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INFORMING DECISION-MAKING WITH INDIGENOUS AND LOCAL KNOWLEDGE AND SCIENCE

Sámi knowledge and ecosystem-based adaptation strategies for managing pastures under threat from multiple land uses

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Abstract

1. Ecosystem-based adaptation (EbA) relies upon the capacity of ecosystems to buffer communities against the adverse impacts of climate change. Maintaining ecosystems that deliver critical services to communities can also provide co-benefits beyond adaptation, such as climate mitigation and protection of biological diversity and livelihoods. EbA has, to a limited extent, drawn upon indigenous and local knowledge for defining critical services and for implementing EbA in decision-making. This is a paradox given that the primary focus of EbA is to enable communities to adapt to climate change.
2. The purpose of this study was to elucidate EbA strategies that take into account the knowledge of Sámi reindeer herders about pastures in tundra regions. We first examined what constitutes critical services through a synthesis of data and literature. We thereafter used content analysis of 91 land use cases from 2010 to 2018 to investigate to what extent the herders' knowledge and maps over seasonal pastures and migratory routes are used in local decision-making. Finally, we propose EbA strategies of relevance to Sámi communities and pastoral communities elsewhere.
3. Our analysis revealed that reindeer herders and organizations representing their interests perceived threats from green energy development, tourism, recreation, public road construction and powerlines. These threats included the loss of key habitats and the loss of connectivity for migration between seasonal pastures. Pastoralists' knowledge is incorporated through participatory tools to protect the ecosystems and services crucial for pastoralists, but multiple competing land uses result in incremental loss of pastures regardless.
4. *Synthesis and applications*. Protecting pasture ecosystems and the services they deliver, including the connectivity between pastures, are necessary Ecosystem-based adaptation (EbA) strategies to buffer the adverse effects of climate change. Drawing on pastoralists' knowledge to elicit EbA strategies can inform decision-making, but it is equally important to implement this knowledge for prioritizing adaptation needs in the assessment of competing land use.

KEYWORDS
Arctic, climate change, ecosystem services, ecosystem-based management, indigenous knowledge, resilience

1 | INTRODUCTION

Ecosystem-based adaptation (EbA) has gained traction in international climate policies as a flexible, low-risk and low-cost approach to adapt to climate change (Milman & Jagannathan, 2017; Ojea, 2015). The United Nations Convention on Biological Diversity (CBD) originally defined ecosystem-based approaches for adaptation as 'the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change' (CBD, 2009, p. 41). The EbA is not another strategy for conserving biological diversity. Instead, it aims at reducing climate change vulnerability and meeting adaptation needs through sustainable ecosystem management (Jones, Hole, & Zavaleta, 2012). Taking care of nature's capacity to buffer shocks and disturbances through the sustainable delivery of ecosystem services can provide communities with a portfolio of adaptation options to tackle future climate challenges.

Unlike other nature-based solutions for adapting to climate change, EbA endorses a more inclusive and participatory approach (Nesshöver et al., 2017). EbA specifically targets those who will be highly exposed to climate change and those who are more reliant on ecosystems and their services for their livelihoods (Munang et al., 2013; Reid, 2016). Indigenous people are among those considered vulnerable to adverse climate impacts due to their subsistence-based livelihoods and their limited financial means for buffering shocks and disturbances (Ford et al., 2016). Furthermore, indigenous people manage or use about one quarter of the Earth's surface (Garnett et al., 2018), areas that hold a large portion of the planet's biological diversity and carbon stocks. The recent IPBES Global Assessment report (IPBES, 2019) finds that land use changes are increasingly putting pressure on indigenous land, but at a slower rate than less remote lands. Managing land to avoid unsustainable land uses and to address the adaptation challenges of indigenous people can provide co-benefits such as climate mitigation, biodiversity conservation and long-term delivery of ecosystems services of relevance to local livelihoods, which is integral to EbA. In spite of this, indigenous knowledge is under-represented in IPCC assessments (Ford et al., 2016), and few studies have incorporated indigenous knowledge to define critical ecosystem services and the management strategies needed to implement EbA on indigenous land (Reid, 2016). A notable exception is the recent 2019 IPBES report that draws on indigenous and local knowledge (ILK) to assess the status of biodiversity and ecosystem services for first time at a planetary scale.

