Received: 28 September 2020 | Accepted: 1 May 2021

DOI: 10.1002/pan3.10234

RESEARCH ARTICLE

PEOPLE AND NATURE | BRITISH ECOLOGICAL SOCIETY

Reindeer husbandry in peril?—How extractive industries exert multiple pressures on an Arctic pastoral ecosystem

Christian Fohringer[1] | Gunhild Rosqvist[2] | Niila Inga[3] | Navinder J. Singh[1]

[1]Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences, Umeå, Sweden

[2]Department of Physical Geography and Quaternary Geology, Stockholm University, Stockholm, Sweden

[3]Laevas Sámi community, Kiruna, Sweden

Correspondence
Christian Fohringer
Email: christian.fohringer@slu.se

Funding information
NordForsk, Grant/Award Number: 76938

Handling Editor: Jana McPherson

Abstract

1. Environmental changes and their consequences on biodiversity are known to have far-reaching effects on the resilience of animal populations and associated livelihoods around the world. To counteract negative demographic and economic effects on pastoralism, knowledge about the historical and current status of the environment is essential.
2. In this study, we show how extractive industries, especially large-scale mining, induced a cascade of land conversions which are affecting animal populations and pastoralists' adaptive responses in northern Sweden. We examine social–ecological vulnerability in Arctic reindeer husbandry by integrating herders' knowledge, population statistics for semi-domesticated reindeer *Rangifer t. tarandus*, public data on socio-economic variables and geospatial tools.
3. We determine that approximately 34% of Laevas reindeer herding community's grazing grounds are functionally unavailable to reindeer at present due to the accumulation of multiple competing land use pressures. Reindeer numbers currently only remain stable due to increased management efforts. Moreover, we identified current hotspots of high cumulative impact and mineral exploration as the spatially dominating land use factor in this area.
4. Our approach and results provide new insights for scientifically robust cumulative impact assessments of anthropogenic stressors by creating a baseline of current developments via a combination of reindeer herder's knowledge with historical data of trends and extents of human activity over the last century.

KEYWORDS

cumulative impacts, herder knowledge, historical time series, land use, reindeer herding, resource extraction, semi-domesticated reindeer

1 | INTRODUCTION

Across the globe, anthropogenic land conversion is increasingly encroaching animal's ranges and indigenous peoples' livelihoods that depend on them (e.g. Dong et al., 2011; IPBES, 2019; Larsen et al., 2017; Schwartz, 2005; Tucker et al., 2018). This is particularly evident at resource-rich high latitudes, where multiple human land users and wildlife are contesting ecosystems and the services provided by them (UNEP, 2001). Simultaneously, these systems are experiencing climate change effects at accelerated rates (IPCC (Intergovernmental Panel on Climate Change), 2014). A before-after-impact-control design is an ideal method to determine land conversion impacts (Conner et al., 2015). In reality, however, such analyses are often impossible to conduct, especially when infrastructure development has already taken place. Nevertheless, it is important to quantify land use changes, their trends and impacts on affected environments, so as to intervene and to restore ecosystems and improve livelihoods that depend upon these lands.

Migratory reindeer *Rangifer tarandus* are particularly sensitive to anthropogenic activities due to their large home ranges and are exposed to these activities across their circumpolar range (Benítez-López et al., 2010; Vors & Boyce, 2009). Many studies have shown change in reindeer populations' behaviour in response to linear infrastructure, resource extraction, tourism, energy developments and human settlements (Ewacha et al., 2017; Plante et al., 2018; reviewed by Skarin & Åhman, 2014; Skarin et al., 2015; Tyler et al., 2016; Wilson et al., 2016).

Reindeer husbandry is an example of a pastoral system where animals move over large areas on a seasonal scale and are thereby subjected to multiple pressures of land use. Semi-domesticated reindeer are of crucial subsistence and socio-cultural importance for the Sámi people of Fennoscandia and Russia (Jernsletten & Klokov, 2002). Despite reindeer herders' high adaptive potential, land conversion and climate change ultimately result in challenges regarding their livelihoods. These challenges are driving human–wildlife conflicts and are hindering the sustainable development and use of natural resources by the indigenous community (Forbes & Kumpula, 2009; Pape & Löffler, 2012).

The Arctic region of northern Sweden is characterized by relatively low human population density and dominated by several key land use interests: resource extraction (timber, ore, peat, rock), renewable energy developments (hydropower and wind power), tourism, military activity and reindeer husbandry (Gallardo et al., 2017; Horstkotte, 2013), which is practiced by a portion of the indigenous population, the Sámi. Most industrial developments on indigenous land started to establish in the early 20th century, but experienced substantial advances in operating technology during the latter half of the 20th century (Klein, 1971). Land use interests of reindeer husbandry and its cultural heritage are often overruled by advancing extractive industries, but the livelihood has managed to coexist alongside multiple pressures of land use changes due to its adaptive potential, including modernization (Bårdsen et al., 2017; Beach, 1981; Helle & Jaakkola, 2008; Lawrence & Larsen, 2017).

Meteorological records from northern Sweden show that this region is in rapid transition (Berglöv et al., 2015). Air temperatures have increased in northern Sweden during all seasons over the past three decades. For example, the average annual temperature for the town of Kiruna changed from −1.7 to −0.4°C (averages for 1961–1990 and 1989–2018 respectively). Even though all seasons became warmer, the largest increase (of 2°C) occurred during the winter (December–February). One result of warmer winters is that periods of melt occur more frequently which in turn results in more frequent formation of very dense snow, ice layers within the snowpack and icy snow surfaces (Johansson et al., 2011; Rasmus et al., 2018). Such conditions radically decrease access to terricolous lichens, the primary winter food source for reindeer (Heggberget et al., 2002). Adaptation demands increased flexibility of reindeer herders to provide suitable grazing areas for their animals (Forbes et al., 2009). Their potential to adapt to weather anomalies however has been increasingly disrupted by cumulative impacts directly linked to land conversion.

Most research into the impact of infrastructure on large ungulates and traditional lands inhabited by indigenous people has focused on either single-impact assessments or generalized cumulative impact assessments (CIAs). These assessments aim to quantify the changes in the environment caused by the combined impact of past, present and future human activities along with natural processes (Lawrence & Larsen, 2017). A common tool used in CIAs is the estimation of a zone-of-influence (ZOI, alternatively zone-of-avoidance; e.g. Boulanger et al., 2012; Nellemann & Cameron, 1996; Nellemann et al., 2001, 2003; Polfus et al., 2011; Weir et al., 2007), which aims to quantify the extent of functionally lost land towards which animals exhibit adverse behaviour. Any land use development plan or climate adaptation strategy also requires information on the status of the system. To facilitate a frame of reference, such baseline information needs to incorporate historical spatiotemporal and empirical datasets including local and/or indigenous knowledge (Bull et al., 2015). However, CIAs often fail to integrate such knowledge, and thus risk missing essential information, such as environmental conditions, local and/or indigenous communities' well-being or animal welfare aspects (Baker & Westman, 2018; Ford et al., 2016; Hausner et al., 2019; Larsen et al., 2017).

Our goal is to document the timeline of land use changes in a Sámi reindeer herding community (RHC, also referred to as *sameby* or herding district) since the onset of industrial resource extraction in northern Sweden, and analyse the interconnection and cumulative impacts of these changes on reindeer grazing areas and herd size. We aim to establish the current baseline (e.g. Bull et al., 2015), by identifying local developments of land use including human and reindeer population trends for the area used for grazing by Laevas RHC. Specifically, we investigate what are the drivers of change that led to loss of land for the herders, timings of these events, the spatial and temporal extent of these changes and their interconnectedness.

We chose the reindeer herding system as a model for characterizing the changing state of the ecosystem due to the fact that reindeer herders have extensive knowledge about the landscape and the changes encountered at socio-ecological and economic scales. In combination with empirical datasets, local herder knowledge is, therefore, an integral component of our analysis. Laevas RHC was chosen as a study system because: (a) Sweden's oldest and most exploited ore fields as well as a cascade of long-established anthropogenic developments are located in their district, exhibiting a conflict of land use interests (Gallardo et al., 2017; Klein, 2000; Reichwald & Svedlund, 1977); (b) this RHC is representative for many other RHCs due to its size, herding style, governance and reindeer population dynamics; (c) previously established trust and ambition to participate in an objective characterization of the state of the system.

By examining the situation of an RHC undergoing changes, we show how inappropriate land use planning can render a culture-bearing pastoral system unviable. We compile, collate and translate available data on land use and climate change and analyse their impacts on traditional livelihoods that rely on mobility. The novelty of this study lies within the combination of extensive empirical datasets with herder knowledge and a historical perspective, allowing for the identification of indicators of change and cascading effects, at the highest available spatiotemporal resolution. Through detailed examination of factors involved in the encroachment of reindeer pastures at the landscape level, this study aims to be an example that can improve CIAs to ensure the persistence of sustainable pastoralism reliant on intact ecosystems. We argue that sustainable land use planning needs to be based on the understanding of processes and actions that created the current environmental status.

