandia. However, inter-annual variability in seasonal temperature and precipitation will probably remain high, or even increase. During the coming decades, warming is likely to continue at approximately the current rate (Figure 5.2), whereas the rate of warming after the mid-21st century will depend strongly on the evolution of greenhouse gas emissions. Several scenarios for greenhouse gas trajectories, so-called representative concentration pathways (RCP), are adopted by the Intergovernmental Panel on Climate Change (IPCC). The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the coming years. According to RCP4.5, the global emissions peak around 2040, and the warming is thereafter modest compared to the high-emission scenario RCP8.5. Thus, while winter temperatures are projected to increase approximately 5 °C by the year 2100 according to RCP4.5, the increase may be as much as approximately 8 °C under RCP8.5 (Kjellström et al. 2016). Similarly, mean annual precipitation is expected to increase by 20% or 40% by the year 2100, depending on the forcing scenario.

Warmer winters with more precipitation will further increase the number of heavy snow accumulation events, at least in the medium term. In the long term, however, warming will result in a prolonged snow-free season. For example, the

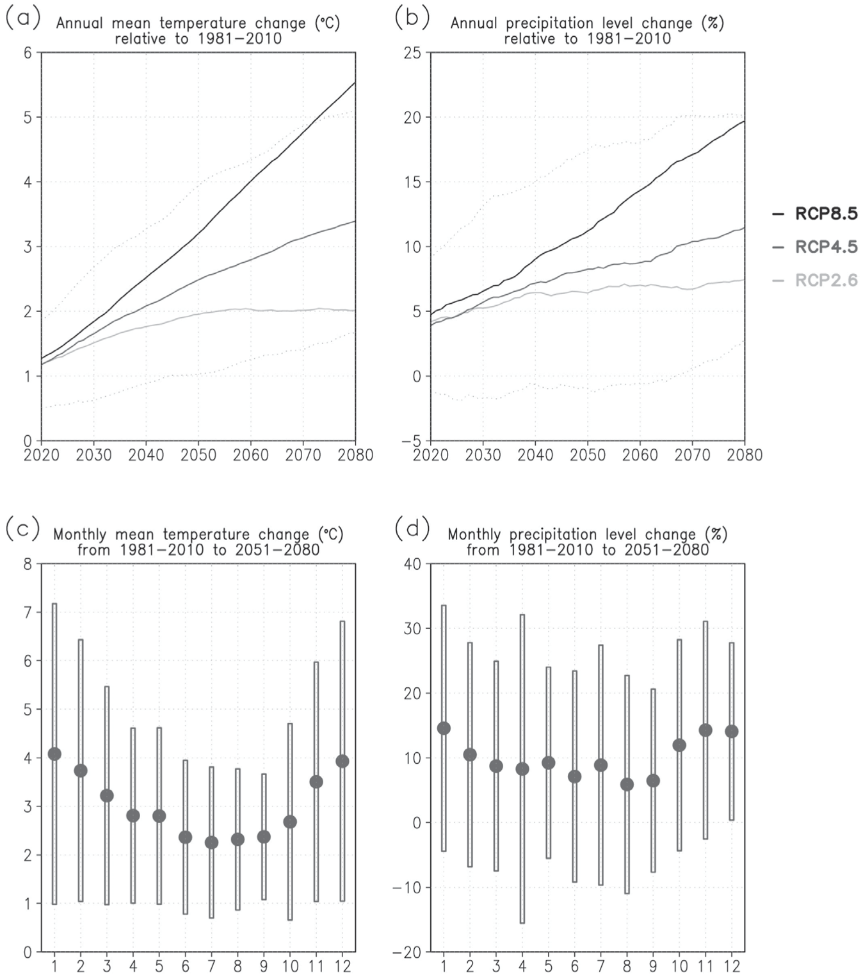

Figure 5.2 Projected multi-model mean change in annual mean temperature (a) and precipitation (b) in Central Finnish Lapland from 2020 to 2080, relative to 1981–2010 values, under three different representative concentration pathways (RCPs). For RCP4.5, the 90% confidence interval is indicated by dotted lines. Projected multi-model mean change with 90% confidence intervals under RCP4.5 is also shown for monthly changes in mean temperature (c) from 1981–2010 to 2051–2080 and precipitation level (d). Projections are based on 28 global climate models participating in the Coupled Model Intercomparison Project Phase 5.