In this paper, we focus on the incorporation of Sámi reindeer herders' knowledge in decision-making and the unique challenges of EbA that pastoralists are facing. Sámi reindeer herders' knowledge can be defined as ILK, which according to IPBES is detailed knowledge of biodiversity and ecosystems that is 'formed through their direct dependence on their local ecosystems, and observations and interpretations of change generated and passed down over many generations, and yet adapted and enriched over time'. Reindeer herders' knowledge about ecosystems and services has evolved through their continuous adaptation to shifting environments (Sara, 2009). These socio-ecological dynamics rely on a tight connection between herders, reindeers and their ecosystems, and on flexible strategies for adapting to changing food supplies. Herd mobility and access to diverse habitats is crucial for dealing with a variable environment, including climate risks and extreme events, but these adaptation options have gradually been constrained by competing land uses (Risvoll & Hovelsrud, 2016). Halting loss of pastures and the services they deliver is a key for enabling reindeer herders to adapt to and cope with climate change impacts. Thus, this perspective must be integrated in any EbA strategies.

Unlike most other indigenous pastoralist systems, Sámi knowledge of seasonal pastures is incorporated in local decision-making through Norwegian legislation (Bjärstig, Nygaard, Riseth & Sandström, 2020). Reindeer herders create their own maps based on their knowledge of seasonal pastures, and report their use, disturbances and threats in local plans. These plans document their need for space and resources at different times of the year and are a tool to protect their pastures against other land uses. Despite these ambitions, it is unclear whether the participatory tools actually represent herders' knowledge sufficiently and whether this knowledge is used in decision-making to avoid loss of services. Furthermore, the tools have not been designed to consider flexibility and adaptation to climate change, nor do they capture the dynamics and changing character of migration routes and pastures over time (albeit an online version of maps is currently under development that potentially can serve this purpose; Landbruksdirektoratet, 2018). Our main objective is therefore to examine how these participatory tools integrate herders' knowledge in decision-making and to what extent these tools can avoid loss of ecosystem services. We ask:

1. Are these tools sufficiently representing pastoralists' knowledge of seasonal pasture and services in land use planning and decision-making?
2. What are the main reasons for loss of critical services?
3. How can we draw on pastoralists' knowledge to implement management strategies that support EbA?

2 | MATERIALS AND METHODS

2.1 | Study system

Semi-domesticated reindeers *Rangifer tarandus* are herded by Sámi pastoralists on approximately 40% of the land in Norway. We focus on Troms and Finnmark county which holds 74% of the reindeer population and 82% (N = 2,717) of the reindeer herders in Norway (Landbruksdirektoratet, 2018). Sámi pastoralists are organized in *siidas* that collectively herd reindeers from coastal summer pastures to inland tundra or mountainous winter pastures (Paine, 1994). Access to forage on winter pastures varies depending on snow and ice conditions, and reindeer herders need flexibility and knowledge about these resource conditions to cope with climate variability (Sara, 2009). Access to pastures along the migratory routes towards calving lands is critical as the reindeers have lost fat during a long winter and need access to high quality fodder for lactating and for their newborn calves (Paine, 1994). Spring floods and late snowmelt could adversely affect reindeer on their way to the calving land. On the calving lands, the female reindeers and their newborn calves should have minor a disturbance from human activities and predators. On the summer pastures grass, herbs and some shrubs are important for the growth of calves and for accumulation of fat reserves for winter, or for calf slaughtering in autumn. Only the Sámi have the right to own reindeers, which traditionally has been marked by distinctive earmarks to indicate the rightful ownership of the animals (Paine, 1994). All the calves that are not slaughtered will be marked with the owners' earmarks before migrating back to the winter pastures.

