



Shifting Strategies between Generations in Sami Reindeer Husbandry: the Challenges of Maintaining Traditions while Adapting to a Changing Context

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Abstract

Many traditional pastoralist systems are greatly impacted by cumulative encroachments of other land users and by climate change. Understanding land degradation and the adaptive capacity of people who are dependent on the rangelands is an urgent priority for many areas in the world. In this research we explore how changing environmental conditions affect herding strategies on winter pastures and the role of indigenous and local traditional knowledge (ILK) in Sami reindeer husbandry. Our results indicate that traditional Sami reindeer herding strategies are still practiced, but that rapidly changing environmental circumstances are forcing herders into uncharted territories where these traditional strategies and the transmission of knowledge between generations may be of limited use. For example, rotational grazing is no longer possible as all pastures are being used, and changes in climate result in unpredictable weather patterns unknown to earlier generations.

Keywords Strategies · Encroachments · Indigenous and local knowledge (ILK) · Knowledge transmission · Traditional ecological knowledge (TEK) · Climate change · Rangelands · Sami reindeer herding · Sweden

Introduction

Rangelands extend over larger areas than any other land type, and are important for food production in general and to pastoral societies in particular. Globally, interacting climate, land-use, political, and economic changes threaten the sustainability of rangelands, the pastoral cultures they support, and the ecosystem services they provide (Reid *et al.* 2014; IPBES 2018). A particular concern to many of these traditional pastoralist systems relates to multiple cumulative encroachments

by other land users (Galvin 2009; Dong *et al.* 2011; López-i-Gelats *et al.* 2016). A recent Assessment Report on Land Degradation and Restoration by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) states that this leads to fragmentation of earlier open, large-scale landscapes and a decline in forage resources, which are major concerns as pastoral systems are dependent on animal movements over long distances or migrations to sustain the herds over the seasons (Naess 2013; Horstkotte *et al.* 2014; IPBES 2018). This fragmentation through competing land uses is further exacerbated by often harsh and unpredictable weather, low productivity, and climate change (e.g., Oteros-Rozas *et al.* 2013; Ims *et al.* 2013; Reid *et al.* 2014). While pastoralist societies have adapted to similar changes in the past (Galvin 2009; Moen and Keskitalo 2010), it has been suggested that their resilience and adaptive capacity are hampered by lack of political and economic power (e.g., Löf 2013; Reid *et al.* 2014). While much of the literature on rangelands focuses on the semi-arid regions in the world, less attention has been paid to rangelands in the Arctic (IPBES 2018).

In Sweden, reindeer husbandry is a form of pastoralism practiced by the indigenous Sami people on mountain pastures and rangelands in the northernmost counties, corresponding to

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approximately 50% of the country. Reindeer husbandry has been central to traditional indigenous Sami livelihoods and culture for centuries (Lundmark 2008). They faced increasing encroachments over the last century from expansion of forestry (Berg *et al.* 2008, 2011; Kivinen *et al.* 2010, 2012; Moen and Keskitalo 2010; Horstkotte *et al.* 2011; Sandström *et al.* 2016), hydropower and wind power development (Össbo 2014; Skarin *et al.* 2015), mining (Sehlin MacNeil 2017), and tourism (Skarin *et al.* 2010; Ims *et al.* 2013). In addition, national policy relating to the conservation of large predators has increased predation pressures on reindeer (Hobbs *et al.* 2012; Åhman *et al.* 2014), and climate change is increasingly impacting the availability of resources necessary for reindeer husbandry (e.g., Moen 2008; Vuojala-Magga *et al.* 2011; Löff 2013; Ims *et al.* 2013; Turunen and Vuojala-Magga 2014; Turunen *et al.* 2016). These encroachments have been well studied, but there is much less research on how the herders respond and adapt to these changes. Various aspects of Sami herders' indigenous knowledge have also been documented (e.g., Ryd 2001; Turi 2016), but the changes in, and transmission of, knowledge has rarely been addressed, especially in relation to landscape and climate change.