2 | METHODS

2.1 | Study area

Laevas RHC is located above the polar circle, at 68° latitude, in Arctic Sweden (Figure 1). One of 33 mountain RHCs in Sweden, Laevas RHC represents a typical seasonal migratory husbandry system. Reindeer are free ranging on their summer pastures in the Scandinavian mountains (west) and descend to lower altitudes towards winter grazing grounds in the boreal forest (east), where they are herded intensively. Spring and autumn pastures—holding reindeer calving and rutting grounds respectively—are utilized mostly west of the town Kiruna at lower altitudes (Figure 1). During the main migration events (spring and autumn migration to and from winter pastures respectively), reindeer are being herded along movement corridors (Figure 1). Spring migration usually occurs between March and April. Autumn migration occurs between November and December, when approximately 6,800 reindeer are assigned to eight or nine winter groups (defined as *siidas*—traditional management units for a herd). The division of the herd per *siida* allows for more efficient management and reduces overexploitation of pasture during the harsh winter conditions. Other major events during the reindeer herding year include the main slaughter during the first 2 weeks of September, and calf marking between summer solstice and the first days of August. The vast majority of Laevas RHC's grazing grounds fall within the administrative boundary of Kiruna municipality in Norrbotten, Sweden's northernmost county. Norrbotten has a relatively low human population density and is dominated by several key land use interests—resource extraction (timber, minerals, peat, ore), tourism, military activity and reindeer husbandry. The north-west portion of the summer grazing ground extends into Norway and transnational movement of animals is permitted. Laevas RHC currently comprises of 178 reindeer owners and employs 17 reindeer herders.

2.2 | Data collection and analysis

Data collection focused on the trends concerning reindeer husbandry, human population and industrial developments within the ecological boundaries of Laevas RHC. This was defined in their annual grazing grounds rather than their administrative boundary, or the next higher administrative order, that is the municipality or county level. Subsequently, we explored the drivers of change in Laevas RHC individually, and developed a timeline and conceptual map of the accumulating impacts of these drivers. The data were

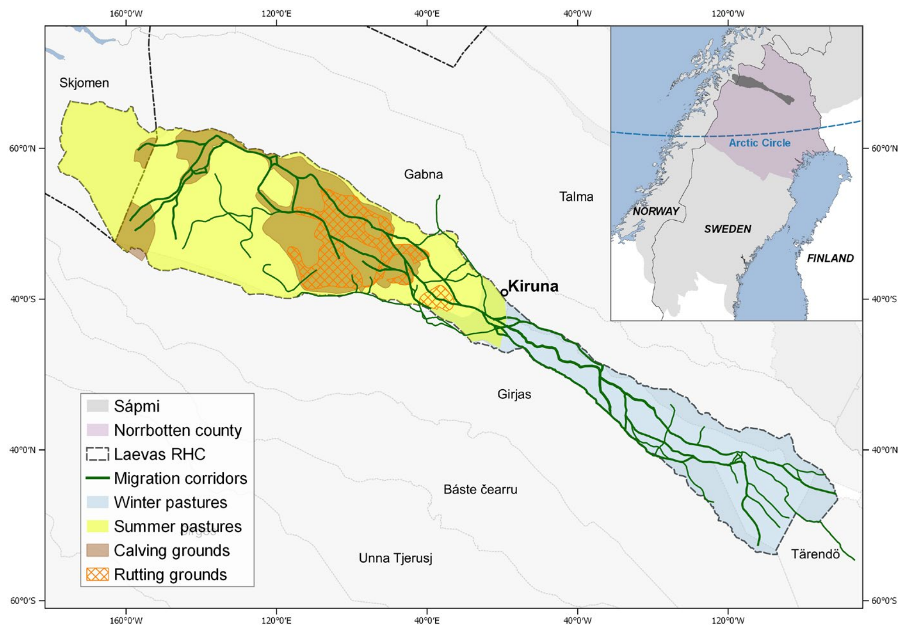

FIGURE 1 Location of Laevas RHC in Norrbotten county of Sweden (in pink) within Sápmi, homeland of the Sámi people (light grey shade). Seasonal delineation of traditional reindeer pastures for winter (blue; November–March) and summer (yellow; June–August). Crosshatched orange and brown shades illustrate rutting grounds (September–October) and calving grounds (May) respectively. Green lines highlight migration corridors

collected and analysed between 2017 and 2018, incorporating primary and secondary datasets publically available online or acquired via contacting local administrations, governmental agencies or companies, allowing for sufficient cross-validation of dating and background information to develop the baseline of current developments (Table 1).

Statistical and spatial analyses were performed on these data using QGIS 3.2 (QGIS Development Team, 2018). Detailed information on the annual use of reindeer pastures and data gaps on anthropogenic development trends was provided by N. Inga, who is representing the source of Sámi reindeer herder knowledge input for Laevas RHC for this study. Specifically, N. Inga provided access to data related to spatiotemporal herding activities and reindeer/slaughter/predator statistics but also verified the occurrence and extent of impacts affecting reindeer husbandry in Laevas RHC (Table 1). As the representative chair and spokesperson—chosen by and for the community—N. Inga's insights related to the issues discussed in this study are representative of the RHC as a whole.

We defined the total area of the RHC by the extent of its annual grazing grounds, encompassing 4,486.42 km^2. This area is designated by herders and restricted by natural boundaries as well as fences to avoid reindeer entering neighbouring RHCs or potentially lethal infrastructure, such as railway tracks or major roads. Moreover, the Reindeer Herding Act regulates the boundaries between RHC's west of the 'cultivation border' (odlingsgränsen; Sveriges Riksdag, 1971). Laevas RHC stretches over a maximum distance of 217.10 km, but exhibits a bottleneck southwest of Kiruna with a minimum width of about 6.24 km, requiring intact habitat for successful migration (Figure 1).

2.3 | Spatiotemporal context

Geospatial extents for all quantifiable land use factors were mapped based on public data or digitized from satellite images (©2016 Google) and herder knowledge (indicated via information obtained from the Sámi Parliament of Sweden and N. Inga; Table 1). Additionally, spatial data on relevant infrastructure for reindeer husbandry and the delineation of grazing grounds from RenGIS 2.0 (Sandström, 2015), a digital tool built for the members of RHCs, were incorporated to complete our framework (Table 1). When available, the temporal extent of infrastructural developments was added to spatial data.

2.4 | Reindeer, slaughter and predator statistics

Data on reindeer population dynamics, demographics, slaughter statistics as well as the number of reproductive units of predators between 1995 and 2017 were accessed via the Sámi Parliament of Sweden. Reindeer numbers from years prior to 1995 originate from the archives of the RHC and the County Administrative Board.

The County Administrative Board of Norrbotten currently sets a maximum threshold of 8,000 reindeer for Laevas RHC, which is based on estimated carrying capacity of the pastures in the district. Animals are counted each year by the reindeer herders after slaughter, and before calving period in May. Reindeer are slaughtered during set annual events for private consumption or sale. The majority of slaughters in Laevas RHC occur during the first 2 weeks of September.

Based on the number of reproductive units of predators (a stationary family group of adult predators and their offspring within a defined area), each RHC receives monetary compensation for the presence and breeding success of wolverine *Gulo gulo* and Eurasian lynx *Lynx lynx*, and the potential damage that they inflict on reindeer in their district. To estimate the total number of these species in northern Sweden, a conversion factor of 6.14 for lynx (Tovmo & Zetterberg, 2018) and 6.27 for wolverines (Eklund et al., 2017) per reproductive unit can be applied. Compensation for reindeer losses to European brown bear *Ursus arctos arctos* and golden eagle *Aquila chrysaetos* is instead based on area, which is why no annual population census exists for these species. The current carnivore policy in Sweden suggests that there should be no established wolf packs in the four northernmost counties of Sweden (i.e. within the majority of Swedish Sápmi), and therefore the species only occurs sporadically in the area.

For the interpretation of reindeer, slaughter and predator statistics in relation to land use and climate change, we rely on herder knowledge.

2.5 | Mines

Details on the periods of and style of extraction, as well as on the minerals mined, were accessed via the Geological Survey of Finland, responsible companies and literature research. Data regarding permits for exploration and mining (e.g. designation of land, expired exploration permits, expired/granted/applied exploration permits, exploitation permits) are provided by The Mineral licence register at The Mining Inspectorate of Sweden (Swedish Geological Survey). Spatial overlaps of permits issued between 1984 and 2017 were excluded to determine the total area of expired exploration permits in Laevas RHC. Data on granted exploitation permits for quarries in Norrbotten county are provided by 'Miljöskyddsenheten' (County Administrative Board of Norrbotten).

The total spatial extent of most mines and quarries in the study area was supported by information outlined by members of Laevas RHC via RenGIS 2.0 (Table 1), illustrating the total extent that is currently unavailable to reindeer.

2.6 | Forestry

We rely on the Swedish Forestry Agency as a single data source regarding clear cuts, which have been documented at a national scale only since 2000 (and more consecutively since 2002) and were available until July 2018 (Table 1).

TABLE 1 Data Sources and geospatial references (all accessible on 23 April 2021)