2.2 | Reindeer herders' maps of seasonal pastures

The siidas are designated to specific management areas called districts. The herders in each of these districts develop plans, which among other things include maps over seasonal pastures, calving lands, and migration routes (Reindeer Husbandry Act, 2007, § 62). The maps over seasonal pastures include subcategories depending on function and grazing intensity (see Appendix S1). In the district plan, the reindeer herders report the timing of movement between the different pastures and the use of motorized transport, fences and other installations necessary to round up the reindeers. The adaptation of reindeer herders to environmental variability differs throughout the study region depending on topography, ecology, land use and regulations (Hausner, Fauchald, & Jernsletten, 2012), and thus the maps reflect the adaptation needs of herders in their respective districts. The maps were first developed by reindeer herders in collaboration with reindeer husbandry administration starting in 1989 and have continually been revised since then. We compiled the seasonal maps of 69 districts from the official online map database to demonstrate the complexity of reindeer herders' knowledge and adaptation needs to resource conditions (see Appendix S1). We excluded summer pastures used by Swedish reindeer herders.

2.3 | Competing land uses and disturbances

Land use and other human activities that disturb reindeers or act as barriers for access to pastures can limit adaptation options for reindeer herders. We therefore collected data on competing land uses and assessed the potential bottlenecks by use of overlay analysis. Data included urban areas, buildings, roads, trails (N250 maps) and military areas downloaded from https://kartkatalog.geonorge.no and powerlines, wind and hydroelectric plants downloaded from https://www.nve.no/karttjenester/kartdata/.

2.4 | Incorporating herders' knowledge in decision-making

The reindeer herders' maps aim at informing land use planning at an early stage, but the herders' knowledge should also feed into decision-making about land use through consultations and hearings (see Appendix S1). In this case, reindeer herders, the reindeer management authority and the Sámi Parliament should be allowed to comment on or appeal public decisions that could affect Sámi reindeer herding. The reindeer management authority and the Sámi Parliament can in addition veto land use plans and applications for hydro- and wind power licenses.

These comments, appeals and vetoes provide case-specific information about these actors' perceptions of impact of new land development on Sámi reindeer herding which we analyzed using content analysis. We collected documents from the period 2010 to 2018 and limited our study to Troms county, as this area has the largest pressure on reindeer pastures. We investigated (a) to what extent the maps are used, (b) the perceived quality of the maps, (c) the perceived threats from competing land uses, and (d) whether herders and those representing them have an impact on decision-making. We noted the type of land development that was of concern, and whether disturbance effects and cumulative impacts of land development were mentioned as threats to reindeer herding. Cumulative effects can mean the combined effect of multiple land uses or the cumulative effects on several critical resources (e.g. effects on both summer pastures and migration routes). Avoidance can make herding difficult and result in indirect losses of pasture because the animals refrain from grazing in certain areas. Disturbance also causes stress, which can increase losses to predation, abortions and collisions with motorized vehicles. We noted the pastures perceived as threatened by the intervention. Finally, we looked at the proportion of development cases opposed by reindeer herders and/or those representing their interests that were denied a license by the authorities. In this case we focused on small-scale hydropower development cases where the Norwegian Water Resources and Energy Directorate is the licensing authority.

2.5 | Ecosystem-based adaptation needs

We reviewed literature on herders' knowledge of pasture quality. We excluded literature from boreal coniferous forests as these regions face different challenges than the tundra regions (e.g. logging of old-growth forests). We searched for knowledge AND Sami or Saami on Google Scholar. Since we retrieved few studies relating to the quality of green pastures, we also included ecological literature searching for pasture* or plant* AND reindeer.

3 | RESULTS

3.1 | Reindeer herders' maps over seasonal pastures

The reindeer herding maps revealed a highly complex and extensive use covering almost the entire area of Troms and Finnmark. On a large scale, interior winter pastures, coastal summer pastures and spring and autumn pastures in the middle are connected by numerous migration routes (Figure 1a). Competing land uses, including urbanization, buildings, roads, energy infrastructure and military training areas are present throughout the region, but is most prevalent in Troms (Figure 1b). On a smaller scale, a more complex picture emerges (Figure 1c). Areas are used in one or several seasons and by different siida groups in different parts of the year. Enclosures are