The incorporation of indigenous and local knowledge (ILK; IPBES 2018) is central to provision of a full account of the impacts of land degradation and restoration on human quality of life as well as responses to address negative impacts. ILK (sometimes called traditional ecological knowledge, TEK, or local ecological knowledge, LEK) is defined by Berkes *et al.* (2000: 1252) as “a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with the environment.” Aswani *et al.* (2018: 1) provide the following description: “Local and indigenous ecological knowledge are understandings, beliefs, and practices that human societies develop longitudinally in relationship with their natural environment, and which are dynamic and co-evolving with social and ecological changes.” Both of these definitions emphasize three key perspectives: the body of knowledge, the dynamic nature of that knowledge, and the transmission of knowledge from older to younger generations.

In response to the identified knowledge gap in the literature on reindeer husbandry as well as to the call by IPBES to further identify ILK-based land management approaches, we use Swedish reindeer husbandry as a case study of a pastoralist community to explore the effects of ILK on herding strategies used to deal with multiple cumulative encroachments by other land users in rangelands. In addition, we explore the role of knowledge transmission, as the rapidly changing environment makes it unclear if traditional strategies can still mitigate negative outcomes. Through paired interviews with reindeer herders from different generations, we identify traditional strategies and how they have shifted in response to

encroachments over time. We focus in particular on the availability of winter pastures, which constitutes a critical bottleneck in the annual herding cycle, as they are crucial to reindeer winter survival and calving success. Lichens, the main winter food for reindeer, grow fairly slowly (Horstkotte and Moen 2019), and consequently sustainable grazing practices should be based on a rotational scheme where they can regenerate between winter grazing periods (Kumpula *et al.* 2014). Lichens are particularly vulnerable to the dominant forest management model in Sweden, based on soil scarification and clear cutting methods. Over the last 60 years, there has been a 71% decline in the area of lichen-rich forests (Sandström *et al.* 2016; Horstkotte and Moen 2019). We were thus specifically interested in strategies for sustainable use of lichen-rich winter pastures and the potential role of rotational grazing strategies. Our interviews focused on (i) what strategies herders use or used to cope with fragmentation of pastures due to competing land uses, (ii) how fragmentation affected their options in responding to variable climate conditions, and (iii) how knowledge is transmitted between generations.

Background¹

Reindeer husbandry in Sweden is the exclusive right of the Sami people. Grazing rights are based on use since time immemorial. The Sami do not own the land on which they graze their herds, but have traditionally established rights to use private and public land in designated reindeer husbandry areas. Legislation stipulates that different stakeholders in these lands must respect others' rights to specific uses at specific times.

The reindeer husbandry area covers roughly 50% of Sweden and is divided into 51 herding districts, which are sub-divided into a total of approximately 1000 reindeer herding companies. Most of the herding districts in Sweden in mountain areas move their reindeer herds between summer pastures in alpine areas close to the Norwegian border to winter pastures in the boreal forest to the east. Those in forest areas move shorter distances and remain in the boreal forest all year round.

There are approximately 4600 reindeer owners in Sweden, about 40% of whom are women, and a little over half (c. 2500) are completely or partly dependent on income from reindeer herding, mostly men. The number of reindeer in Sweden varies between 225,000 and 280,000 based on the number of animals in the winter herd, plus about 50 000 calves in the summer. As the reindeer are dependent on natural, low productivity pastures, the herds move over large areas depending on the seasons.

¹ The following is based on information from the Sami parliament (www.sametinget.se; accessed 2020-06-03) and The Swedish Sami Association (www.sapmi.se; accessed 2020-06-03).

Semi-domesticated reindeer are sensitive to disturbances from other land uses, such as agriculture or industry, and from predators, especially during calving in spring and when they are gathered for marking and slaughter. Reindeer husbandry today is primarily focused on meat production, and most herding districts practice calf slaughter. While reindeer husbandry has little economic importance nationally, culturally it can be locally important and is central to the Sami way of life.

A typical herding year reflects the seasonality of northern Sweden. Calves are generally born in May, and in most districts, summer is spent grazing freely in the mountains, where reindeer selectively feed on highly palatable forage, such as herbs, shrubs and grasses, to maximize their growth and to build up reserves for the winter. After mid-summer, owners gather their herds for marking the ears of the calves. Towards autumn, selected reindeer bulls are slaughtered before the beginning of the rutting season. In late November, the herds are split into smaller winter groups (so called *siida* or *sijte*), which are cared for by a varying number of families that share winter herding, which is more intensive than during summer. During winter, reindeer feed primarily on terrestrial lichens (of the genera *Cladonia* and *Cetraria*) in dry, oligotrophic pine forests. Lichen availability and the impact of snow cover on reindeer foraging are critical variables during winter. When snow conditions such as deep drifts or ice crusts hinder reindeer from digging for lichens, the availability of arboreal lichens (of the genera *Bryoria* and *Alectoria*, for instance) is essential for survival. Migration or transportation back to the calving grounds in the mountains begins in March.