Source: Flato et al. 2013.

number of snow cover days will decrease by between 40 and 60 days in certain mountain catchments in northern Sweden according to IPCC scenarios (Berglöv et al. 2015). The shorter snow season and shrubs protruding through the snow will result in a prolonged period of absorption of solar radiation by tundra vegetation, contributing to regional warming and furthering the growth of shrubs (Te Beest et al. 2016).

Ice crusts on the ground or in the snow are likely to become more frequent due to the increased frequency of thaw-freeze cycles. Increases in winter warming and rain-on-snow (ROS) events have already been reported in the Nordic Arctic regions (Vikhammar-Schuler et al. 2016; Kivinen et al. 2017; Rosqvist et al. 2020), as well as increases in extremely warm events in spring and autumn. Indeed, within this century, "extremes are becoming routine in an emerging new Arctic" (Landrum & Holland 2020).

Adverse weather events and climate change – seasonal impacts and herders' coping strategies

The annual cycle of reindeer ecology and natural pasture use determine seasonal herding activities (Table 5.1). Each season is characterized by particular weather-related risks that are critical in reindeer husbandry and require strategic responses by herders. In a changing climate, some climatic features become more frequent, and others more rare, with both positive and negative impacts on reindeer husbandry (Moen 2008; Turunen et al. 2016). Direct, primary impacts of climate change are related, for example, to weather events; secondary

Table 5.1 Conventional seasons, eight seasons of reindeer husbandry; seasonal features typical for reindeer husbandry and weather and weather-related conditions during each season adversely affecting the practice

Conventional seasons	*Seasons of reindeer husbandry*	*Typical seasonal features, relevant for reindeer husbandry*	*Adverse conditions for reindeer husbandry*
Autumn	Autumn	First frosts and first snow Autumn pastures: mixed forests, bogs Migration to winter pastures Rut Round-ups start	Highly variable weather Temperature varies above and below 0 °C Snow falls on unfrozen ground
	Early winter	Start of the polar night Snow cover formation River/lake ice formation Ground frost formation Migration to winter pastures and round-ups continue Herding Supplementary feeding	Highly variable weather High temperatures Rain-on-snow events Temperature varies above and below 0 °C

Table 5.1 Cont.

Conventional seasons	*Seasons of reindeer husbandry*	*Typical seasonal features, relevant for reindeer husbandry*	*Adverse conditions for reindeer husbandry*
Winter	Winter	Polar night Low temperatures Winter pastures: lichen pastures, old-growth forests Foraging lichen below the snow or arboreal lichen Round-ups continue Herding Supplementary feeding	Highly variable weather Long periods of very low temperatures Deep or hard snow; formation of thick ice crust Temperature varies above and below 0 °C
Spring	Late winter	Foraging lichen below the snow or arboreal lichen Herding Supplementary feeding	Deep soft snow cover with no ice crusts (in forest region)
	Spring	Snowmelt Spring floods Migration to spring/summer pastures: bogs, slopes, deciduous forests	Deep soft snow cover with no ice crusts Low temperatures Late snowmelt
Summer	Early summer	Start of the polar day Start of the growing season Summer pastures: forests, bogs, fjells Calving	Low temperatures, sleet Late snowmelt Late start to the growing season
	Summer	Polar day High temperatures Insect harassment Calf-marking Hay-making for supplementary feeding	Long heat and drought Plenty of insects Forest fires Lack of snow patches on the mountains Rainy summers (especially in hay-making districts)
	Late summer	Light decreases End of the growing season Mushrooms	Poor mushroom yields due to dry weather

impacts include ecosystem responses to changing climate, e.g., spreading new zoonotic diseases or vegetation shifts; tertiary impacts are political or cultural consequences such as changes in traditional knowledge and skills (Butler & Harvey 2010; Magga et al. 2011; Turi 2016). While these dynamics are challenging in themselves, they may be amplified by multiple pressures originating from factors such as competing forms of land use, constraining herders' adaptation options (e.g. Hovelsrud et al. 2021; Landauer et al. 2021; see Table 5.2 for definitions of key concepts used in this chapter).