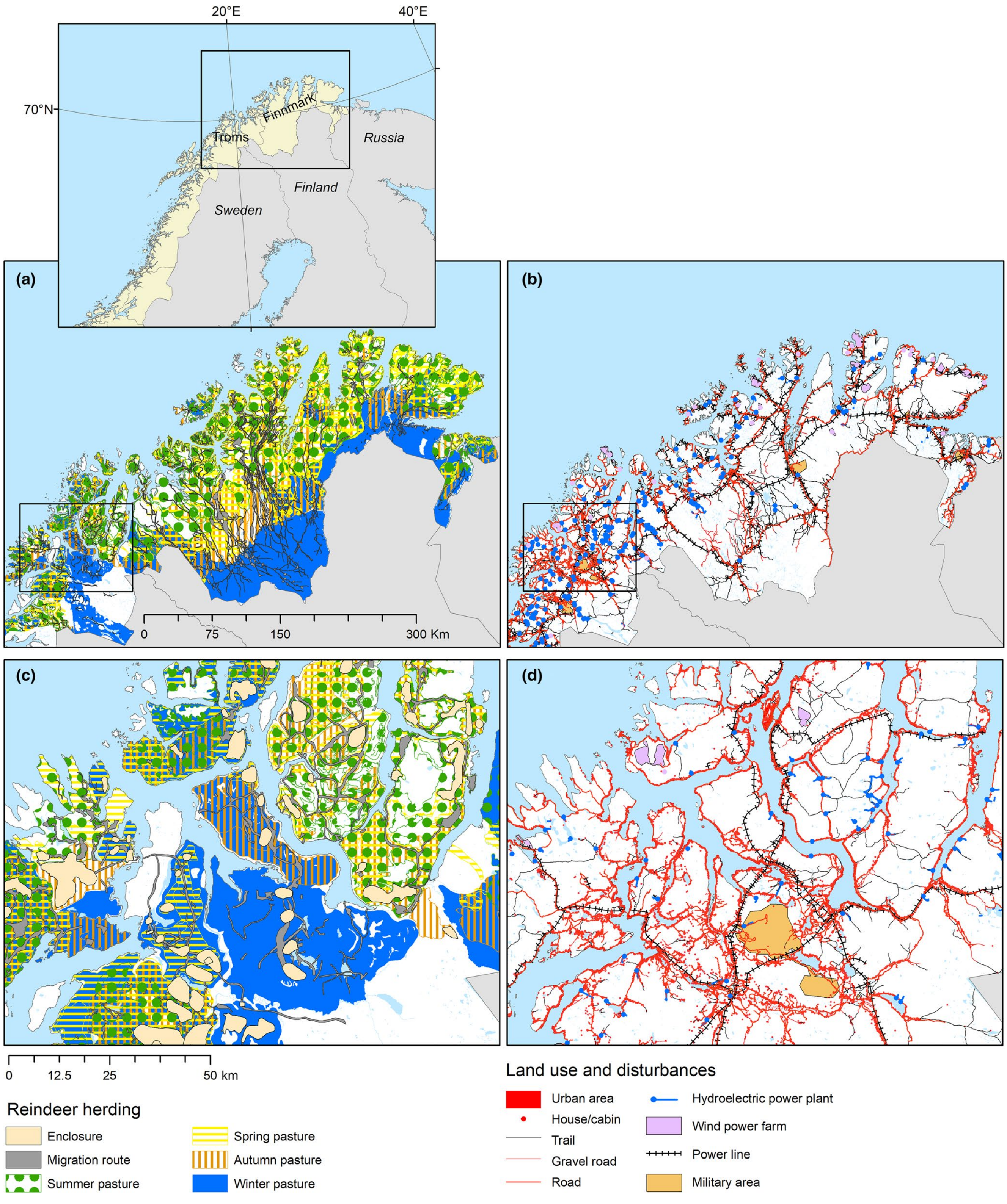

FIGURE 1 Reindeer herding pastures (a, c) and competing area use (b, d) in Finnmark and Troms. Reindeer herding data were mapped by the local herding districts in the area. Data on competing land uses are from the official statistics (see Section 2)

used to collect animals prior to round-ups where animals are slaughtered, marked or the flock is split before migration. During migration, the herd is intensively herded to cope with risks associated with crossing rivers, fjords and steep mountainous areas. The seasonal pastures are further subdivided into habitats that reflect specific adaptation needs (Table 2). Disturbance from other human activities (Figure 1b,d) will reduce the available options or even disconnect the different pastures, making some areas inaccessible. Areas of special concern are typically migratory pathways and calving lands. However, the effect of a disturbance will ultimately depend on the general mix of different pastures available to the herd.