Methods and Materials

Our explorative case study is based on a purposive sampling strategy covering variations in time, leadership, place-based knowledge, potential geographic variation including different administrative regimes, and size of reindeer herding communities.

To reflect the cumulative and dynamic perspective of ILK, we used four biographies and one transcribed interview of older reindeer herders previously published to guide our formulation of questions for informants. The five were active in different reindeer herding areas in Sweden, and their stories all consist of descriptions of different perspectives of reindeer herding (Turi 1910; Pirak 1937; Skum-Nilsson 1955; Bäckman and Kjellström 1979; Kuhmunen 2000).

To capture changes over time and how knowledge is transferred between generations, but also how strategies may have changed or adapted to land use changes, we paired an older herder (>50 years of reindeer herding experience) with a younger herder (>20 years of reindeer herding experience) from the same *sijte* (South Sami) (a small winter group, usually consisting of one family with close relatives). Participants

were selected based on having, now or in the past, a leading position in their *sijte*. The informants all belonged to a *sijte* with 5–15 reindeer owners. They all had experience of planning and taking strategic decisions necessary to utilize grazing pastures in the most efficient and appropriate ways. Another criterion for the selections was that at least one of their parents and grandparents had grown up in the same area and Sami community, thus including place-based knowledge across at least three generations.

To cover geographic variations, and different sizes of the herding communities, we selected herders from five different reindeer herding communities covering a gradient from north to south, and from large to small. The five reindeer herding communities are situated in three counties: Sirges, Tuorpun, and Luokta Mavas in the county of Norrbotten, Ubmeje in the county of Västerbotten, and Ohredahke in the county of Jämtland (Fig. 1). Sirges is the largest herding community in Sweden, with 101 herding companies, while Ohredahke only has five companies. These companies are usually family-based. A *sijte* may be comprised of one or several companies, and the composition may change from year to year as families decide to merge or split their herds depending on winter conditions.

Thus, our data is based on a unique compilation of in-depth semi-structured interviews (following the ethical guidelines of the Swedish Research Council) with ten reindeer herders from five mountain-based herding communities. Following free, prior, and informed consent procedures, prior to the interviews we informed our respondents about the purpose of the study and how the interviews were going to be used. All selected participants agreed to participate in this research (Close 2018:193–194). The interviews were conducted in the spring of 2016, lasted between 90 and 135 min, and were digitally recorded with the permission of the participants and then transcribed in full. The participants had the opportunity to read, change, and clarify the transcribed interviews, but no such changes were suggested. The interviews were conducted in Swedish (with the necessary Sami expressions translated to the Swedish interviewer) in the homes of the informants. One of the two interviewers is a Sami-speaking active reindeer herder (AMF), which facilitated communication and analysis of the results. This made it possible to ask in-depth questions and to understand the context of the herders' responses. In designing this research, we considered it important to adopt a data collection strategy that would enable collection of new information, provide flexibility to explore different topics in depth with the informants, and enable procedural adaptation. With this in mind, we collected data in such a way to allow critical interrogation of engagement and the clarification of people's meanings, intentions, and aspirations. Our questions focused on reindeer herding knowledge in general and winter herding strategies in particular: how a reindeer herder learns their trade, what strategies are used, how the winter land looks