Data type	Description	Temporal resolution	Analysis	Source
Mines	Details on individual mining sites (location, extraction style, extracted material, status of operation, ownership, etc.)	Compiled 2018	Impact of mining on grazing grounds	Geological Survey of Finland (https://hakku.gtk.fi/en)
	Designated Land, Exploitation Concessions Exploration/Exploitation permits; Designation of land	1984–2018	Trend activity and extent of mining infrastructure	The Mineral licence register at The Mining Inspectorate of Sweden (https://www.sgu.se/produkter/kartor/kartvisaren/bergkartvisare/mineralrattigheter/) RenGIS 2.0 (Sámi Parliament of Sweden; https://www.sametinget.se/111684) SGU (2018) LKAB (2017a, 2017b) LKAB (2018)
Quarries	Exploitation permits	Compiled 2018	Impact of mining on grazing grounds	County Administrative Board of Norrbotten (www.lansstyrelsen.se/norrbotten) RenGIS 2.0 (Sámi Parliament of Sweden; https://www.sametinget.se/111684) Zachrisson (2015)
Forestry	Total area of clear cuts	2000–2018	Impact and extent of forestry on grazing grounds	Swedish Forest Agency (http://geodpags.skogsstyrelsen.se/geodataport/feeds/UtfordAvverk.xml)
Roads	Spatial distribution of road network (all scales, paved and unpaved roads)	Compiled 2018	Impact and extent of roads on grazing grounds	Swedish Transport Administration (https://lastkajen.trafikverket.se/107_OA_FileStorage/Default.aspx)
Snowmobile tracks	Spatial distribution of snowmobile tracks	Compiled 2018	Impact of snowmobile tracks on grazing grounds	Skoterkarta.com Skoterleder.com Mapping of data gaps (C. Fohringer; N. Inga)
Hiking trails	Spatial distribution of hiking trails	Compiled 2018	Impact of hiking trails on grazing grounds	RenGIS 2.0 (Sámi Parliament of Sweden; https://www.sametinget.se/111684) Digitized from Google (©2016) satellite images, C. Fohringer
Railway	Spatial distribution of railway tracks	Compiled 2018	Impact of railway on grazing grounds	Swedish Transport Administration (https://lastkajen.trafikverket.se/107_OA_FileStorage/Default.aspx)
Power lines	Spatial distribution of power line network	Compiled 2017	Impact of power lines on grazing grounds	Lantmäteriet (https://www.lantmateriet.se/sv/Kartor-och-geografisk-information/geodataprodukter/produktlista/oversiktskartan/)
Settlements	Spatial distribution of villages and urban areas	Compiled 2015	Impact of settlements on grazing grounds	Statistics Sweden (https://www.scb.se/hitta-statistik/regional-statistik-och-kartor/geodata/oppna-geodata/)
Industrial areas	Spatial distribution of airports	Compiled 2010	Impact airports on grazing grounds	Statistics Sweden (https://www.scb.se/hitta-statistik/regional-statistik-och-kartor/geodata/oppna-geodata/)
Passenger numbers Kiruna airport	Monthly and annual counts of passenger arrivals at airports	1958–2018	Trend in human influx to the area; proxy for visitor rates	Swedavia (www.swedavia.se)
Number of overnight stays in cabins	Annual count of overnight stays in mountain stations and cabins, with seasonal distinction	1965–2017	Trend in recreational activity	Swedish Tourist Association (https://www.svenskaturistforeningen.se/)

(Continues)

TABLE 1 (Continued)

Data type	Description	Temporal resolution	Analysis	Source
Number of overnight stays in Norrbotten	Monthly and annual counts of overnight stays at registered accommodation units	1978–2018	Trend in recreational activity	Statistics Sweden (http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__NV__NV1701__NV1701A/?rxid=5f706427-062f-47ad-9b96-c71587348c0b)
Human population	Annual inventory of the population in Kiruna and Kiruna municipality	1900–1998	Trend in local human population	Warg (2007)
	Inventory of the population in Kiruna and Kiruna municipality	2000, 2005, 2010, 2015–2017		Statistics Sweden (http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101A/BefolkningNy/)
Wind power plants	Spatial distribution of operating and wind power plants and planned projects	Compiled 2018	Impact of wind power on grazing grounds	Vindbrukskollens map service at Vindlov (http://ext-dokument.lansstyrelsen.se/gemensamt/geodata/ATOM/ATOM_LST.VKOLLEN_PROJEKTERINGSOMRADEN.xml)
Military	Spatial distribution of military range, associated infrastructure, zone-of influence, development and activity schedule	Compiled 2018	Impact, extend of military on grazing grounds	Swedish Armed Forces (www.forsvarsmakten.se)
Agriculture	Total area of used for agriculture	Compiled 2018	Impact and extent of agriculture on grazing grounds	Swedish Board of Agriculture (https://nya.jordbruksverket.se/download/18.521ba5ac16c37936e1cb6908/1570791329759/Jordbruksblock2019.zip)
Reindeer statistics	Total number of reindeer in Laevas RHC	1971, 1977–1983, 1985–1988, 1993, 1994	Trends for reindeer numbers and reindeer slaughters	N. Inga
	Total number of reindeer in Laevas RHC	1960–1970, 1972–1976, 1984, 1989		County Administrative Board of Norrbotten (https://www.lansstyrelsen.se/norrbotten)
	Total number of reindeer; number of males, females, calves in Laevas RHC	1995–2017		Sámi Parliament of Sweden (https://www.sametinget.se/statistik/renhjorden)
	Number of slaughtered animals and slaughter weights in Laevas RHC; national reindeer meat market value (SEK*kg^{-1})	1995–2017		Sámi Parliament of Sweden (https://www.sametinget.se/statistik/renslakt)
Number of predators	Annual counts of reproductive units of lynx and wolverine	1995–2017	Trend for total number of predators	Sámi Parliament of Sweden (https://www.sametinget.se/statistik/rovdjur)
Sámi land use	Distribution of reindeer grazing/calving/rutting grounds, migration corridors, RHC boundaries	Compiled 2018	Quantification and illustration of competing land use on traditional reindeer pastures	RenGIS 2.0 (https://www.sametinget.se/111684) N. Inga

2.7 | Human population and activity

To quantify and illustrate recreational activity and its trends, we compiled data from multiple sources, including airport statistics and overnight stays in registered accommodation units (Table 1). Data provided by the Swedish Tourist Association allowed a distinction of the number of overnights between winter (February–May) and summer (June–September).

2.8 | Zone-of-influence

Anthropogenic developments (i.e. trails, railroad, main roads, snow-scooter trails, power lines, mines, quarries, wind farms, settlements, airport) were buffered by a ZOI of 500 m as assumedly functionally unavailable to reindeer (Environment Canada, 2011; Rudolph et al., 2017). The choice of using a conservative buffer of fixed size is based on the relatively high spatiotemporal plasticity that reindeer (and caribou) exhibit towards different types of human activity and infrastructure. Despite the potential differences regarding avoidance behaviour between wild caribou and reindeer and semi-domesticated reindeer, that likely exhibit adaptations to humans related due to herder management and selective breeding, we assume that they respond to stochastic and sudden anthropogenic disturbances that are not related to herding, with similarly strong avoidance behaviour. We justify the applicability of Environment Canada's model (based on wild caribou) to our case (semi-domesticated reindeer in a pastoral system) because undisturbed home ranges are essential for the welfare of both subspecies and the people who culturally and economically depend on them. We assume that pastures within the ZOI become less suitable or not suitable for reindeer grazing due to the reindeers' avoidance behaviour and a reduced pasture quality in addition to general land loss and habitat fragmentation. Resulting buffers were merged with the designated area of noise influence around the military base, the total area of clear cuts (since 2000) and the contested pasture with Tärendö concession-RHC (located at the eastern extent of Laevas RHC). The resulting layer overlaps were removed and clipped to the extent of Laevas RHC's grazing grounds to calculate the ZOI for Laevas RHC.

Clear cuts were not assigned a ZOI, since reindeer do not avoid clear cuts. This is in contrast to the behaviour of wild woodland caribou *R.t. caribou* in Canada and is caused by different predator–prey dynamics (see Environment Canada, 2011). Recently disturbed forest (e.g. via forestry) in Canada attracts other ungulate species, the major prey species for wolves and bears. Apparent competition therefore increases caribou vulnerability to these predators (Frenette et al., 2020). In Laevas RHC, these predators are either absent (wolves) or in torpor (bears) when reindeer spend the winter in the forest lowlands affected by forestry. Nevertheless, grazing grounds become unsuitable after clear cutting and affected areas are therefore included as a non-buffered ZOI.

Due to the unknown intensity and timing of exploratory drilling, areas with granted mineral exploration permits were not included in the ZOI.

3 | RESULTS

3.1 | Industrial development

The turn of the 20th century demarcates the onset of industrial-scale mining in the area as the first driver of change which lead to a cascade of other following changes (Figure 2). As for 2018, we identified 11 mining complexes (five ore mines, five quarries and one peat mine) that caused land loss on Laevas RHC's grazing grounds, corresponding to a total of 10.51 km^2 (Table 2; Figure 2). We found that mineral exploitation concessions are currently restricted to the community's winter grazing grounds, whereas mineral exploration also occurs in all other seasonal grazing grounds (Supporting Information, Figure S1). Currently, two iron ore mines are operating year-round, while other sites are only seasonally active (mostly quarries), lay dormant or have been abandoned.

The largest city within the RHC is Kiruna, founded by the Swedish mining company Luossavaara-Kiirunavaara Aktiebolag (LKAB) in 1899. The population trend for the city reflects that of the larger municipality, which holds most of Laevas RHC's grazing grounds (3,545.17 km^2, 79.02%, Table 2). Since the inauguration of the city, the population in the area increased dramatically reaching its peak in the mid-1970s, with just over 31,000 inhabitants (Supporting Information, Figure S2). Two decades of substantial emigration followed after which a population of around 23,000 was reached, which has not changed significantly since.

3.2 | Railway

Mining and human immigration were followed by the construction of the railway (finalized 1903) and road system for efficient transportation of ore to the Atlantic and the Baltic coast for processing and shipment. This was the second major change that increased access to mineral exploration and exploitation to previously pristine land in the following decades. Moreover, it allowed the tourism sector and other infrastructure (including a military base and an airport) to flourish, causing increased encroachment of available reindeer grazing grounds during all seasons (Figure 2; Supporting Information, Figures S3 and S4). The third major change occurred at the end of the 1960s, when a major reindeer migration route remaining between the mine and the town of Kiruna was cut off as the town and mine merged together. Another industrial milestone was the extension of the railway to the east of Kiruna to the mining complex of Svappavaara in 1964. Further encroachment in the area around Kiruna occurred when mine tailing dams were constructed during the 1970s.