Overlay analyses of the disturbances and the different pastures (Table 1) showed that lowland areas with early green growth, especially spring pastures close to the coast (male and yearlings), experience higher disturbances from competing land uses than pastures in more remote areas.

3.2 | Use of maps and herders' knowledge in decision-making

Our search yielded 91 cases in Troms county from 2010 to 2018 where concerns had been raised about the effect of land use on reindeer pastures and migratory routes. Green energy development represented 59% of the cases (52 small hydropower projects 1–10 MW, one large >10 MW and one on wind power development), followed by tourism facilities and second homes (30%). Four larger public roads and one large power line (420 kV) also generated complaints.

Perceived threats to migration routes were present in the highest proportion of the cases (68%), followed by spring pastures (44%) and calving lands (43%; Figure 2). The reindeer herders reported that cumulative effects of new development were often ignored (58%), and in addition to the direct loss of pasture, disturbance was also considered a threat in many cases (55%). Disturbance effects were reported for all types of land development (i.e. green energy, tourism and recreation, roads and powerline). Disturbance effects were present in

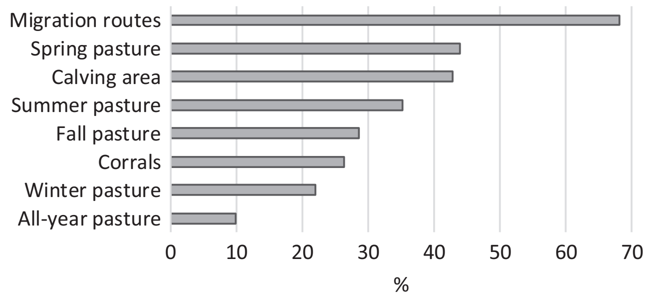

FIGURE 2 Perceptions of threats to reindeer pastures from new land development in Troms county from 2010 to 2018. We found 91 cases where concerns regarding competing land use were raised by reindeer herders and/or their representatives. The figure shows the proportion of cases where the various pastures were perceived as threatened by land development

TABLE 1 Density of disturbance (disturbance per area unit) from competing land use on seasonal reindeer pastures and migratory routes

	Winter		Spring		Summer		Autumn		
	Early: mostly snow-rich, low-land	Late: low icing and snow	Calving area	Early green growth: yearlings and males	Early: low-land	Late: high altitude	Early: rich pastures	Late: rut	Migratory routes
Competing area use[a]									
Urban areas	0.0471	0.0023	0.0039	0.0598	0.0219	0.0498	0.0294	0.0076	0.0059
Wind farms	0.0034	0.0002	0.0158	0.0250	0.0242	0.0178	0.0037	0.0040	0.0085
Military areas	0.0108	0.0158	0.0031	0.0110	0.0088	0.0095	0.0047	0.0083	0.0079
Linear infrastructure[b]									
Roads	0.136	0.126	0.110	0.189	0.119	0.099	0.127	0.103	0.128
Trails	0.084	0.082	0.078	0.073	0.062	0.060	0.083	0.100	0.138
Power lines	0.063	0.080	0.103	0.122	0.115	0.107	0.103	0.078	0.116
Point disturbances[c]									
Houses and cabins	0.2611	0.2085	0.2025	0.3510	0.2101	0.1827	0.2168	0.1491	0.1729
Hydroelectric plants	0.0020	0.0006	0.0017	0.0033	0.0027	0.0014	0.0018	0.0009	0.0016
Average rank	4.1	6.3	6.3	1.9	4.4	5.6	5.0	6.6	4.9

Note: Results from overlay analysis of infrastructure, buildings, energy facilities and military areas; and reindeer herders maps (see Section 2), including average rank of the disturbance density among pastures/migratory route.

[a]Percent of area.

[b]Length per area; 1/km.

[c]Number per area; *N*/km.

many of the cases where calving area (85%), summer pasture (84%), corrals (83%), fall pasture (81%), winter pasture (75%), all-year pasture (67%), migration routes (61%) where considered threatened.