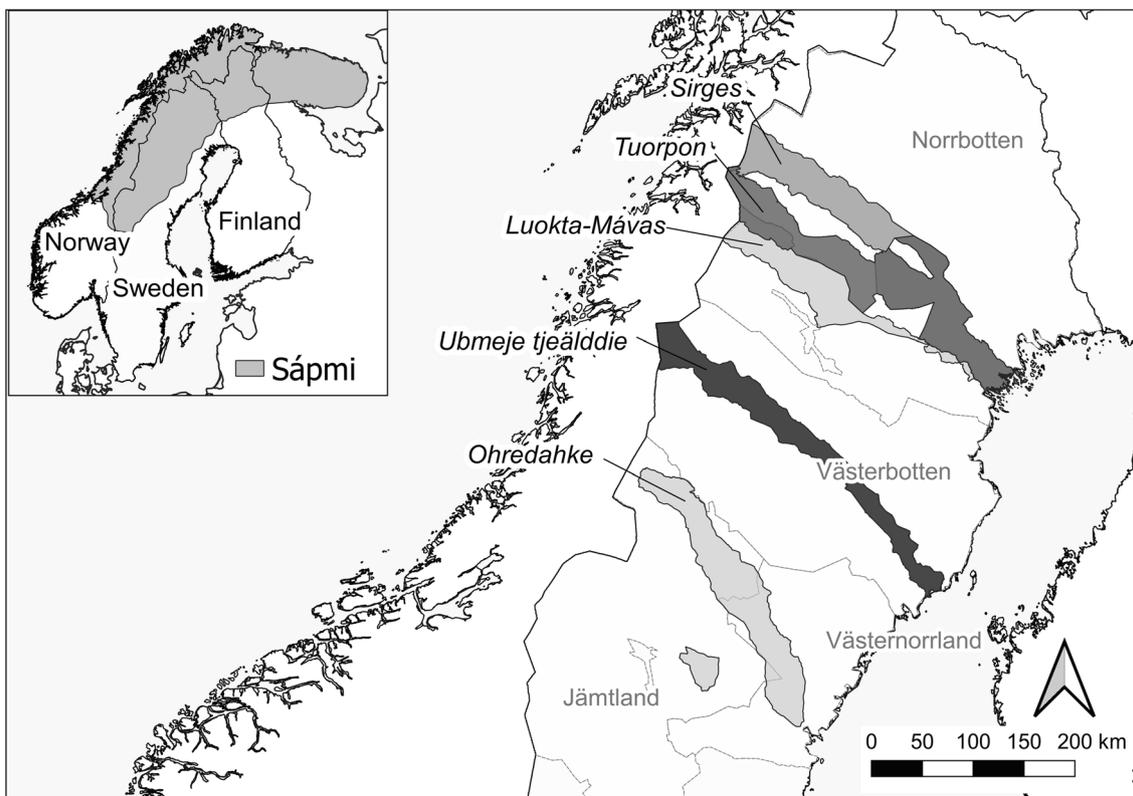


Fig. 1 Map of northern Sweden, showing the Sami reindeer herding districts taking part in the study: Sirges, Tuorpon, and Luokta Mávas in the county of Norrbotten, Umeje in the county of Västerbotten, and Ohredahke in the county of Jämtland. These districts cover a gradient from north to south in the reindeer herding area of northern Sweden.

Please note that Sirges and Tuorpon share the same winter grazing area and thus divide it between themselves. The shading of the different herding districts is used to highlight their respective areas. The grey area in the small inset roughly describes Sápmi, the traditional area of the Sami people. Map produced by Tim Horstkotte.

today compared to previous years, and how winter planning strategies have changed accordingly. We also asked about strategies to save pastures for the late winter period the same year (short-term strategy), or pasture rotational schemes where land is left un-grazed between years in order to allow the lichens to recover (long-term strategy).

Given the explorative nature of our study, we applied a thematic analysis, i.e., a focus on identifying patterned meaning across a dataset that provides an answer to the research question being addressed. Thematic analysis is suitable to answer questions related to people's experiences, or people's views and perceptions (Ritchie *et al.* 2014). During data analysis patterns are identified through a rigorous process that includes six steps: *familiarisation* with the data, which in our case included the whole research team reading and re-reading the data to become familiar with its content; *Coding*, which was done by three researchers, included the identification of important features of the data of relevance to address the research question; the three researchers continued to *generate initial themes*, where the data were carefully analyzed to identify overarching themes; the whole team was then involved in the process of *reviewing themes*, i.e., to check the themes against the dataset, and *defining themes* and in our case

also reindeer herders' strategies. This phase also included a detailed analysis of each theme or strategy. The final step, *writing up*, was done by the first author and later re-written and revised in an iterative way by the whole team to build a cohesive narrative based on the data and to contextualize the analysis in relation to existing literature.