Table 5.2 Definitions of key concepts used in this chapter

Concept	*Definition*
Climate change risk	The potential for adverse consequences for human or ecological systems or communities, arising from impacts of climate change and human responses to climate change.
Vulnerability	Set of conditions and processes resulting from physical, social, economic and environmental factors, which increase the likelihood that climate change will have negative impacts on a system or community. Combination of exposure, sensitivity of the system to climatic conditions and the adaptive capacity.
Adaptive capacity	Potential of a system or a community to adapt to climate change, to moderate potential damage, to utilize the opportunities or to manage the consequences. Increased adaptive capacity results in reduced vulnerability.
Climate change adaptation	Adjustments in response to actual or expected climatic stimuli (including variability and extremes) and their impacts; changes in processes, practices and structures to moderate potential damage or to benefit from opportunities associated with climate change. Successful adaptation results in reduced vulnerability.
Coping/reactive adaptation	Adjustments implemented in order to maintain basic functioning of the system, often in the short or medium term.
Planned/proactive adaptation	Adjustments resulting from deliberate policy/livelihood decisions, implemented in order to return to, maintain or achieve a desired state of the system also in the long term, often before certain impacts are observed.
Institutional adaptation	Adaptive actions taken and/or implemented at the (formal) institutional level, e.g. in terms of policy or rules.
Maladaptation	Adaptive actions resulting in increased vulnerability of the system, or other actors or sectors, even in the future.

Sources: Smit & Wandel, 2006; Parry et al. 2007; Pelling et al. 2010; IPCC 2012.

Impacts and strategies in autumn

Warm, wet early autumns may favour mushrooms, a vital forage to increase the body condition of reindeer by the onset of winter. However, warm late autumns with unfrozen soils may result in the growth of mycotoxin-producing microfungi (moulds) below the snow, adversely affecting forage resources (Kumpula et al. 2000).

Early slaughter is optimal, since calves start losing weight after the snow cover forms, especially if access to forage is limited. However, to obtain sufficient meat to sell, slaughter cannot happen too early – not before calves have gained enough weight (Näkkäläjärvi et al. 2020). In addition, reindeer need enough time for rutting and to recover from it before round-ups for slaughtering. Timing of the rut is affected by weather and grazing conditions during the previous spring and summer (Paoli et al. 2020), but herders have also noted that warm autumns can cause late or unsynchronized rutting (Rasmus et al. 2020).

Precipitation and temperature shifts during late autumn and early winter determine snow conditions at the base of the snowpack and thus access to ground vegetation (e.g. Löf et al. 2012; Rosqvist et al. 2021). A late rut, the absence of snow, formation of ground ice due to variable weather – combined with low lichen biomasses (Chapter 4) – can cause herds to disperse over a wide area while searching for food. This makes gathering and moving them to round-up sites difficult, and delays the slaughter (Turunen et al. 2016; Rasmus et al. 2020). Controlling the herds becomes difficult when the snow cover is thin. A herder from a fell district in Finland explains that "*if our herds have already been separated according to herding groups/siidas, but snow is scarce, it is difficult to keep the herds apart*" (all direct quotes in this chapter are from Rasmus et al. 2020).