3.3 | Forestry

Generally, the 1950s are seen as the time when Swedish forestry rapidly changed from selective cutting to clear cutting (Östlund

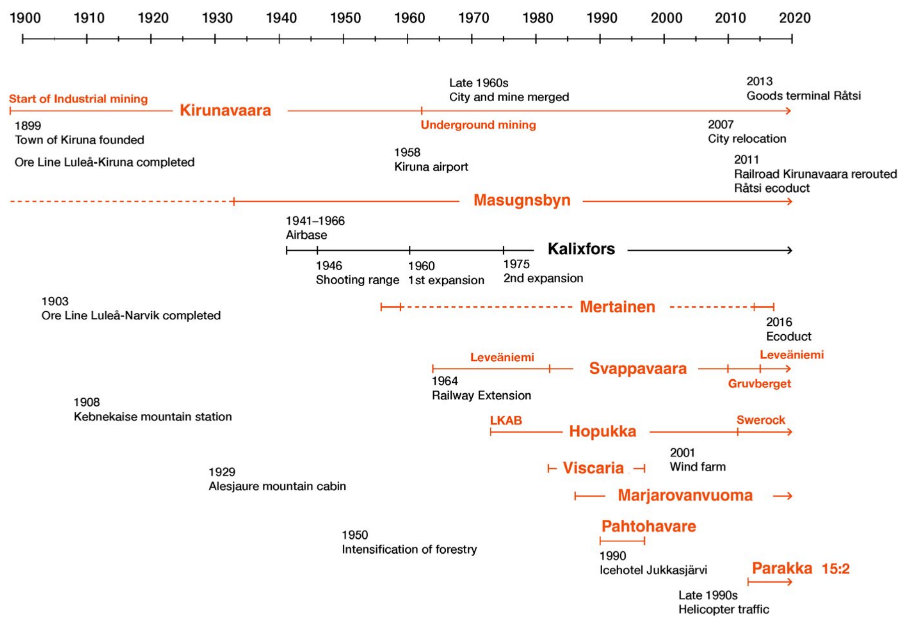

FIGURE 2 Timeline illustrating the establishment of industrial developments since their onset on Laevas RHC's grazing grounds from 1900 to present. Orange text represents mines and quarries, while black text represents other infrastructural developments associated with mining. Arrows indicate the ongoing operation of mines. Line breaks indicate changes within development and single dates indicate the establishment and gradual build-up of a factor. Dates refer to the commissioning and further continuation of anthropogenic developments and activities that are considered to have reduced reindeer pasture availability. Gradual changes in land use factors include general dating, for example the intensification of forestry or when Kiruna and the Kiirunavaara merged

TABLE 2 Quantifiable extents of polygonal and linear features currently occurring on Laevas RHC's grazing grounds. Relative extent of polygonal features to total extent and winter grazing grounds

Polygonal features	Extent (km^2)	% of total (4,486.42 km^2)	% winter (1552.77 km^2)	Linear features	Extent (km)
Mineral exploration permits (expired)[a]	959.07	21.38	61.77	Roads	867.77
Mineral exploration permits (granted)[b]	214.88	4.79	13.83	Snowmobile trails	636.94
Military	107.04	2.39	6.89	Trails	580.17
Tärendö RHC	79.65	1.78	5.13	Power lines	102.06
Designation of land (mining)	59.04	1.32	3.80	Railway	69.48
Clear cuts[c]	30.70	0.68	1.98		
Mineral exploitation concessions	9.17	0.20	0.59		
Settlements	1.33	0.03	0.09		
Agriculture	0.93	0.02	0.06		
Wind farm	0.80	0.02	0.05		
Quarries	0.74	0.02	0.05		
Peat mine	0.60	0.01	0.04		
Kiruna airport	0.28	0.01	0.02		

[a]($n = 160$, 1984–2018).
[b]($n = 24$, eight owners).
[c]($n = 420$, 2000–2018).

et al., 1997), which prevails as the predominant forestry practice across Sweden. We found that forest harvest by clear cutting is carried out only on the unprotected forested area east of Kiruna, that is on Laevas winter grazing grounds. The cumulative area of clear cuts carried out between 2000 and 2018 comprises approximately 2% (30.70 km^2) of the winter grazing grounds (Table 2).

3.4 | Tourism and related activities and infrastructure

Laevas RHC's grazing grounds are located in an area with high value for recreational activities, most of which we found to exhibit high spatiotemporal variance. We identified the main pressures linked to the recreational sector to include backcountry skiing, snowmobile traffic, dogsledding that co-occur during winter (October–May), while hiking, fishing, hunting and ferry travel occur during the snow-free period (June–September). The spatial overlap of some activities was found to be substantial e.g. hiking trails or dirt roads frequently coincide with snowmobile trails; Figure 3). Recreational activities were found to be mostly exercised in the mountainous areas west of Kiruna. The most frequented section of the King's trail ('Kungsleden') crosses 40 km of Laevas RHC's summer grazing grounds, as well as calving grounds. During the winter, it is a ski trail with approximately the same route. The construction of the railway between Kiruna and Narvik in 1902 followed by the establishment of several mountain cabins marks the onset of increased access and popularity of this area to recreational activities, which we identified as another major driver of change (Figure 2). Commercial helicopter traffic commenced in the late 1990s and was determined to strongly associate with interests of recreationists, lasting from May to September without areal restrictions. We detected an increasing overall trend in records of overnight stays in registered accommodation units, as well as for the number of passengers landing at Kiruna airport. Moreover, we found the largest increment in the number of overnights to occur during summer, peaking in July and August (Supporting Information, Figure S4).

3.5 | Military establishments and activities

We determined that military activities at Kalixfors extend over 107.04 km^2 and are entirely located within the winter grazing grounds of Laevas RHC (Table 2; Supporting Information, Figure S5), excluding any other forms of land conversion. Kalixfors military zone was established in 1946, experiencing two expansions in 1960 and 1975 (Figure 2). A related airbase was already established in 1941 but stopped operating in 1966. Its total area of influence (i.e. ZOI used in this study) is 216.03 km^2. Year-round military training at various intensities was found to restrict reindeer herds to pass during migration and to roam freely between November and the end of April. Due to its large extent and persistence, we identified military activity as a major stressor for Laevas RHC.

As the underground mining at Kiirunavaara expanded, the city relocation (including a rerouting of the railway) started in 2007 to avoid parts of the town to collapse. This project is ongoing, causing further land loss and representing the latest driver of change to accumulate in this area at a yet unprecedented scale. Recent mitigation efforts to compensate Laevas RHC for the impacts of infrastructure expansion and relocation included the funding of GPS collars for reindeer by LKAB to track animals (particularly their behavioural response towards mines) and the construction of an ecoduct after the rerouting of the railway to reduce collision risk. However, both attempts failed due to collars causing lesions and due to improper placement and width of the bridge causing an obstruction for reindeer to move across respectively.

3.6 | Cumulative zone-of-influence

The clipped extent of merged ZOIs resulted in a non-overlapping total extent of 1526.536 km^2 (34.03%), representing functionally unavailable all-year reindeer pasture (Figure 3). Regarding the proportion of functionally unavailable seasonal pastures, we estimated that 63.60% of winter pasture and 20.81% summer pasture are impacted. By overlapping the ZOI of individual factors, we highlighted how the highest intensity of accumulating impacts coincides with Laevas RHC's central bottleneck near the mines around Kiruna (Supporting Information, Figure S5).

We included the areal overlap with Tärendö concession-RHC as a non-buffered ZOI due to the year-round utilization of pastures by this community, which results in forage depletion before Laevas

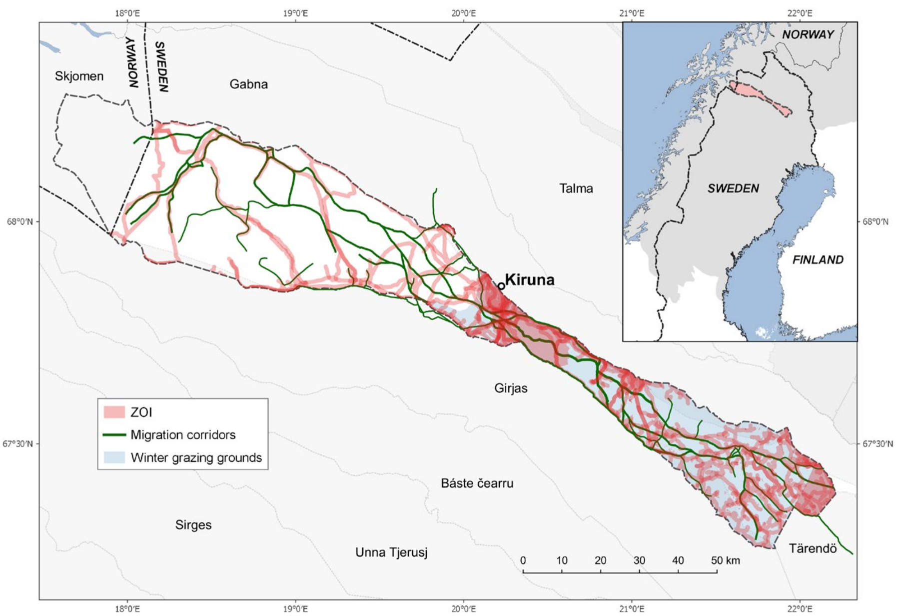

FIGURE 3 Overlapping ZOIs based on 500-m buffers and total area of factors encroaching Laevas RHC's grazing grounds. Red shades intensify by accumulation of land use from multiple factors. Grey-shaded areas surrounding Laevas RHC delineate neighbouring RHCs in Sweden and Norway; grey shades darken when communities overlap. Winter grazing grounds and migration corridors are included to illustrate where and when impacts are most pronounced