Results

Central and strikingly similar themes in all the interviews were the loss of available grazing land, the difficulties in predicting the weather, and how the available margins for maneuverability have decreased. Despite being situated in different reindeer herding communities spread across the country, our informants also identified the same encroachments in their areas as have been repeatedly identified in other studies, including forestry, infrastructure (roads, railroads), hydropower developments, mining, wind power development, and tourism (see references above). We found no differences related to, for example, geographic variations, different sizes of the herding communities, or other independent variables suggesting that the selected cases are also representative of other reindeer

herding communities. These encroachments affect the feasibility of what we, based on the thematic analysis, identify as proactive strategies to control the reindeer and, for example, preserve pastures (i.e., strategies intended to maintain control over the reindeer and the available grazing resources), and reactive strategies that emerge as adaptive responses to the unforeseen, such as weather changes or the presence of predators. To answer our two research questions on strategies, we give two examples of what would be defined as traditional strategies that are described in the stories from the older reindeer herders and that were also mentioned in all the interviews; one proactive and traditional strategy that has been slightly adapted to the changing circumstances, and new proactive and reactive strategies to cope with uncertainty. We then address research question (iii) on the transmission of traditional knowledge.

Adapting Proactive Strategies Due to the Fragmentation of Land

The traditional strategy for reindeer herders during the winter is to keep reindeer together and prevent them from wandering off or into the pastures of the neighboring *sijte* or herding district. Kuhmunen (2000: 69) writes that both terrain and grazing conditions determine how closely the herds are monitored (see also Bäckman and Kjellström 1979: 239; Turi 1910: 29). Many of the older Sami authors also write about the importance of not disturbing the reindeer in the winter more than needed to keep them together (e.g., Skum-Nilsson 1955: 30; Bäckman and Kjellström 1979: 239; Pirak 1937: 142), since unsettled reindeer do not feed well as they expend energy moving and being forced to dig new snow pits to reach the forage. However, the current situation has made it necessary for the herders to be more active in monitoring their herds since it has become more difficult to keep them together.

The loss of both terrestrial lichen pastures and areas rich in arboreal lichens due to modern forestry was mentioned in all interviews. Herders describe how the available lichen pastures are much smaller, more fragmented, and that the quality has deteriorated compared to the situation for the previous generation and to the conditions described in the biographies: (all translations by the authors)

The pastures have become so small, such small areas. You have to have some [reindeer] here and some there. Thus there are sort-of small cookies [of grazing] you have, you have no large area, no. You must have one with a few hundred [reindeer] there and then a few hundred there. It [the grazing] is not enough; it does not take long before it is finished. (younger herder, Ubmeje)

To control the herd, it is important to return stray reindeer back into the herd continuously, thereby creating an “edge”

around the herd. The older generation maintained a tight “edge” and control by skiing around the herd. Today, herders use snowmobiles for the same purpose. However the fragmentation of pastures necessitates using a much larger area to provide enough forage for the herds and the edges, as a consequence, become extended:

When I grew up then we had the reindeer grazing down in the forests. We used to ski around them, but now you have to drive with snowmobiles around them. The forest is so devastated that it is clear that the reindeer must spread out to where there is food. (older herder, Tuorpon)

There are several consequences of this use of snowmobiles: for instance, the tracks become very hard, making it impossible for the reindeer to dig through and as a result the lichens beneath cannot be reached. On the other hand, the hard tracks are easy for the reindeer to walk on, so they tend to wander off along these tracks. The young herders are aware of these consequences and try to make as few tracks as possible and avoid driving over lichen-rich heaths. Several herders said that they would have used skis if it were possible, because that would allow them to come closer to the reindeer in their everyday work and they would not have to use expensive fossil fuel.

Further, tourism, and especially the increased recreational use of snowmobiles, cause additional problems. In the worst case, grazing areas with good amounts of lichens may have to be avoided as there is no “grazing peace” for the reindeer as they are repeatedly disturbed by recreational snowmobiling.

This is a much bigger problem than when we started with reindeer. What we call *hobpehtahke* [South Sami], that is un-trodden snow; there is no such snow today. There are snowmobile tracks everywhere. When I started it was very important not to drive [snowmobiles] on better grazing. Nowadays there are hundreds of tracks in every direction. (younger herder, Ohredahke)

The fragmentation of land due to both modern forestry as well as other types of land use, here illustrated by the increasing use of snowmobiles for recreational purposes, has forced the younger reindeer herders to successively adapt and change the traditional herding strategies. The strategy to keep the herd together is more difficult in a fragmented landscape, and it has become more work-intensive and expensive, which affects both their opportunities to make a living but also their wellbeing.