Prolonged autumns, but also earlier springs, require herders to change the timing of other strategic events, such as migration between seasonal pastures. For example, in Finnmark, Norway, the prolonged growing season may allow longer time spent on coastal summer pastures and calf slaughter before migration, sparing the winter grazing areas (Riseth & Tømmervik 2017). At the same time, prolonged grazing in these summer pastures can prevent increased growth of shrubs and trees, perceived as detrimental to both migration and valuable grazing resources (Horstkotte et al. 2017; Riseth & Tømmervik 2017). In Sweden, herders have also chosen to stay longer on the summer pastures in the mountains or on the transitional spring/autumn pastures (Löf et al. 2012).

Due to late formation of permanent snow cover, increasingly, reindeer need to be gathered and moved to the round-up sites using all-terrain vehicles or helicopters instead of snowmobiles (Löf et al. 2012, Turunen et al. 2016). Late and weak ice formation on waterbodies and late freezing of bogs can make gathering even more difficult and hinder migration between seasonal pastures. As the bearing capacity of ice is decreased, there are risks to both reindeer and herders (Näkkäläjärvi et al. 2020). On the other hand, late ice formation can facilitate herding, because open water bodies can provide effective barriers. In Sweden, trucks may be necessary in some herding districts to transport reindeer between different seasonal pastures because of lost migration routes or unsafe ice conditions (Löf et al. 2012).

Impacts and strategies in winter

Herders note that weather has become more variable in all seasons (Vuojala-Magga et al. 2011; Löf et al. 2012; Risvoll & Hovelsrud 2016; Horstkotte et al. 2017). Higher temperatures, increased windiness, more frequent rainfall and increased snow-loads on trees in winter are observed by herders in all three countries (Horstkotte et al. 2017; Rasmus et al. 2020). Some herders also report increased snow depth, but later snow cover formation and earlier snowmelt (Näkkälärvi et al. 2020). Younger herders, therefore, conclude that they have hardly lived through a "normal winter" compared to those experienced by the previous generation (Löf 2013; Axelsson Linkowski et al. 2020).

Winters with long snowless periods or thin snow cover can provide better opportunities for grazing, and warmer weather can help reindeer maintain good body condition (Helle & Kojola 2008). However, warm winters have more frequent and longer-lasting thawing events (air temperatures above zero). More frequent freeze-thaw cycles or ROS events cause the formation of very dense snow or ice layers on the ground or within the snowpack (Rasmus et al. 2018; Nilsen et al. 2020). Formation of ground ice makes the ground vegetation layer harder to access ("locked pastures"). Even a single intensive snowfall on unfrozen ground or ROS event can severely affect grazing conditions for the rest of the winter (Rasmus et al. 2018; Rosqvist et al. 2021). Therefore, deep and/or icy snow may increase reindeer mortality and reduce calving success.

The responses of herders to such events vary and depend on the local context, including pasture environment, herding system and culture. Difficult grazing conditions can be avoided by making use of pasture diversity and mobility, e.g. migration to the coast, usually used during summer in Northern Norway (Eira et al. 2018). Herders exposed to oceanic climate in their winter areas in Norway may need to reverse their former grazing rotation. Previously, coastal pastures were more often locked by ice crusts than inland ones. Nowadays, coastal areas are often snow-free, while inland pastures are more likely to become locked (Risvoll & Hovelsrud 2016). However, coastal pastures are fragmented and are shared with many other forms of land use. Some herders in Norway, therefore, use winter pastures further inland across the Swedish border, based on informal agreements with the herders in Sweden (Risvoll & Hovelsrud 2016). Tyler et al. (2007) report "trading snow"; neighbouring herding partnerships (*siidas*) may allow one another to exploit an area of undisturbed snow. In Sweden, herders might migrate in early winter with their herds to particularly lichen-rich grazing grounds, to avoid the risk that these become inaccessible later (Axelsson Linkowski et al. 2020).