The incorporation of knowledge in the participatory processes was reported unsatisfactory in 60% of the cases. These cases include insufficient representation of herders' knowledge, lack of scientific knowledge or of reliable impact assessments. Only in 8% of the cases the herders' maps were described as outdated, incorrect or not detailed enough. There are some indications that reindeer herders have a say in decision-making. For example, 43% of the small-scale hydropower development cases were denied a license by the Norwegian Water Resources and Energy Directorate solely or partly (i.e., along with other considerations such as the environment) out of consideration for reindeer herding.

3.3 | Ecosystem-based adaptation needs

The maps are relatively coarse and knowledge about adverse effects for reindeer herding needs more detailed information about forage available within seasonal pastures. Table 2 summarizes the key ecosystem services and possible ecosystem-based adaption strategies that are relevant for reindeer herders. Most studies on herders' knowledge in Scandinavia focus on reindeer herders' adaptation to snow and ice conditions in winter, while only a handful document herders' knowledge about the diversity of plants and ecosystem services. The maps reflect the need for pasture resources and not the actual use as an ongoing adaptation to land use.

4 | DISCUSSION

4.1 | Herders' knowledge of pastures and critical services

The participatory tool examined here attempts to incorporate herders' knowledge and their adaptation needs into decision-making. The maps created by reindeer herders illustrate the seasonal adaptation to food supply and the need for space and flexibility to move across administrative and natural boundaries to access pastures, if needed. The maps include habitats that serve multiple functions, including pastures that can act as an insurance against climate risks and extreme events. In an online version that is currently tested, reindeer herders can also continually update the maps in response to novel adaptation needs. These tools can contribute with necessary knowledge for implementing EbA at a landscape scale, but lack sufficient details for evaluating plant diversity and ecosystem services on a smaller scale (see Table 2). Documenting herders' knowledge at a finer scale or incorporating knowledge of pasture quality through participatory processes is therefore necessary.

Sámi knowledge of pasture quality can be combined with GPS data that provided real-time data on habitat preferences of reindeers (Iversen et al., 2014), thereby offering more precise data for estimating effects of land use change and loss of reindeer to other factors such as predation (Sandstrom, Sandstrom, Svensson, Jougda, & Baer, 2012). Monitoring by tracking devices can reveal habitat preferences and could as such complement the seasonal maps. However, GPS tracking is costly (Valinger, Berg, & Lind, 2018) and lack herders' knowledge of pastures necessary for coping with climate variability and for adapting to climate change over time. In this context, the maps produced on the basis of the herders' local knowledge cannot be replaced by maps derived from tracking devices.

4.2 | Land use change and incorporation of herders' knowledge in decision-making

Reindeer herders and those representing their interests were dissatisfied with the evidence used in 60% of the cases relating to land use change in Troms county. These cases also demonstrated the inadequate weight given to the knowledge of reindeer herders' interests in land use decisions. Competing land uses threaten migratory routes, calving lands and spring pastures, all of which are priority areas that should be protected according to the Norwegian planning system. On a countrywide scale, Riseth and Nygaard (2018) found that Sámi concerns were incorporated to a much larger extent in 'core' Sámi areas in the inner part of Finnmark, whereas coastal and southern regions, where land development has been most prevalent (Section 3.1, Figure 1b), have incorporated herders' knowledge to a lesser extent. They showed how the tendencies of local politicians to decide in favour of developers can turn an otherwise exemplary planning process to the detriment of reindeer herding. Thus, the main bottleneck for incorporating herders' knowledge in decision-making is not that the knowledge is inadequately represented in the official evidence base (i.e. on maps), but the insufficient recognition of herders' knowledge in land use planning in areas outside of the 'core' Sámi areas.

Competing land uses can considerably reduce the adaptation options for reindeer herders to climate change. In our case, the numerous interventions relating to green energy, recreation and tourism development result in piecewise reduction of pastures and landscape connectivity (see Figure 1, Table 1). The loss and fragmentation of pastures is also a global challenge (IPBES, 2019) caused by activities such as agriculture, mining, ranching, tourism and the construction of infrastructure and urban areas that are subsequently increasing the vulnerability of pastoralists to climate change at a global scale (López-i-Gelats, Fraser, Morton, & Rivera-Ferre, 2016).

