Regional Environmental Change (2024) 24:89
https://doi.org/10.1007/s10113-024-02241-4

ORIGINAL ARTICLE

Perceptions on and impacts of environmental changes under multiple stressors: a case study from two communities in northern Fennoscandia

Salla Eilola[1] · Tim Horstkotte[2] · Bruce C. Forbes[3] · Joachim Otto Habeck[4] · Teresa Komu[3] · Sirpa Rasmus[3,5] · Nora Fagerholm[1]

Received: 18 October 2023 / Accepted: 25 April 2024

Abstract

Against the backcloth of particularly fast environmental change in the Arctic, this study juxtaposes local perceptions of environmental change in two communities in the boreal zone of Northern Europe with scientific data. The local knowledge was gathered through an online participatory mapping survey among the two communities and scientific evidence was gathered from various peer-reviewed and official monitoring sources. Local knowledge of environmental change in Savukoski (Finland) resembles that in Jokkmokk (Sweden). Most perceived changes are in line with scientific studies, public discourse, and local concerns in the Arctic. What differs, however, is the degree of correspondence between local and scientific knowledge on certain phenomena: some dynamics are well documented in both local and scientific observations whereas other dynamics require more nuanced scientific research, particularly considering their relevance for local livelihoods. Among these are: berry yields, the abundance of mosquitoes and other Nematocera, peatland thaw and frost, and changes in river and lake ice conditions. It is noteworthy that in both Savukoski and Jokkmokk, for many people the most impactful changes are caused by resource extraction rather than climate change. Local concerns and perceptions of environmental change are not all shared nor easily translate into adaptation strategies, but nonetheless they have clear policy implications.

Keywords Adaptation · Arctic · Climate change · Knowledge integration · Local knowledge · Participatory mapping

Introduction

Arctic environments are undergoing rapid changes. The major driving forces are climate change, increased land use pressure, and natural resource extraction (IPCC 2019; Horstkotte et al. 2022b). Northern regions, among them Fennoscandia, are experiencing stronger warming than any other part of the globe since the 1980s (Serreze and Barry 2011; AMAP 2017, 2021a; Meredith et al. 2019; Rantanen et al. 2022). This warming trend has well-documented effects on the habitats, species dynamics, permafrost, and hydrological cycles as well as the local human populations, their cultures, and ways of life (Christie and Sommerkorn 2012; Meredith et al. 2019; AMAP 2021a). Moreover, increasing direct human impacts such as global demand on Arctic marine and terrestrial resources precipitated by the renewable energy transition (Kårtveit 2021), tourism and recreation industry exacerbate these effects (Nordic Council of Ministers 2014; Arctic Council 2016; AMAP 2021b).

Communicated by Feisal Rahman

✉ Salla Eilola
salla.eilola@utu.fi

1 Department of Geography and Geology, University of Turku, 20014 Turku, Finland

2 Department of Ecology and Environmental Science, Umeå University, 901 87 Umeå, Sweden

3 Arctic Centre, University of Lapland, P.O. Box 122 (Pohjoisranta 4), 96101 Rovaniemi, Finland

4 Institute for Social and Cultural Anthropology, Universität Hamburg, Edmund-Siemers-Allee 1, 20146 Hamburg, Germany

5 Ecosystems and Environment Research Programme, Faculty of Biological and Environmental Sciences, University of Helsinki, PO Box 65, 00014 Helsinki, Finland

Published online: 25 May 2024

While the impacts of environmental and social changes are experienced first and foremost at the local level, the involvement of local communities and integration of their knowledge in research, land use planning, and development of global and Arctic strategies is crucial (Arctic Council 2016; Flynn et al. 2018; Nilsson et al. 2021). Perception of environmental changes is formed in the everyday relation between people and their surroundings (Ingold 2000; Ingold and Kurttila 2000). People's observations and experiences in their socio-economic environment as well as held environmental knowledge—knowledge formed through formal and informal education, media, and science communication—influence perceptions of change and environmental concern (Karjalainen and Habeck 2004). Furthermore, environmental perception is performative: together with adaptation opportunities, it influences people's behavior and decisions, thus action or inaction under changing environmental conditions (Karjalainen and Habeck 2004). The value of local and indigenous knowledge (hereafter referred jointly as local knowledge) has been recognized for sustainability transformation research (Lam et al. 2020). In the Arctic, this particular importance is exemplified by reindeer herders' traditional knowledge on environmental conditions (Riseth et al. 2011; Horstkotte et al. 2022a) as well as co-management of the environment (Armitage et al. 2011; Bélisle and Asselin 2021; Horstkotte et al. 2022b) and in enhancing adaptive capacity and early warning systems (Alessa et al. 2016).