Developing Pro- and Reactive Strategies to Handle Uncertainty

A main traditional strategy for reindeer herders to handle uncertainty during winter is to lead the herd to good grazing and

to plan for rotational grazing schemes between different seasons. Skum-Nilsson (1955: 30), for example, writes that it has always been important to change the pasture area regularly during winter so that the reindeer have new land to feed on. It has also been considered important to save certain areas for use later in the winter when the snow is thicker and it is more difficult for the reindeer to graze (Kuhmunen 2000: 54). In the biographies and old stories older herders also describe the possibility of grazing in a smaller area during winters if there were good snow conditions (e.g., Turi 1910: 28–29; Bäckman and Kjellström 1979: 239; Kuhmunen 2000: 53), which meant that lichens in other areas could recover from grazing.

All of the interviewed herders stated that almost all available pastures are currently used every year; the pastures are grazed more intensely than when the older generation were active, and in some cases the same area may even have to be used a second time in the same winter depending on shifts in the snow conditions. This represents a new way to use the pastures that contrasts with the traditional strategy to graze only *aevis laante* (South Sami: untrodden/ungrazed land).

That is something you wish for and dream about, to have such an opportunity. To allow some pastures to rest one or a couple of years. It was easier before when everything was not so heavily exploited. There were more pastures then, so it was more common to [save pastures]. (younger herder, Sirges)

The older herders said that they used to be able to choose which pastures to graze in the winter. For instance, they may have grazed what they considered to be low-quality pastures (i.e., pastures with low abundance of lichens) early in the winter season to save the best pastures for more critical times in late winter. As other land uses have fragmented the pastures, and climate change is making weather conditions more unpredictable, as a proactive strategy herders today tend to send the reindeer to the good pastures rich in lichens (pine heaths) first as they may become inaccessible later in the season due to icing events. More elevated areas or spruce forests – less rich in lichens – constitute reserve areas in case the pine heaths become covered in ice. For instance, after separating the reindeer into smaller winter herds, the herders try to begin the winter season in an area that they suspect will be unavailable later due to snow. In the past, there were more predictable weather patterns and the retired herders always anticipated a thaw at the end of November, after which they started to descend into the forests.

Nowadays, we have to use the lichen heaths in November, because in the late winter they become inaccessible. Before, these heaths were used in late winter (March), and now we joke that we have to use them

when it is *bievle* (South Sami: no snow) because otherwise it will be too late. (younger herder, Ohredahke)

While there are few alternative pastures where lichens can be left to regrow, there is an interaction with the increasing occurrence of ice-formation on the ground that coincidentally may allow for lichen regrowth. Ice-formations, such as thawing in mid-winter or rain-on-snow events, lock-down the pastures so that the reindeer cannot reach the lichens. Herders now say that: “the ground ice saves the lichens.” They have noticed that the lichens regenerate well in these areas and that they will provide good grazing pastures later unless “there is ground ice-formation again.”

In the past, since the reindeer have to be fed during these ice-forming events, the herds would be moved to areas with abundant arboreal lichens (Berg *et al.* 2011). However, such areas are very scarce in the modern forest landscape, and the herders now have to rely on reactive strategies and feed the animals expensive supplementary food, such as commercial pellets or lichens gathered from locations outside the reindeer herding area.

Some herding districts could potentially use areas close to the Baltic coast as alternative pastures. However, there are many potential conflicts with people in these more heavily populated areas. The herders have to balance the gain of better pastures with the costs of transport, and sometimes it may be less costly to feed their herds pellets instead.

We have the possibility of going further down [towards the coast], but then it has to be very good grazing. We don't move down to move up again if the grazing becomes bad [because of the costs]. Then you have to consider if the costs increase whether you should pay for commercial pellets rather than for the transport costs. (younger herder, Umbyn)

Even though the reindeer herders still plan for the use of grazing areas for the winter and wish to use rotational grazing schemes for different seasons, they have had to adapt their strategies quite substantially to be able to find good grazing for their herds. They have also had to develop completely new and more reactive strategies, such as supplementary feeding, when there are no other affordable options.