4.3 | EBA strategies for pastoral systems

Pastoralists that move with their herds to track accessible plant resources have accrued considerable knowledge on how to adapt to variable conditions in marginal environments of dryland, steppe, and alpine and high latitude areas (López-i-Gelats et al., 2016). They are among those who are most at risk when climate warms, but have at

TABLE 2 Review of the key ecosystem services and ecosystem-based adaptation strategies

Landscape	Key habitats	Ecosystem services	Ecosystem-based adaptation strategies	Sources
Winter pastures	Inland winter pastures less likely to experience icing or deep snow in mid-late winter Snow rich lowlands used early in winter	Snow and ice conditions determine access to ground lichens on winter pastures. Winter pastures with a lichen mat 5 cm high and 74% coverage consisting mainly of *Cladonia* spp. Regarded as good winter pastures Woodland or shrubs can provide shelter and forage when ice crusts cover lichen pastures Wintergreen species such as lingonberry *Vaccinium vitis-idaea*, grasses *Poaceae* spp., dwarf shrubs, and mushrooms preserved under snow can be alternative forage Lowlands can be used when the snow is not too deep	Protect lichen pastures in different parts of the landscape so that the reindeer always find available patches Avoid human impacts or intensive grazing by reindeers to ensure abundant lichen pastures over time Ensure pasture heterogeneity and optional pastures that can be used under different weather conditions Avoid planting trees for climate mitigation, as this obstructs reindeers' movement and utilization of pasture	Eira et al. (2013); Inga (2007); Inga and Danell (2013); Riseth and Tømmervik (2017); Turunen, Rasmus, Bavay, Ruosteenoja, and Heiskanen (2016)
Spring pastures	Remote and undisturbed calving land Spring pastures for males and last years calved. Later used by females and calves	Undisturbed land by predators and human activities Ridges and hillsides near calving lands that produce green shoots early, such as wavy hair-grass *Avenella flexuosa*, tufted hair grass *Deschampsia cespitosa*, tussock cottongrass *Eriophorum vaginatum*, and several sedges *Cyperacea* spp. Wetlands thaw earlier providing green shoots and roots from sedges *Carex* spp. Common cottongrass *Eriophorum angustifolium* have nutritious rhizomes that reindeers eat Trees and shrubs with early bud burst such as willows *Salix* spp. Sun exposed hills and ridges that provide earlier snowmelt and forage for reindeer	Avoid disturbance or high number of predators on calving lands Protect habitats on spring pastures that provide early forage for reindeer after snowmelt Protect spring pastures with high abundance of willows, grasses and sedges	Inga and Danell (2013); Iversen et al. (2014); Kitti, Gunslay, and Forbes (2006); Rautio, Linkowski, and Östlund (2016); Riseth and Tømmervik (2017); Warenberg, Danell, and Nieminen (1997)
Summer pastures	Lowland, early green growth summer pasture Highland summer pastures	Mires, riparian habitats and woodlands are important in early summer. Bogbean *Menyanthes trifoliata* and purple marshlocks *Comarum palustre* have rhizomes the reindeer can dig up Late melting snow patches and altitudinal gradients can provide fresh grasses, forbs and leaves throughout the summer Glaciers, mountains, mires and hills provide cooling and insect relief Riperian habitats provide high quality pastures including *Salix* spp. Pastures near fresh water can have a variety of herbs and grasses growing at different time of the year Norwegian angelica *Angelica archangelica archangelica*, mountain sorrel *Oxyria digyna*, alpine sow-thistle *Cicerbita alpine*, rosebay willowherb *Chamerion angustifolium*, woodland geranium *Geranium sylvaticum* og common cow-wheat *Melampyrum pratense* are important forage in summer	Grazing has been proposed to counteract the expansion of trees and shrubs that can reduce herbaceous plant communities. Crowberry *Empetrum nigrum* can on the other hand be facilitated by grazing Protect glaciers, mountains, mires and hills where reindeer can escape warm weather and insects	Bråthen, Gonzalez, and Yoccoz (2018); Hausner et al. (2011); Horstkotte et al. (2017); Inga and Danell (2013); Kitti et al. (2006); Paine (1994); Pape and Löffler (2015); Riseth and Tømmervik (2017); Warenberg et al. (1997)