Combination of and attempts to integrate local knowledge and scientific evidence in studying environmental and climate change have increased in recent years. These ways of knowing operate on different temporal and geographical scales, which provide scientists with both opportunities and challenges (see, e.g., Reyes-García et al. 2019; Tengö et al. 2014). Local perceptions and observations of changes have been combined with primary scientific data of a comparable spatial scale (Soriano et al. 2017; Williams et al. 2018; Anisimov et al. 2019) and secondary sources with an appropriate level of generalizability to the study area (Turunen et al. 2016; Forbes et al. 2019; Markkula et al. 2019). Integration of these ways of knowing can better account for the complexity of ongoing dynamics and drivers of change, which large scale observation systems by default simplify into narrow sets of variables (González-Puente et al. 2014; Eicken et al. 2021).

In northern Fennoscandia, environmental change perceptions of reindeer herders have been studied in particular in terms of climate conditions, vegetation dynamics and herders' coping strategies (see, e.g., Horstkotte et al. 2017; Lépy et al. 2018; Markkula et al. 2019; Näkkäläjärvi et al. 2020; Turunen et al. 2016). There has been, however, less research on environmental change perceptions and adaptation among the wider community and people who are not engaged in reindeer herding in these communities. Studies in the Arctic region show differences in perceptions based on people's livelihoods and nature-based activities as well as demographics and socioeconomic status (Anisimov and Orttung 2019; Chan et al. 2019; Horne et al. 2021; Takakura et al. 2021). The recognition of diverse knowledge holders has been emphasized in circumpolar research (Hitomi and Loring 2018). Engaging with the wider local community helps to reveal more nuanced information on the complex changes as well as contradicting priorities and vulnerabilities in communities that Arctic policies are to address.

In this article, we aim to expand the understanding of the perceived environmental changes and their impacts on the local population in northern Fennoscandia, Europe. We conducted a survey in two communities on the boreal forest margin in Finland (Savukoski) and Sweden (Jokkmokk). The communities share socioeconomic and environmental similarities that enable us to construct a shared knowledge base of local changes and their impacts. We combine the local change perceptions with secondary data on scientific evidence of the same phenomena. Our assumption is that integrating the perceptual and scientific knowledge sets allows us to better identify local relevance and complexity of changes and their implications at community level. Our specific research questions are as follows: (1) what kind of environmental changes are perceived by the local communities and what does the scientific evidence say about the same phenomena? and (2) what does experienced impacts of and adaptation to the perceived changes reveal about the relevancy of these changes?

Material and methods

Case study area

This study includes two communities located in the boreal zone north from or at the Arctic circle (approx. 66° N). The communities were selected due to being located at the northern fringe of boreal forest zone and sharing similar socioeconomic characteristics and most importantly having interest in engaging in the research project.

The study area in Finland is Savukoski municipality and its surroundings, a rural municipality in northeastern Finland with approximately 1000 inhabitants and a land area of 6497 km^2 (Fig. 1) (Statistics Finland 2022; National Land Survey of Finland 2023). In Northern Sweden, the case study area falls roughly within the municipality of Jokkmokk, which has nearly 5000 inhabitants and a land area of 19,477 km^2 (Fig. 1) (Official Statistics of Sweden 2022a). Savukoski has a continental climate characterized by distinct diurnal and seasonal temperature variation (mean annual temperature −0.5 °C; mean of coldest month −11.4 °C; and warmest month +13.1 °C) and relatively low precipitation (mean