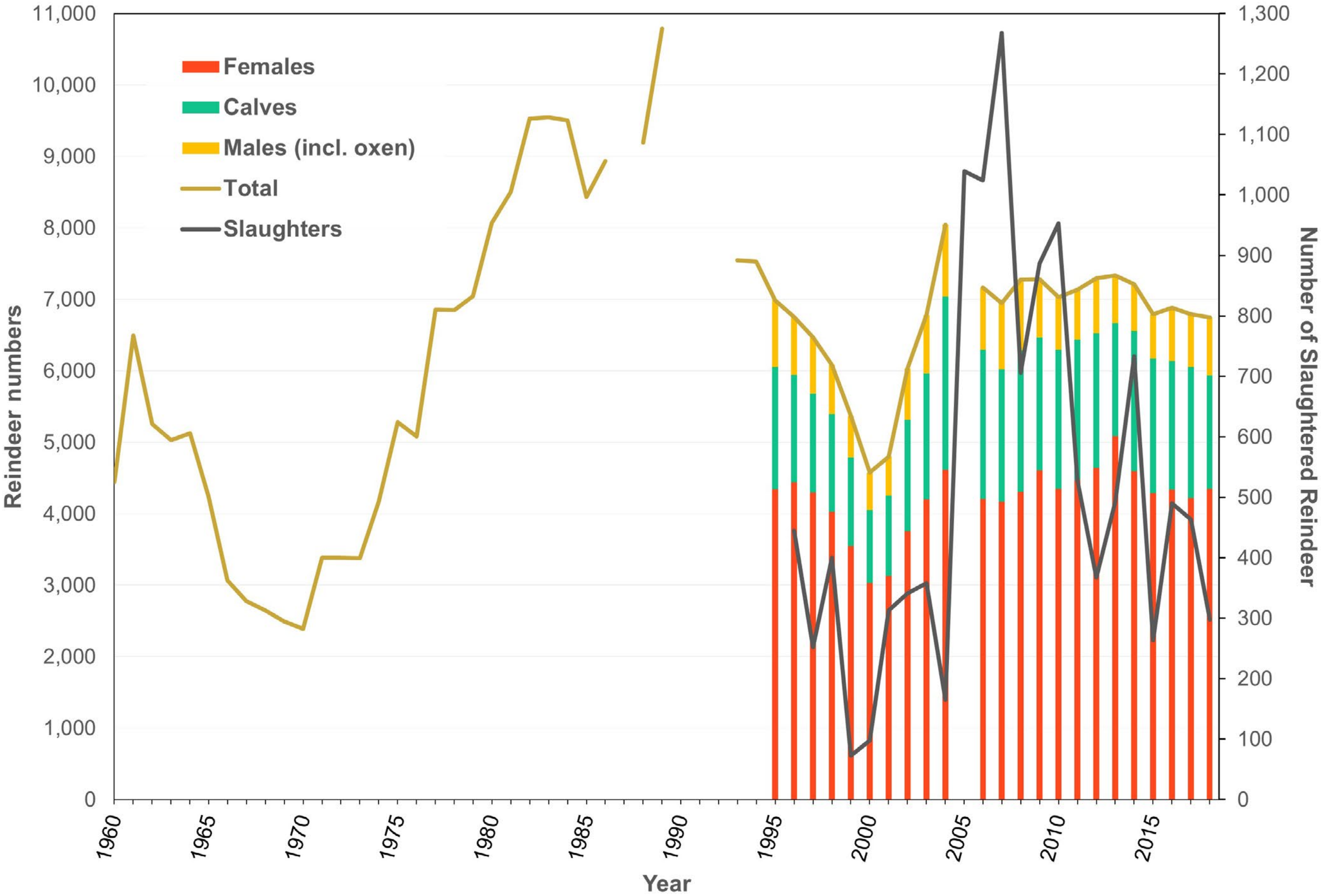

FIGURE 4 Reindeer demographics, overall population and slaughter dynamics in Laevas RHC for existing records between 1960 and 2018. The trend for the total number of reindeer (counted post-slaughter and distinguished into males, females and calves since 1995) is associated with the primary *y*-axis. The trend in slaughtered animals follows the black line associated with the secondary *y*-axis

RHC's reindeer can have access to this area in winter. Moreover, this zone is avoided by Laevas RHC due to the risk of interchange of reindeer between communities. In total, we determined that the contested area comprises approximately 80 km^2 of Laevas RHC's grazing grounds (Table 2).

3.7 | Response of reindeer husbandry

Reindeer numbers in Laevas RHC, determined post-slaughter in September every year, show strong fluctuations during the last 57 years (Figure 4). A series of bad winters, characterized by a sequence of ice-locked pastures and high snow cover, caused mass starvation of reindeer in the area during the mid-1960s, when supplementary fodder was unavailable. This loss of animals forced many herders to abandon their livelihoods. The combination of favourable conditions (no icing events and average snow accumulation) as well as the influx and purchase of animals from other parts of Sápmi throughout the 1970s and 1980s was the reason for the increase in total number of reindeer, peaking in 1989. A series of unfavourable winters, with a high frequency of icing and rain-on-snow events, lead to the decline that followed during the 1990s. The total number of reindeer has remained stable at around 7,000 animals during the last decade, while the number of slaughtered animals has decreased substantially in recent years. The reindeer meat market price (SEK*kg^{-1}) has been increasing in recent years (Supporting Information, Figure S6). No overall increase in lynx and wolverine numbers was evident (Supporting Information, Figure S7). According to reindeer herders, predation is regarded as part of the system and does not explain the net decline in reindeer numbers that we detected. This has therefore not been discussed further.

4 | DISCUSSION

The case of Laevas RHC exemplifies how establishment of extractive industry in the region, subsequent infrastructure development and economic activities lead to cascading effects on the entire landscape and indigenous livelihood that this landscape supports (Figures 2 and 4). We highlighted that the winter grazing grounds, where forage is naturally limited both in quality and quantity, receive most pressures (Figure 3; Table 2). This trend may apply to many other RHCs, as the human population and infrastructure developments generally increase towards the Baltic coast in northern Sweden (Kennedy et al., 2019). Geographical factors such as natural bottlenecks in topography interact with these accumulating pressures from other forms of land use, and thus affect herders' response to these changes while also restricting their options.

A characteristic feature of any pastoral system, including reindeer husbandry, is its high plasticity and adaptive potential to counteract environmental stochasticity (Brännlund & Axelsson, 2011; Hausner et al., 2019). This characteristic becomes particularly evident when reindeer statistics are examined in close detail: Laevas RHC has been experiencing declines in the number of reindeer, and has responded by reducing slaughters and sales to a minimum, in order to keep a viable herd. Therefore, reindeer slaughters in Laevas RHC are only conducted for private use. Even though we found an increasing trend in the reindeer meat market value, the lack of animals to sell is forcing more and more community members to seek alternative occupations for extra income to compensate. Therefore, a decline in the total number of reindeer in response to the accumulation of impacts related to climate change and habitat loss and fragmentation is likely masked by responsive management intervention (Bårdsen et al., 2017; Hausner et al., 2019; Lundqvist et al., 2009).

At the current rate of environmental change, additional adaptations to counteract the current net decline in reindeer numbers and welfare include supplementary feeding, animal transport and increased herding efforts due to pasture fragmentation or loss. These adaptations are culturally and economically costly and are pushing reindeer husbandry as a traditional and sustainable livelihood to its margins (Persson, 2018). Such examples of increasing vulnerability and marginalization of pastoral systems due to pasture degradation and sedentarization can be found world-wide (e.g. Haynes et al., 2014; Kassahun et al., 2008; Næss, 2013; Schmidt & Pearson, 2016; Schwartz, 2005; Singh et al., 2013; Yager et al., 2019).

Most human disturbances and infrastructural developments—especially mines—exhibit high spatiotemporal variation in activity and influence, and the response of pastoralists and their animals can therefore also vary accordingly (Plante et al., 2018; Rudolph et al., 2017; Skarin & Åhman, 2014; Vistnes & Nellemann, 2008). Most mines, when assessed for their impact, are dealt within isolation. Impact assessments can therefore be misleading, as they often fail to expand the potential influence of mines beyond the 'hole in the ground'. All mines are different based on the longevity, extraction style, amount and type of material extracted as well as the time of the year they operate, but they commonly cause physical land loss, and animal avoidance due to human presence, noise and dust. The development of mega-mining projects entails a multitude of additional infrastructural developments, energy demands and manpower that likely accumulate and amplify their effects over their lifetime on any landscape (Keeling & Sandlos, 2015; McCarthy et al., 2005). As our data for such a trajectory of development in northern Sweden have shown, infrastructural developments such as road, rail and air links, and related economic boom trigger a cascade of secondary developments. These include increased access for recreational activities and expansion or increased feasibility of new extractive industries (i.e. mining, forestry, wind power plants, hydropower plants; Avango et al., 2013; Horowitz et al., 2018; Klein, 2000).

Modern forestry practices brought about denser even-aged monocultures, soil scarification, fertilization, application of herbicides and the introduction of exotic species, which have reduced ecological variation in boreal forests (Horstkotte, 2013). This has caused a reduction of the abundance of terricolous and arboreal lichen—a critical winter resource that may constitute up to 80% of reindeer forage—by up to 50% (Berg et al., 2008; Horstkotte & Moen, 2019; Kivinen et al., 2012; Sandström et al., 2006). The depletion of lichen-rich winter pastures in Laevas RHC's case is also driven by competition over grazing grounds with a neighbouring RHC. These pastures therefore become unavailable, which is increasingly problematic given the progressing fragmentation of alternative pastures due to advancing infrastructural developments in the remaining winter range.

Military establishments are an inevitable superior 'national interest' that limits all other land users including reindeer herders from these areas. Besides human activity and noise, main issues include erosion, contamination and compaction of snow and soil due to heavy bandwagons and missile testing (Lawrence et al., 2015). The effects of military and recreational activities on mobile wildlife and pastoralists are often difficult to quantify due their high spatiotemporal unpredictability and dependence on environmental conditions, such as snow cover (Valente et al., 2020).