(Continues)

TABLE 2 (Continued)

Landscape	Key habitats	Ecosystem services	Ecosystem-based adaptation strategies	Sources
Autumn pastures	Seasonal land for rutting Early autumn to build up reserves after disturbance by insects and to build fat reserves	Forests in lowlands provide mushrooms, which is a protein-rich food source for reindeer in August and September Herbs and grasses are grazed but are less nutritious this time of year	Minimise human disturbance, since late rut, absence of snow, and more mushrooms can result in dispersed herds that are difficult to manage	Inga (2007); Turunen et al. (2016); Warenberg et al. (1997)
	Late autumn/early winter pastures that is used before snow becomes too deep Scattered autumn pastures that is optionally used	Mires are important also after the ground is frozen for foraging, drinking and resting Heather *Calluna vulgaris* and blueberries *Vaccinium myrtillus* become more important as forage late in the autumn		

the same time a great potential to cope with climate variability and to adapt to climate change by using their own knowledge (Sara, 2009). EbA is about protecting the ecosystems and their services to enable pastoralists to adapt to climate change. Our study demonstrates challenges for implementing EbA that is also relevant for other mobile pastoralists throughout the world.

Firstly, mobile pastoralists need space and flexibility to move across administrative and natural boundaries. The closing of administrative borders has historically limited the opportunity of pastoralists to adapt to change (Paine, 1994), but the Norwegian reindeer herders can move between traditional pastures independent of who owns or manages the land within national borders. Disturbance from land development such as roads, tourist developments and buildings are obstacles that curb the flexibility of pastoralists, especially along the migration routes. Maps over seasonal pastures and migration routes are used by all sectors and municipalities to consider the adaptation needs of reindeer herders at an early stage in the planning process. If these maps were adequately used by the different land use interests and the planning system, the reindeer herders could spend less time engaging in hearings and consultations to protect their pastures.

Secondly, land use changes are among the greatest threats to indigenous land worldwide (IPBES, 2019). In high pressure areas (cf. Figure 1), pastures have already been reduced considerably, and the many small interventions result in loss of pastures bit-by-bit that in sum constrains adaptation options. IPBES (2009) has warned that green energy development can put additional pressure on indigenous land. Similarly, nature-based tourism that is currently expanding in remote areas (Balmford et al., 2009), are often presented as alternative livelihoods for local communities, but are in our case a source of conflict with indigenous land uses. In other words, the co-benefit approach that is propagated by EbA is not always feasible, because fundamental tradeoffs exist between protecting natural pastures and accommodating new land uses associated with climate mitigation and tourism.

Thirdly, EbA strategies need to be multi-scale, and landscape-level maps are not enough for representing herders' knowledge and adaptation needs. Pastoralists adapt to a diversity of plant services on a finer scale, and can have extensive knowledge about forage species diversity, abundance and trends of forage resources as well as the underlying drivers causing these patterns (Naah & Braun, 2019). Herders' knowledge on this scale is important for predicting future adaptation needs of pastoralists, but has not been documented sufficiently in the existing literature.

Fourth, it is important to note that herders have other adaptation strategies beyond EbA to sustain their livelihoods. For instance, habitat loss, predation, fragmentation and climate change have not resulted in decline of reindeer populations in Sweden. This is most likely due to changes in herd structure, more intensive grazing of remaining pastures, changes in herding strategies and grazing patterns, and supplementary feeding (Bårdsen, Næss, Singh, & Åhman, 2017). Knowledge about how reindeers are herded to avoid predators and climate risks and the institutions necessary for adaptations is also important (Hausner et al., 2012; Sara, 2009), but was not the focus here.

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AUTHORS' CONTRIBUTIONS

V.H.H. led the writing of the manuscript; P.F. compiled and synthesized the spatial data; S.E. led the content analysis and C.B. contributed with literature synthesis of IK, critical services and ecosystem-based adaptation strategies; All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via the Dryad Digital Repository https://doi.org/10.5061/dryad.31zcrjdgh (Engen, Hausner, Brattland, & Fauchald, 2019).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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