Transmission of Knowledge between Generations

Despite having to develop new pro- and reactive strategies, all the herders stressed the importance of learning reindeer herding in the field with more experienced herders passing on their knowledge. All of them had learned from their fathers or a close male relative, and the younger herders with children continue to pass this knowledge on. Some herders have also found that helping out in other herding districts or *sijte* can

provide an opportunity to learn new ideas, different interpretations of reindeer behavior, and alternative ways of organizing their herding activities.

One has to be out there and learn. It is the case that many who start with reindeer husbandry, say after a year, “Now, I know this!” But one year is not the same as another one, there is always variation. It is how it is. It is an eternal school and one is never fully educated. (older herder, Tuorpon)

New situations due to climate change are so far outside earlier experiences that there are no Sami words to describe them. Thus, a severely changing environment, such as increasing encroachment or a changing climate, may challenge the usefulness of the experiences of previous generations. For instance, while variations in winter weather have always been a part of traditional reindeer husbandry, the current increased uncertainty of weather patterns poses a challenge for the younger generation because there is no previous knowledge to learn from. Even herding practices on the winter pastures in the boreal forests are difficult to continue. For instance, older herders recall how they sent the reindeer to graze on a single forested slope for an entire winter, but under current conditions this is impossible for the younger herders.

The autumns have become so strange nowadays, so you can tell the difference between my dad and myself; he may start to worry that there might be a thaw [that causes ice-formation] even before the snow falls. But I know that there is no reason to worry now because things can change so much. You see differences even from when I started, with so much more slush. Further back in time it became cold in the autumn and then it stayed cold and cold snow fell on the cold ground. Well, then you have forage everywhere and you don’t have to think about it. But that is like a story [Sw: sägner], just something you have heard about. (younger herder, Tuorpon)

In the old times you called it *gååre* (South Sami: bad, miserable), when it is all frozen. But I have never experienced this thing that he [his son] is telling me; “That the pastures are so frozen with ice so that even reindeer slip”. I never experienced this, I had quit before this time. (older herder, Ohredahke)

At the same time as certain traditional practices continue to play an important role in reindeer husbandry, climate change as well as cumulative effects of encroachments have compelled the younger reindeer herders to adapt to unprecedented conditions and develop new and innovative strategies to handle increasing uncertainty. One of the most important pieces of herding knowledge that the younger herders are trying to

teach the next generation is how to use the landscape, for instance identifying where you can leave the herd overnight or when it is time to move them again, or the location of important pastures in different weather conditions. However, they are well aware that conditions are changing so rapidly due to both climate change and other land users that the knowledge they themselves have acquired may quickly be becoming obsolete. Several of the herders emphasized that their focus must now be on principles of herding and teaching the children to think for themselves. They do not use the phrase ‘adaptive management,’ but the concept is very much present in instilling an approach in which it is necessary to test what works or not under changing new conditions.

Discussion

We have shown that changing environmental conditions, such as cumulative encroachments and climate change, force the current reindeer herders to find new solutions in parallel to their traditional knowledge system (ILK) that has evolved slowly over the years and that is traditionally transmitted from generation to generation.

The overall patterns of encroachments and the herders’ responses to these are strikingly consistent across the different informants and reindeer herding districts, and they also mirror changes found in many rangeland social-ecological systems in the world (e.g., Galvin 2009; Dong *et al.* 2011; Ims *et al.* 2013; Naess 2013; Oteros-Rozas *et al.* 2013; Reid *et al.* 2014; López-i-Gelats *et al.* 2016). However, while some authors have suggested that pastoralist systems tend to be flexible and have been able to adapt to various changes in the past (e.g., Galvin 2009; Moen and Keskitalo 2010), others suggest that institutional systems and lack of power severely restrict their adaptive capacity (e.g., Löf 2013; Kløcker Larsen *et al.* 2017). As the results of our study show, pastoralists are forced to adjust both their pro- and reactive strategies, but also to rapidly develop new ones in order to handle changes that are outside their control.

All herders in our study, both old and young, confirm that in order to learn reindeer husbandry it is essential to be out in the forest with the reindeer together with more experienced herders, as traditional reindeer herding strategies are passed on during the daily work (see also Turunen and Vuojala-Magga 2014). The herders constantly evaluate the effects of snow cover and ground icing and consequent shifts (both spatial and temporal) in pasture quality when they plan for their winter grazing season (Roturier 2011), and this is something that they have to learn from more experienced herders.