By adopting the conservative ZOI according to Environment Canada's (2012) model to the case study of Laevas RHC, we determined that only 36% of winter grazing grounds (and at maximum 66% of the total reindeer grazing grounds) are currently undisturbed by the regarded land use pressures. We acknowledge that this is likely an underestimation due to the decision not to buffer clear cuts or mineral exploration, that is factors we were uncertain of having a similarly adverse impact in the Fennoscandian context. Given that the suggested threshold of intact habitat ensuring the viability of caribou herds is 65% (Environment Canada, 2012), we raise concern about the consequences Laevas RHC is facing based on our data. Future land development goals such as increase in renewable energy production, production of metal ore and increased demands of electricity and linear infrastructure to support these will exacerbate the already costly adaptations that Laevas RHC is making. These developments are not restricted to northern Sweden but relevant to many resource-rich regions in the Arctic and elsewhere (Tucker et al., 2018). Compensational efforts from industries and governmental agencies to finically support and modernize herding practices have been pushing reindeer herder's flexibilities further. Rather than monetary compensation, Laevas RHC and pastoral communities world-wide might likely benefit more from the protection of remaining pastures (especially winter pasture where effects of climate and land use change are exacerbated) in order to remain flexible and manage herds sustainably when conditions are unfavourable.

With further land loss and fragmentation on top of extreme winter weather conditions, mobility between suitable seasonal pastures might eventually be rendered impossible. Future climate scenarios for northern Sweden predict higher temperatures during all seasons and more winter precipitation (Berglöv et al., 2015). Thus the frequency of freeze-thaw cycles and rain-on-snow events will most likely continue to increase, which will further increase climate stress on reindeer husbandry (Rosqvist et al., forthcoming; Turunen et al., 2016). If these scenarios exacerbate, Laevas RHC might face a future that entails the loss of access to essential winter pastures. As evident from Figure 3, barrier effects will be most pronounced around Kiruna's bottleneck due to the ongoing city centre relocation, and we predict landscape connectivity to cease there first (detailed in Supporting Information, Figure S5). The loss of winter pastures would imply a substantial reduction of the carrying capacity on the remaining portion of Laevas RHC's grazing grounds, entailing an unsustainable reduction in reindeer numbers. Short-term solutions to counteract reindeer losses include the purchase of supplementary fodder and vaccines as well as intensified herding and hiring vehicles to move animals. These 'solutions' are, however, unsustainable as they will cause both the loss of traditional herding practices as well as economic losses, eventually depriving most Sámi reindeer herders and owners in this area of their livelihood.

To avoid such a scenario, several structural changes would have to take place immediately. These may include the conservation of grazing habitat that is yet intact as well as assuring that landscape connectivity is not further reduced. Moreover, remediation and restoration processes of sites previously subject to resource extraction should provide alternative grazing grounds and re-establishment of movement corridors in the future. It is well known that the resource extraction will continue in this area in the near future.

By quantifying current spatial extents and examining historical trends at the landscape level, we offer a more holistic overview of cumulative impact hotspots. Our approach highlights the importance of the inclusion of multiple data sources to identify multiple pressures on pastures, which is inadequately regulated by law but highly relevant to aid well-informed decision-making processes. In our analyses, herders' knowledge was an integral part of the spatio-temporal trends for all land use concerning their community—that is, all industrial developments as well as their effects on reindeer numbers, migration routes, pastures and herders' adaptive measures—and critical in fully understanding the cumulative impacts on their land. Therefore, without the inclusion of herder knowledge, impact assessments may fail to fully realize their purpose. It is essential that the current status of the environment—or baseline—against which future accumulation of impacts and their effects can be gauged is defined (e.g. Bull et al., 2015; Schultz, 2010). Any assessments of an incoming exploitative land user should consider past developments and local adaptations by herders in order to fully understand the current status of the impacted system and the consequence of their accumulation.

A lack of an interconnected functional ecosystem means that buffering capacity against unfavourable weather via traditional herding strategies where one could chose alternative pastures or reduce or increase mobility will be lost, consequentially preventing sustainable pastoralism to persist. Moreover, not only reindeer and reindeer herders are experiencing the detrimental effects of accumulating land use, but other important wild animals, for example moose *Alces alces*, that are also exposed to these stressors, and the ecosystem services such as hunting and browsing that they provide (Allen et al., 2016; Fohringer et al., 2021; Johnson et al., 2005).

Previously, the assessment of impacts of climate change and anthropogenic encroachment have been dealt with in isolation on a project-by-project basis. Because the effects of accumulating land use pressures are likely amplified by consequences of climate change, there is an increasing need to analyse how these interact to affect reindeer herding (Hausner et al., 2019; Kivinen, 2015). The peril that we demonstrate above, that Laevas RHC is facing is particularly pronounced due to the long history of resource extraction at a latitude that is experiencing accelerated climate change (Reichwald & Svedlund, 1977). We conclude by raising this alarm over the state of environment and the society in this highly vulnerable area and hope that our findings and approach will be useful for similar assessments and socio-ecological baseline developments in other pastoral systems that are exposed to cumulative land use impacts.

ACKNOWLEDGEMENTS

The authors thank the reindeer herding community of Laevas RHC, represented by Niila Inga, for valuable Sámi reindeer herder knowledge input on their land as well as access to spatial data and recent reindeer statistics from the Sámi Parliament of Sweden. They also thank all local stakeholders as well as governmental agencies that shared data contributing to this study. This study was financed by the project 'Resource Extraction and Sustainable Arctic Communities' (REXSAC), which is funded by NordForsk—a 'Nordic Centre of Excellence'—(project number 76938).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

C.F., G.R., N.J.S. and N.I. designed the study together; N.I. provided access to data stored in the archives of Laevas RHC and the Sámi Parliament of Sweden; N.I. and C.F. reviewed spatial data as well as data related to reindeer and predator statistics; C.F. analysed the data and wrote the first draft of the manuscript. All the authors contributed data and revised the manuscript.

DATA AVAILABILITY STATEMENT

Data can be accessed from individual sources detailed in Table 1 and upon request via the corresponding author.

ORCID

Christian Fohringer https://orcid.org/0000-0003-0257-6743
Gunhild Rosqvist https://orcid.org/0000-0002-9195-607X
Navinder J. Singh https://orcid.org/0000-0002-5131-0004

REFERENCES

Allen, A. M., Månsson, J., Sand, H., Malmsten, J., Ericsson, G., & Singh, N. J. (2016). Scaling up movements: From individual space use to population patterns. *Ecosphere*, *7*(10), 1–16. https://doi.org/10.1002/ecs2.1524

Avango, D., Nilsson, A. E., & Roberts, P. (2013). Assessing Arctic futures: Voices, resources and governance. *The Polar Journal*, *3*(2), 431–446. https://doi.org/10.1080/2154896X.2013.790197

Baker, J. M., & Westman, C. N. (2018). Extracting knowledge: Social science, environmental impact assessment, and Indigenous consultation in the oil sands of Alberta, Canada. *The Extractive Industries and Society*, *5*(1), 144–153. https://doi.org/10.1016/j.exis.2017.12.008

Bårdsen, B.-J., Næss, M. W., Singh, N. J., & Åhman, B. (2017). The pursuit of population collapses: Long-term dynamics of semi-domestic reindeer in Sweden. *Human Ecology*, *45*, 161–175. https://doi.org/10.1007/s10745-016-9880-3

Beach, H. (1981). *Reindeer-herd management in transition: The case of Tuorpon Saameby in Northern Sweden* (PhD thesis.). Uppsala University.

Benítez-López, A., Alkemade, R., & Verweij, P. A. (2010). The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation*, *143*, 1307–1316. https://doi.org/10.1016/j.biocon.2010.02.009

Berg, A., Östlund, L., Moen, J., & Olofsson, J. (2008). A century of logging and forestry in a reindeer herding area in northern Sweden. *Forest Ecology and Management*, *256*(5), 1009–1020. http://doi.org/10.1016/j.foreco.2008.06.003

Berglöv, G., Asp, M., Berggreen-Clausen, S., Björck, E., Mårtensson, J. A., Nylén, L., Håkan, P., & Sjökvist, E. (2015). Framtidsklimat i Norrbottens län – enligt RCP-scenarier. Report 32. Swedish Meteorological and Hydrological Institute.

Boulanger, J., Poole, K. G., Gunn, A., & Wierzchowski, J. (2012). Estimating the zone of influence of industrial developments on wildlife: A migratory caribou *Rangifer tarandus groenlandicus* and diamond mine case study. *Wildlife Biology*, *18*, 164–179. https://doi.org/10.2981/11-045

Brännlund, I., & Axelsson, P. (2011). Reindeer management during the colonization of Sami lands: A long-term perspective of vulnerability and adaptation strategies. *Global Environmental Change*, *21*, 1095–1105. https://doi.org/10.1016/j.gloenvcha.2011.03.005

Bull, J. W., Singh, N. J., Suttle, K. B., Bykova, E. A., & Milner-Gulland, E. J. (2015). Creating a frame of reference for conservation interventions. *Land Use Policy*, *49*, 273–286. https://doi.org/10.1016/j.landusepol.2015.08.005

Conner, M. M., Saunders, W. C., Bouwes, N., & Jordan, C. (2015). Evaluating impacts using a BACI design, ratios, and a Bayesian approach with a focus on restoration. *Environmental Monitoring and Assessment*, *188*(10), 555. https://doi.org/10.1007/s10661-016-5526-6

Dong, S., Wen, L. U., Liu, S., Zhang, X., Lassoie, J. P., Yi, S., Li, X., Li, J., & Li, Y. (2011). Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. *Ecology and Society*, *16*(2), 10. https://doi.org/10.5751/ES-04093-160210

Eklund, A., Mattisson, J., Höglund, L., & Tovmo, M. (2017). Inventering av järv 2017. Bestandsovervåking av jerv i 2017. Bestandsstatus for store rovdyr I Skandinavia. Beståndsstatus för stora rovdjur i Skandinavien. 3-2017. 31 s.