Utilizing local topographical diversity can buffer against adverse weather events; small-scale topographical variation may allow grazing at least in some places (Löf et al. 2012; Horstkotte et al. 2014; Riseth & Tømmervik 2017; Ohredahke herding community 2018). Depending on the snow conditions that need to be avoided, herds can be moved to wind-exposed habitats with less snow, or to forest regions with softer snow and arboreal lichens (where these still remain). However, herders do not consider using spring pastures in the mountains during winter to be a viable long-term strategy as grazing resources on spring pastures are vital during calving.

Under difficult grazing conditions, reindeer tend to disperse in search of grazing resources, particularly arboreal lichens (Eira et al. 2018; Horstkotte et al. 2014). Under such conditions, more active gathering, moving and monitoring of animals by herders are needed to prevent traffic accidents or losses to carnivores (Ohredahke herding community 2018; Axelsson Linkowski et al. 2020). This increases the need for snowmobiles, terrestrial vehicles, drones or helicopters. Herders also report letting the reindeer roam free as a "strategy of last resort" when pastures are locked. However, this choice is associated with increased stress and concern, negatively affecting herders' well-being (Löf et al. 2012).

Deep snow cover affects reindeer even without ice layers therein. A herder from Finland explains problems with deep and soft snow: "*Reindeer get tired of digging for forage … The snow cover does not support their weight, so it is not possible to forage for epiphytic lichens either. Predators catch reindeer easily in deep snow*." Increasing the herd's percentage of old bulls or castrates, which are better than females at breaking hard snow or digging through deep snow, is a strategy resembling a more traditional herd composition, instead of a focus on maximum productivity with a high percentage of females (Oskal et al. 2009; Riseth & Tømmervik 2017).

Supplementary feed has always been provided for reindeer when needed, e.g. by felling lichen-rich trees (Berg et al. 2011; Turunen & Vuojala-Magga 2014). It also plays an important role in adapting to changing winter conditions. This is particularly seen in the southern and central part of the RHA in Finland, with its long history of forestry. Forestry has reduced winter grazing resources, compounding the negative impacts of climate change. Changing winter conditions and increasing land use pressure enhance the need for supplementary feeding in all three countries (chapter 12). However, in Norway and Sweden many herders are adamant that supplementary feeding is not a preferred adaptation strategy and, indeed, that it increases vulnerability in the long run (Horstkotte et al. 2020).

The majority of the herders in the forest districts in Finland report that changing winter conditions have increased the need for feeding and enclosing reindeer (Rasmus et al. 2020). Enclosure feeding started early in southern districts in Finland. Now this experience is partly seen as an advantage: "*Our use of enclosures, which started at the turn of the 60s into the 70s due to the decreased amount of old forests, has reduced the impact of climate change*." Nevertheless, keeping enclosures clean and reindeer in them healthy are becoming more important and also problematic: "*It is more challenging than before due to mild weather and rains*."

Impacts and strategies in spring

Timing of calving is critical for the survival and growth of calves. Calves born early will suffer if there is rain or sleet, amplified by wind, in their first days (Cuyler & Øritsland 2004). Calves born late are weak and vulnerable when reindeer gather into large summer herds. Timing of calving depends on timing of the rut in the previous autumn, and also on the winter and spring weather and grazing conditions. In northern Finland, calving currently happens approximately one week earlier than in the 1970s (Paoli et al. 2018).

Early snowmelt and start of the growing season help reindeer recover from a difficult winter and are particularly favourable for lactating reindeer and their newborn calves (Turunen et al. 2009; Vuojala-Magga et al. 2011; Tveraa et al. 2013). When spring comes early, supplementary feeding can be discontinued early, reducing expenses. In Finland, reindeer fed in enclosures can be released to summer pastures much earlier (Rasmus et al. 2020). Nevertheless, early spring can also cause problems. In Sweden, herders report that early snowmelt can force them to move their animals earlier to spring pastures, because reindeer are more difficult to keep gathered when snow is disappearing (Ran herding community 2018). However, as spring pastures often are located at higher elevations, they do not show the same trend of early spring onset; snowmelt may even be delayed due to increased winter precipitation (Beniston et al. 2018). Consequently, herders may need to provide supplementary feeding, often within enclosures, upon early arrival (Ohredahke herding community 2018). Similarly, early spring requires herders in coastal winter pastures in Norway to move their animals to spring pastures in the mountains to avoid conflicts with agriculture, with the risk of facing difficult snow conditions (Riseth & Tømmervik 2017).