Changing conditions also force the herders to adapt their strategies. An earlier example is the change from traditional migration routes in some herding districts to the practice of moving reindeer on trucks. This adaptation was made in

relation to the expansion of hydropower between 1940s and 1990s (Össbo 2014). The benefits of saving time and not losing any reindeer on the way to the winter pastures must be placed within the context of the cost of renting trucks as well as the “costs” entailed in the earlier arrival of the herds in the winter pastures and the lost opportunity for them to use the resources available between the summer and winter pastures, which further increases the grazing pressure on the shrinking area of winter pastures. There is also the risk of losing knowledge associated with migration on foot, as clearly shown in a study of Spanish transhumant pastoralists, where the continuation of transhumance on foot was found to preserve traditional knowledge among young herders (Oteros-Rozas *et al.* 2013).

The increased fragmentation of pastures also has the indirect effect of making it more difficult to buffer against bad winters in traditional ways (Vuojala-Magga *et al.* 2011). All the herders in our study point out that strategies for dealing with encroachments are further complicated by the increasing unpredictability of the winter weather with, for example, a lot of slush or wet snow that easily turns into ice when the temperature falls below zero (see also Rasmus *et al.* 2016; Turunen *et al.* 2016). A proactive strategy for handling bad weather has traditionally been to move to new pastures with a rotational grazing scheme (Rasmus *et al.* 2016). The interviewed herders stressed the need to have a range of forests to choose from as the effects of weather differ between forests of different ages. For instance, ground ice rarely forms simultaneously in all places in a varied landscape, and forest canopies of different ages have different effects on the snow on the ground (Horstkotte and Roturier 2013). However, the currently fragmented and degraded winter pastures necessitate that all pastures are used so that there are no unused pastures to move to. This has forced the herders to change their strategy by either spreading out the herd over a larger area in the hope that the reindeer can find available forage somewhere, or to increase supplemental feeding (see Fernández-Giménez *et al.* 2018 for a similar situation for Mongolian herders).

The interviews with the herders show a loss of applicability of traditional knowledge to new conditions. Knowledge is still being transmitted between the generations, but it is likely that knowledge about earlier herding practices, such as skiing with the reindeer, maintaining compliant herds through close interactions, and maintaining migration routes, may be at risk of being lost as the older generation that has experienced such practices dies. In a review of global trends of local ecological knowledge, Aswani *et al.* (2018) show that local ecological knowledge had eroded in 77% of the reported cases, while knowledge persistence occurred in 14% of the cases. None of the papers included in that review dealt with reindeer herding or Sami knowledge. However, the persistence of knowledge that we found was often related to the maintenance of traditional practices and the creation of so-called

‘hybrid knowledge’ where traditional knowledge is able to adapt to a changing context. This shows the importance of adaptive management, or trying different approaches based on traditional knowledge in new settings, as described by some of the herders, where it may ensure that knowledge is continuously added and flexibility is maintained.

Conclusions Increasingly unpredictable and variable climate change in the Arctic will result in a variety of changing climate conditions, with serious implications for land use. Sami pastoralists have for centuries adapted to climatic variability, and successively developed ways of knowing and handling these variations. The Sami have also had to adapt and develop strategies over the years to handle a number of encroachments, some more permanent such as the damming of valleys for hydropower development, while others, such as the presence of predators and depredation risks, can change from day to day. Our study shows that the combination of rapidly changing circumstances due to climate change in combination with the cumulative impacts of many encroachments create a very unpredictable situation for the herders where traditional strategies and the transmission of knowledge between generations may be of limited use. Traditional Sami reindeer herding strategies are still being used today, although they have altered to handle the rapidly changing circumstances.

However, our study also shows that the options for sustainable reindeer husbandry are shrinking due to the cumulative effects of different encroachments. There is thus a pressing need to develop policies to support pastoralism and allow for the necessary land use flexibility in the face of an increasingly variable climate. Pastoralists’ knowledge about their land is essential for the sustained survival of their livelihoods, but it may also be important for the sustainable management of biodiversity and continued delivery of ecosystem services of rangelands in the future.

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Compliance with Ethical Standards

Conflict of Interest The authors declare they have no competing interests.

Informed Consent We followed the ethical guidelines of the Swedish Research Council and the informants were informed before the interviews

about the purpose of the study and how the interviews were going to be used, i.e., a free, prior and informed consent procedure.

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