Environment Canada. (2011). *Scientific assessment to inform the identification of critical habitat for woodland caribou (*Rangifer tarandus caribou*), boreal population, in Canada: 2011 update*. Environment Canada.

Environment Canada. (2012). *Recovery strategy for the woodland caribou, boreal population (*Rangifer tarandus caribou*) in Canada*. Environment Canada.

Ewacha, M. V. A., Roth, J. D., Anderson, W. G., Brannen, D. C., & Dupont, D. L. J. (2017). Disturbance and chronic levels of cortisol in boreal woodland caribou. *The Journal of Wildlife Management*, *81*(7), 1266–1275. https://doi.org/10.1002/jwmg.21288

Fohringer, C., Dudka, I., Spitzer, R., Stenbacka, F., Rzhepishevska, O., Cromsigt, J. P. G. M., Gröbner, G., Ericsson, G., & Singh, N. J. (2021). Integrating omics to characterize eco-physiological adaptations: How moose diet and metabolism differ across biogeographic zones. *Ecology and Evolution*, *11*(7), 3159–3183. http://doi.org/10.1002/ece3.7265

Forbes, B. C., & Kumpula, T. (2009). The Ecological role and geography of reindeer (*Rangifer tarandus*) in Northern Eurasia. *Geography Compass*, *3*(4), 1356–1380. https://doi.org/10.1111/j.1749-8198. 2009.00250.x

Forbes, B. C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A., & Kaarlejärvi, E. (2009). High resilience in the Yamal-Nenets social–ecological system, West Siberian Arctic, Russia. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(52), 22041–22048. https://doi.org/10.1073/pnas.0908286106

Ford, J. D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Willox, A. C., & Pearce, T. (2016). Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, *6*(4), 349–353. https://doi.org/10.1038/nclimate2954

Frenette, J., Pelletier, F., & St-Laurent, M. H. (2020). Linking habitat, predators and alternative prey to explain recruitment variations of an endangered caribou population. *Global Ecology and Conservation*, *22*, https://doi.org/10.1016/j.gecco.2020.e00920

Gallardo, G. L., Saunders, F., Sokolova, F., Börebäck, K., van Laerhoven, F., Kokko, S., & Tuvendal, M. (2017). We adapt … but is it good or bad? Locating the political ecology and social-ecological systems debate in reindeer herding in the Swedish Sub-Arctic. *Journal of Political Ecology*, *24*. https://doi.org/10.2458/v24i1.20960

Hausner, V. H., Engen, S., Brattland, C., & Fauchald, P. (2019). Sámi knowledge and ecosystem-based adaptation strategies for managing pastures under threat from multiple land uses. *Journal of Applied Ecology*, *57*(9), 1656–1665. https://doi.org/10.1111/1365-2664.13559

Haynes, M. A., Kung, K.-J.- S., Brandt, J. S., Yongping, Y., & Waller, D. M. (2014). Accelerated climate change and its potential impact on Yak herding livelihoods in the eastern Tibetan plateau. *Climatic Change*, *123*, 147–160. https://doi.org/10.1007/s10584-013-1043-6

Heggberget, T. M., Gaare, E., & Ball, J. P. (2002). Reindeer (*Rangifer tarandus*) and climate change: Importance of winter forage. *Rangifer*, *22*(1), 13–31. https://doi.org/10.7557/2.22.1.388

Helle, T., & Jaakkola, L. (2008). Transitions in herd management of semi-domesticated reindeer in northern Finland. *Annales Zoologici Fennici*, *45*(2), 81–101. https://doi.org/10.5735/086.045.0201

Horowitz, L. A., Keeling, A., Lévesque, F., Rodon, T., Schott, S., & Thériault, S. (2018). Indigenous peoples' relationships to large-scale mining in post/colonial contexts: Toward multidisciplinary comparative perspectives. *The Extractive Industries and Society*, *5*(3), 404–414. https://doi.org/10.1016/j.exis.2018.05.004

Horstkotte, T. (2013). Contested landscapes: Social-ecological interactions between forestry and reindeer husbandry. In *Department of Ecology and Environmental Sciences*. Umeå University.

Horstkotte, T., & Moen, J. (2019). Successional pathways of terrestrial lichens in changing Swedish boreal forests. *Forest Ecology and Management*, *453*, https://doi.org/10.1016/j.foreco.2019.117572

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services In S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, & C. N. Zayas (Eds.), (p. 56). IPBES Secretariat. https://doi.org/10.5281/zenodo.3553579

IPCC (Intergovernmental Panel on Climate Change). (2014). *Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK*.

Jernsletten, J.-L.- L., & Klokov, K. (2002). *Sustainable Reindeer Husbandry: Arctic Council 2000–2002*. Centre for Saami Studies, University of Tromsø.

Johansson, C., Pohjola, V. A., Jonasson, C., & Callaghan, T. V. (2011). Multi-decadal changes in snow characteristics in sub-Arctic Sweden. *Ambio*, *40*(6), 566–574. https://doi.org/10.1007/s13280-011-0164-2

Johnson, C. J., Boyce, M. S., Case, R. L., Cluff, H. D., Gau, R. J., Gunn, A., & Mulders, R. (2005). Cumulative effects of human developments on arctic wildlife. *Wildlife Monographs*, *160*, 1–36.

Kassahun, A., Snymanb, H. A., & Smit, G. N. (2008). Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia. *Journal of Arid Environments*, *72*, 1265–1281. https://doi.org/10.1016/j.jaridenv.2008.01.002

Keeling, A., & Sandlos, J. (2015). Mining and communities in Northern Canada: History, politics, memory. In A. Keeling & J. Sandlos (Eds.), *Canadian History and Environment Series*, *3*. University of Calgary Press.

Kennedy, C. M., Oakleaf, J. R., Theobald, D. M., Baruch-Mordo, S., & Kiesecker, J. (2019). Managing the middle: A shift in conservation priorities based on the global human modification gradient. *Global Change Biology*, *25*, 811–826. https://doi.org/10.1111/gcb.14549

Kivinen, S. (2015). Many a little makes a mickle: Cumulative land cover changes and traditional land use in the Kyrö reindeer herding district, northern Finland. *Applied Geography*, *63*, 204–211. https://doi.org/10.1016/j.apgeog.2015.06.013

Kivinen, S., Berg, A., Moen, J., Östlund, L., & Olofsson, J. (2012). Forest fragmentation and landscape transformation in a reindeer husbandry area in Sweden. *Environmental Management*, *49*(2), 295–304. https://doi.org/10.1007/s00267-011-9788-z

Klein, D. R. (1971). Reaction of reindeer to obstructions and disturbances. *Science*, *173*, 393–398. https://doi.org/10.1126/Science.173.3995.393

Klein, D. R. (2000). Arctic grazing systems and industrial development: Can we minimize conflicts? *Polar Research*, *19*(1), 91–98. https://doi.org/10.3402/polar.v19i1.6534

Larsen, R. K., Raitio, K., Stinnerbom, M., & Wik-Karlsson, J. (2017). Sami-state collaboration in the governance of cumulative effects assessment: A critical action research approach. *Environmental Impact Assessment Review*, *64*, 67–76. https://doi.org/10.1016/j.eiar.2017.03.003

Lawrence, M. J., Stemberger, H. L. J., Zolderdo, A. J., Struthers, D. P., & Cooke, S. J. (2015). The effects of modern war and military activities on biodiversity and the environment. *Environmental Reviews*, *23*(4), 443–460. https://doi.org/10.1139/er-2015-0039

Lawrence, R., & Larsen, R. K. (2017). The politics of planning: Assessing the impacts of mining on Sami lands. *Third World Quarterly*, *38*(5), 1164–1180. https://doi.org/10.1080/01436597.2016.1257909

LKAB. (2017a). *LKAB Annual and Sustainability Report*. Retrieved from https://www.lkab.com/en/SysSiteAssets/documents/finansiell-information/en/annual-reports/lkab_2017_annual_and_sustainability_report.pdf

LKAB. (2017b). *This is LKAB*. Retrieved from https://www.lkab.com/en/SysSiteAssets/documents/publikationer/broschyrer/this-is-lkab.pdf

LKAB. (2018). *Where mine meets town*. Retrieved from https://www.lkab.com/en/SysSiteAssets/documents/publikationer/broschyrer/where-mine-meets-town.pdf

Lundqvist, H., Norell, L., & Danell, Ö. (2009). Relationships between biotic and abiotic range characteristics and productivity of reindeer husbandry in Sweden. *Rangifer*, *27*(1), 5–23. https://doi.org/10.7557/2.29.1.198

McCarthy, J. J., Martello, M. L., Corell, R. W., Eckley, N., Fox, S., Hovelsrud-Broda, G. K., Mathiesen, S. D., Polsky, C., Selin, H., Tyler, N. J. C., Strøm Bull, K., Siegel Causey, D., Eira, I. G., Eira, N. I., Eriksen, S., Hanssen-Bauer, I., Kalstad, J. K., Nellemann, C., Oskal, N., … Turi, J. M. (2005). *Climate change in the context of multiple stressors and resilience Arctic. Arctic climate impact assessment scientific report* (pp. 945–988). Cambridge University Press.