Snow and ice conditions affect moving and migration of herds to spring pastures and calving grounds. Some herders have noted that long periods of hard snow, favourable for migration, have become more rare in recent springs (Näkkäläjärvi et al. 2020). Rapid snowmelt may be problematic for calves, as explained by herders from fell districts in Finland: "*When the warming happens fast, small rivers flood severely. Often the female reindeer have to cross these rivers and the calves may drown.*"

Impacts and strategies in summer

The number of hot summer days is increasing in some regions within the RHA but, more notably, many herders report increased precipitation or heavy rains in summer (Näkkäläjärvi et al. 2020; Rasmus et al. 2020). Heat increases thermal stress in cold-adapted reindeer (Soppela et al. 1986; Klokov et al. 2019). Young calves particularly suffer from long periods of hot weather and insect harassment, but also from heavy rains and cold weather during summer. Insect harassment affects weight and reproduction and increases mortality, because stressed reindeer spend less time grazing, and their energy expenditure increases (Weladji et al. 2003). Heat and insect harassment draw reindeer into large herds, e.g. on snow patches, which facilitates gathering and moving animals for calf-marking in June–July. Snow patch habitats are threatened during the warming climate.

During heatwaves, handling causes extra stress. Therefore the calves are often marked at night. Stressing calves can be avoided by rescheduling the calf-markings or leaving calves unmarked until the autumn round-ups (Turunen et al. 2016; Rasmus et al. 2020). Gathering reindeer for calf-marking has become more difficult in some places because the timing of warm periods and insect harassment has changed. In some districts, this has been the reason for giving up summer calf-marking. A herder from a forest district in Finland also explains that "*heat during the calving period causes reindeer to gather into summer herds earlier. When the large herd moves around, many young female reindeer lose their [weak] calves that were born late.*"

Climate change affects the geographic distribution and epidemiology of climate-sensitive infectious diseases, many of which are zoonotic. This creates new risks for herders. For example, warmer and wetter seasons and increase in shrub and forest vegetation increase tick distribution and abundance (Hovelsrud et al. 2020). Warmer summers with increased precipitation may lead to more frequent parasite epidemics and new invasive alien species (Härkönen et al. 2010; Laaksonen et al. 2010). When reindeer are gathered in enclosures for calf-marking, there is a significant risk of disease outbreaks and parasite transmission, especially in wet, muddy conditions. This can be mitigated by frequently relocating the calf-marking site (Riseth et al. 2020). Wet summers also have negative impacts on hay-making and the quality of winter forage (Rasmus et al. 2020).

As a consequence of the lengthening growing seasons, forests will become more dense and expand northwards and to higher elevations (Karlsen et al. 2017). Climate models predict that pronounced increases in temperature and precipitation could transform more than half of the tundra into shrublands before the next century (Pearson et al. 2013). These vegetation transformations will also have consequences for herding strategies. For example, calf-marking sites may need to be relocated. Grazing can partly mitigate this development and keep landscapes open (Horstkotte et al. 2017). The dry summer of 2018 caused extensive forest fires in Sweden, including the RHA. Climate change may increase the likelihood of fires (Lehtonen et al. 2016), meaning a major adaptation challenge ahead for reindeer husbandry.

Towards holistic adaptation – constraints and ways forward

Knowledge as a key component of adaptive capacity

Knowledge and learning are important components of adaptive capacity (Buchanan et al. 2016; Ford et al. 2016a). Herders have coped with adverse weather conditions for centuries using their knowledge and skills. This knowledge is known as traditional ecological knowledge (TEK), Indigenous knowledge if referring to Indigenous knowledge holders, local knowledge or practitioners' knowledge (Alexander et al. 2011) and has been developed through context-situated learning. New knowledge and practices are accumulated, incorporated, exchanged within the herding community and transmitted from one generation to another (Turunen & Vuojala-Magga 2014).