Næss, M. W. (2013). Climate change, risk management and the end of Nomadic pastoralism. *International Journal of Sustainable Development & World Ecology*, *20*(2), 123–133. https://doi.org/10.1080/13504509.2013.779615

Nellemann, C., & Cameron, R. D. (1996). Effects of petroleum development on terrain preferences of calving caribou. *ARCTIC*, *49*(1), 23–28. https://doi.org/10.14430/arctic1180

Nellemann, C., Vistnes, I., Jordhoy, P., & Strand, O. (2001). Winter distribution of wild reindeer in relation to power lines, roads and resorts. *Biological Conservation*, *101*, 351–360. https://doi.org/10.1016/S0006-3207(01)00082-9

Nellemann, C., Vistnes, I., Jordhoy, P., Strand, O., & Newton, A. (2003). Progressive impact of piecemeal infrastructure development on wild reindeer. *Biological Conservation*, *113*, 307–317. https://doi.org/10.1016/S0006-3207(03)00048-X

Östlund, L., Zackrisson, O., & Axelsson, A.-L. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. *Canadian Journal of Forest Research*, *27*(8), 1198–1206. https://doi.org/10.1139/x97-070

Pape, R., & Löffler, J. (2012). Climate change, land use conflicts, predation and ecological degradation as challenges for reindeer husbandry in Northern Europe: What do we really know after half a century of research? *Ambio*, *41*(5), 421–434. https://doi.org/10.1007/s13280-012-0257-6

Persson, A.-M. (2018). *Status of supplementary feeding of reindeer in Sweden and its consequences*. Master's thesis. Department of Forest Resource Management, Swedish University of Agricultural Sciences.

Plante, S., Dussault, C., Richard, J. H., & Côté, S. D. (2018). Human disturbance effects and cumulative habitat loss in endangered migratory caribou. *Biological Conservation*, *224*, 129–143. https://doi.org/10.1016/j.biocon.2018.05.022

Polfus, J. L., Hebblewhite, M., & Heinemever, K. (2011). Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. *Biological Conservation*, *144*, 2637–2646. https://doi.org/10.1016/j.biocon.2011.07.023

QGIS Development Team. (2018). *QGIS Geographic Information System*. Open Source Geospatial Foundation Project. Retrieved from http://qgis.osgeo.org

Rasmus, S., Kivinen, S., & Irannezhad, M. (2018). Basal ice formation in snow cover in Northern Finland between 1948 and 2016. *Environmental Research Letters*, *13*(11), 114009. https://doi.org/10.1088/1748-9326/aae541

Reichwald, A., & Svedlund, B. (1977). *Laevas Sameby i dag - historia i morgon. Bokförlaget PAN/Norstedts, Stockholm 1977*. ISBN 91-1-761651-4.

Riksdag, S. (1971). *Rennäringslag 1971:437 (Reindeer Husbandry Act)*. Retrieved from http://rkrattsbaser.gov.se/sfst?bet=1971:437

Rosqvist, G., Inga, N., & Eriksson, P. (forthcoming). Impacts of climate warming on reindeer husbandry demand new land use strategies.

Rudolph, T. D., Drapeau, P., Imbeau, L., Brodeur, V., Légaré, S., & St-Laurent, M.-S. (2017). Demographic responses of boreal caribou to cumulative disturbances highlight elasticity of range-specific tolerance thresholds. *Biodiversity and Conservation*, *26*, 1179–1198. https://doi.org/10.1007/s10531-017-1292-1

Sandström, C., Moen, J., Widmark, C., & Danell, Ö. (2006). Progressing toward co-management through collaborative learning: Forestry and reindeer husbandry in dialogue. *International Journal of Biodiversity Science*, *2*, 326–333. https://doi.org/10.1080/17451590609618153

Sandström, P. (2015). *A toolbox for co-production of knowledge and improved land use dialogues: The perspective of reindeer husbandry*. Department of Forest Resource Management, Swedish University of Agricultural Sciences.

Schmidt, M., & Pearson, O. (2016). Pastoral livelihoods under pressure: Ecological, political and socioeconomic transitions in Afar (Ethiopia). *Journal of Arid Environments*, *124*, 22–30. https://doi.org/10.1016/j.jaridenv.2015.07.003

Schultz, C. A. (2010). Challenges in connecting cumulative effects analysis to effective wildlife conservation planning. *BioScience*, *60*(7), 545–555. https://doi.org/10.1525/bio.2010.60.7.10

Schwartz, H. J. (2005). Ecological and economic consequences of reduced mobility in pastoral livestock production systems. In E. Fratkin & E. A. Roth (Eds.), *As pastoralists settle social, health, and economic consequences of pastoral sedentarization in Marsabit District, Kenya* (pp. 69–86). Studies in Human Ecology and Adaptation, Kluwer Academic Publishers.

SGU. (2018). *Geological survey of Sweden. Statistics of the swedish mining industry 2017.* Retrieved from http://resource.sgu.se/produkter/pp/pp2018-1-rapport.pdf

Singh, N. J., Bhatnagar, Y. V., Lecomte, N., Fox, J. L., & Yoccoz, N. G. (2013). No longer tracking greenery in high altitudes: Pastoral practices of Rupshu nomads and their implications for biodiversity conservation. *Pastoralism: Research, Policy and Practice*, *3*(1), 1–15. https://doi.org/10.1186/2041-7136-3-16

Skarin, A., & Åhman, B. (2014). Do human activity and infrastructure disturb domesticated reindeer? The need for the reindeer's perspective. *Polar Biology*, *37*(7), 1041–1054. https://doi.org/10.1007/s00300-014-1499-5

Skarin, A., Nellemann, C., Rönnegård, L., Sandström, P., & Lundqvist, H. (2015). Wind farm construction impacts reindeer migration and movement corridors. *Landscape Ecology*, *30*, 1527–1540. https://doi.org/10.1007/s10980-015-0210-8

Tovmo, M., & Zetterberg, A. (2018). Bestandsovervåking av gaupe i 2018. Inventering av lodjur 2018. Bestandsstatus for store rovdyr i Skandinavia. Beståndsstatus för stora rovdjur i Skandinavien. Nr 2 2018. 34 s.

Tucker, M. A., Böhning-Gaese, K., Fagan, W. F., Fryxell, J. M., Van Moorter, B., Alberts, S. C., Ali, A. H., Allen, A. M., Attias, N., Avgar, T., Bartlam-Brooks, H., Bayarbaatar, B., Belant, J. L., Bertassoni, A., Beyer, D., Bidner, L., van Beest, F. M., Blake, S., Blaum, N., … Mueller, T. (2018). Moving in the Anthropocene: Global reductions in terrestrial mammalian movements. *Science*, *359*(6374), 466–469. https://doi.org/10.1126/science.aam9712

Turunen, M. T., Rasmus, S., Bavay, M., Ruosteenoja, K., & Heiskanen, J. (2016). Coping with difficult weather and snow conditions: Reindeer herders' views on climate change impacts and coping strategies. *Climate Risk Management*, *11*, 15–36. https://doi.org/10.1016/j.crm.2016.01.002

Tyler, N. J., Stokkan, K. A., Hogg, C. R., Nellemann, C., & Vistnes, A. I. (2016). Cryptic impact: Visual detection of corona light and avoidance of power lines by reindeer. *Wildlife Society Bulletin*, *40*(1), 50–58. https://doi.org/10.1002/wsb.620

UNEP. (2001). 5.4 Impacts on the Arctic. In C. Nellemann, L. Kullerud, I. Vistnes, B. C. Forbes, G. Kofinas, B. P. Kaltenborn, O. Grøn, D. Henry, M. Magomedova, C. Lambrechts, T. S. Larsen, P. J. Schei, & R. Bobiwash (Eds.), *GLOBIO-global Methodology for Mapping Human Impacts on the Biosphere* (pp. 17–18). United Nations Environmental Programme.

Valente, S., Skarin, A., Ciucci, P., & Uboni, A. (2020). Attacked from two fronts: Interactive effects of anthropogenic and biotic disturbances generate complex movement patterns. *Arctic, Antarctic, and Alpine Research*, *52*(1), 27–40. https://doi.org/10.1080/15230430.2019.1698251

Vistnes, I., & Nellemann, C. (2008). The matter of spatial and temporal scales: A review of reindeer and caribou response to human activity. *Polar Biology*, *31*, 399–407. https://doi.org/10.1007/s00300-007-0377-9

Vors, L. S., & Boyce, M. S. (2009). Global declines of caribou and reindeer. *Global Change Biology*, *15*, 2626–2633. https://doi.org/10.1111/j.1365-2486.2009.01974.x

Warg, S. (2007). *Befolkningsutvecklingen – en dramatisk förändring från vildmark till stad. Kiruna 100-årsboken, del II (in Swedish)* (pp. 460–466). Kiruna Kommun.

Weir, J. N., Mahoney, S. P., McLaren, B., & Ferguson, S. H. (2007). Effects of mine development on woodland caribou *Rangifer tarandus* distribution. *Wildlife Biology*, *13*, 66–74. https://doi.org/10.2981/0909-6396(2007)13[66:EOMDOW]2.0.CO;2

Wilson, R. R., Parrett, L. S., Joly, K., & Dau, J. R. (2016). Effects of roads on individual caribou movements during migration. *Biological Conservation*, *195*, 2–8. https://doi.org/10.1016/j.biocon.2015.12.035

Yager, K., Valdivia, C., Slayback, D., Jimenez, E., Meneses, R. I., Palabral, A., Bracho, M., Romero, D., Hubbard, A., Pacheco, P., Calle, A., Alberto, H., Yana, O., Ulloa, D., Zeballos, G., & Romero, A. (2019). Socio-ecological dimensions of Andean pastoral landscape change: Bridging traditional ecological knowledge and satellite image analysis in Sajama National Park, Bolivia. *Regional Environmental Change*, *19*, 1353–1369. https://doi.org/10.1007/s10113-019-01466-y

Zachrisson, A. (2015). Samrådsunderlag- Ansökan om utökad verksamhet vid dolomittäkt i Masugnsbyn. Luleå: LKAB (LKAB Meddelande, 15-M123).

SUPPORTING INFORMATION

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

How to cite this article: Fohringer, C., Rosqvist, G., Inga, N., & Singh, N. J. (2021). Reindeer husbandry in peril?—How extractive industries exert multiple pressures on an Arctic pastoral ecosystem. *People and Nature*, 3, 872–886. https://doi.org/10.1002/pan3.10234