In response to rapidly changing conditions that affect reindeer herding, herders creatively seek new solutions to add to their traditional knowledge (Axelsson Linkowski et al. 2020). Examples include veterinary education about new diseases (see chapter 13), new infrastructural development and other forms of technical innovation such as mobile slaughterhouses and using drones and GPS to support herding activities. GPS collars provide new information to herders and may facilitate dialogue with other actors (Andersson & Keskitalo 2017). Ideally, these tools demonstrate the pressures on and needs of herding communities and could help to create a platform for more collaborative approaches to land use planning (Sandström et al. 2020). However, besides increasing the financial burdens for herders, this requires balanced arenas for negotiation and interactions between actors – technological innovations alone are not enough (Kuoljok 2019).

Due to the rapid development of technology used in reindeer husbandry and a changing environment, the knowledge and know-how of generations can vary greatly (Axelsson Linkowski et al. 2020; Näkkäläjärvi et al. 2020). Rapid environmental change also creates conditions never experienced before, challenging traditional strategies and knowledge about landscapes and animals and no adaptation strategies may currently exist (Löf 2013; Eira et al. 2018; Ran herding community 2018). This also places new demands on scientific knowledge production for monitoring changes and developing appropriate responses, during all seasons. Winter is considered the most critical season for reindeer husbandry; it is also the most studied season in impact and adaptation research. Nevertheless, survival and productivity of reindeer depend on the cumulative impacts of conditions during the entire herding year (Paoli et al. 2018, 2020).

Adaptation or maladaptation?

Adaptation implies deliberation – to achieve or maintain a desired state of a system in response to change (Smit & Wandel 2006). While many responses described above sustain the essential functioning of reindeer husbandry in the short term, they may result in outcomes that are far from optimal in the long run and from a holistic perspective, including ecological, economic and cultural aspirations. Indeed, strategies can be maladaptive rather than adaptive. Instead of building long-term capacity to adapt to change, they can lay groundwork for future conflict, or increase vulnerability (Noble et al. 2014). For example, changes in seasonal pasture rotation may compromise pasture quality during other seasons, some technical solutions may lead to loss of knowledge and skills, and intensive supplementary feeding may affect reindeer behaviour, increase the risk of disease and be incompatible with herders' views of what constitutes sustainable herding (Horstkotte et al. 2020).

There are also limits to adaptation. Reindeer physiology and behaviour impose certain limits (Chapters 3 and 10). Herders emphasize that they need to work according to the biological rhythm of reindeer, rather than struggling against their reindeer's instincts. Lack of time, workforce or resources can hinder the implementation of adaptative actions. The options are dependent on geographical space available for adjustments and changes to practice as well as variation in topography and vegetation. In many regions, pastures are shrinking (Chapter 4), and growing predator populations further limit the use of certain areas (Chapter 6, Turunen et al. 2020).

Herders often perceive a rift between the demands placed on them to adapt and the lack of power to influence institutional decision-making processes (Löf 2013; Kløcker Larsen et al. 2017; Risvoll & Kaarhus 2020). They describe being stuck in an "adaptation squeeze" (Löf 2013). In analysing adaptation, it becomes evident that herders' options are increasingly restricted and affected by socio-political factors and competing forms of land use (Chapter 8; Hovelsrud et al. 2021; Landauer et al. 2021). These restrict access to or availability of pastures (Chapter 4), which hampers desirable adaptations and exacerbates the impacts of climate change (Risvoll 2016). The overall situation for reindeer husbandry, characterized by unclear rights and lack of balanced institutional arenas, places a heavy adaptation burden on herding communities (Chapter 8; Tyler et al. 2021). Therefore, planned adaptation initiatives at an institutional level are required – initiatives that are able to address and reconsider power structures and relationships between different actors in the landscape.

Towards adaptation policies?

The first step towards institutional adaptation is developing and harmonizing policies. While the governments in Norway, Sweden and Finland all acknowledge the severity of climate change and the challenges facing reindeer husbandry in particular (e.g. SOU 2007:60), they still lack policies to address the structural dimension of adaptation. National policies for climate change adaptation in reindeer husbandry vary, but they typically emphasize technical solutions or compensatory schemes, rather than long-term solutions. These include financial instruments (state-implemented subsidies and compensation) to alleviate the detrimental impacts of natural events. For example, the Finnish Act on compensation for damage inflicted on reindeer husbandry (987/2011 and 655/2016) aims to support herders financially to cope with extensive and unexpected damage resulting from natural events, in practice compensating the supplementary feeding costs. In Norway and Sweden compensation schemes are also available to counter catastrophic grazing conditions, as these are needed as short-term solutions (Näkkäläjärvi 2020).

However important emergency support is for herders to cope financially during these conditions, it is not a long-term solution. It neither addresses nor seeks to govern the multiple goal conflicts apparent between reindeer husbandry and competing forms of land use. The structural needs to balance existing power asymmetries between actors in consultation and planning processes (see Chapter 8) thus remain. As herders, state actors and other land users perceive problems and potential solutions differently, it is profoundly difficult to assess the effectiveness of the support provided. Consequently, herders often find that current adaptation policies implemented by governments only address the symptoms, while the herders' voices and perspectives are left unheard and their knowledge considered less relevant than scientific knowledge (Chapters 7, 8 and 9).

How future land use, including anticipated adaptation actions by other sectors, encroach on adaptation options for reindeer husbandry is of particular concern but is ignored in the current development of institutional adaptation. For instance, in its strategy for the Arctic Region, Sweden expresses an intention to strengthen knowledge about Sámi livelihoods, including reindeer husbandry and the necessary pathways to adaptation to climate change (Regeringskansliet 2020). While the importance of intact ecosystems to act as functional calving grounds, migration routes and provide connectivity between seasonal grazing areas is mentioned, the same strategy also emphasizes the importance of developing extractive land use, such as mining and wind power development on the *same* lands without recognizing the incompatibility. In Finland, adaptation to climate change is guided by The National Climate Change Adaptation Plan 2022 (MAF 2014). Measures to mitigate the adverse effects of climate change on reindeer husbandry are mentioned, including maintaining the connectivity and diversity of pasture areas, environmental protection and considering reindeer husbandry in the legislation steering land use planning. The concrete tools to implement these aims are, however, lacking. Likewise, Norway's Arctic Strategy (Norwegian Ministries 2017) emphasizes the contribution of reindeer husbandry to value-creation and the ambition to maintain the livelihood alongside other forms of land use without specifying how.

Concluding remarks

The current instrumental approaches to climate change adaptation place a considerable burden on herding communities and individual actors. Our analysis emphasizes the need for more proactive and deliberate adaptation actions, backed by political support. This requires just and equitable dialogue about desired adaptation strategies and outcomes for various livelihoods within the RHA, and about the pathways leading there. With such a holistic perspective on adaptation, there is the potential to link climate change adaptation to broader policy goals, such as implementing Indigenous rights and developing just regional land use planning. Including herders' knowledge in these processes increases the likelihood of success – if the needed adjustments in the herding system are rooted in local customs and decision-making processes (Ford et al. 2016 b). In pastoralist systems, adaptation to change requires flexibility. Fixed policies or rigid governing instruments do not work well (Marin et al. 2020). Collaborative processes are essential.

Herders express optimism about continuing with their livelihood, even if, simultaneously, they worry whether adaptation leads to cultural losses. It is, therefore, crucial to co-develop adaptation strategies that are sustainable not only economically and environmentally but also culturally and socially. Success in this respect will shape the future of reindeer husbandry for decades to come.

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