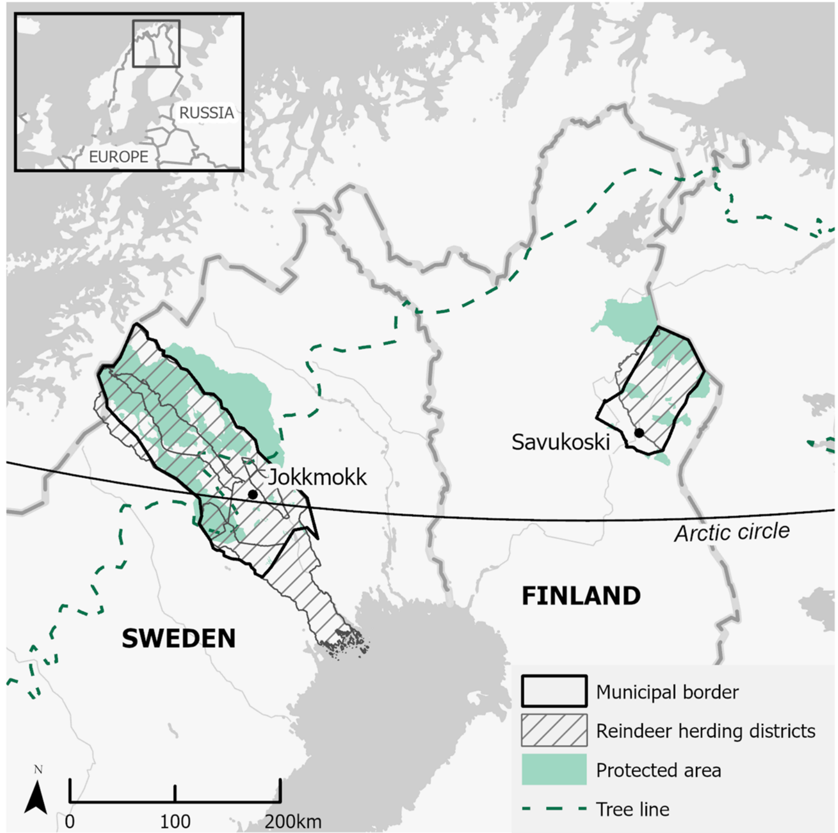


Fig. 1 Location of the two studied municipalities and the area of nearest herding districts. The tree line denotes the border between boreal forest and tundra vegetation characterized by, e.g., mountain birch, heath or meadow vegetation, mires, mosses, and lichens

annual precipitation 601 mm). Boreal forests of mostly pine (*Pinus sylvestris*), spruce (*Picea abies*), and birch (*Betula* sp.) as well as peatlands and a number of fjelds dominate the mostly flat terrain (Rasmus and Turunen 2015; Finnish Meteorological Institute 2022). Fjelds are rocky, barren plateaus of the Scandinavian upland. While the Jokkmokk area is similar in climate, it is influenced by the moderating effect of the Atlantic Ocean to the west across the Scandinavian Mountain chain with mean annual temperature − 0.2 °C, mean of coldest quarter − 12.2 °C and warmest quarter + 13.0 °C, and mean annual precipitation 543 mm (SMHI 2024). Approximately a third of its area is mountainous habitat above the tree line and the rest is boreal forest dominated by pine, spruce, and birch (Zachrisson and Beland Lindahl 2013). During this century due to climate change, the mean annual temperature in Northern Finland is expected to rise by 1.9–5.8 compared to 1980–2010 period, it already rose by 0.6 °C during 1991–2020 and the mean annual precipitation is expected to increase by 7–19% (Finnish Meteorological Institute 2022). In Northern Sweden, the mean annual temperature is likewise predicted to increase by 2.0–5.5 °C relative to 1971–2000 period and mean monthly precipitation to increase by 4–14 mm. The temperature has already risen by 0.5 °C compared to 1961–1990 period (SMHI 2024). Large rivers, the Kemijoki in Savukoski and the Lule River and the Lesser Lule River in Jokkmokk, flow through the municipalities; dams for hydropower have been built in Jokkmokk and downstream from Savukoski municipality. One-third of the Savukoski territory is protected, including four nature protection areas. Nearly half of Jokkmokk municipality is protected (9400 km^2) and forms Laponia, a UNESCO World heritage site with its outstanding environmental and cultural values.

Savukoski borders the Sámi homeland in the north (i.e., the administrative area in Finland where Sámi rights are extended and under particular protection). The reindeer herding district of Kemin-Sompio roughly follows the municipal border. Contrary to Sweden, where reindeer herding is practiced exclusively by the Sámi, reindeer herding can be practiced by anyone living in the reindeer herding area and accepted as a member by a herding district. In and around Jokkmokk, the herding districts Sirges, Tuorpon, and Jåhkågaska tjiellde have their summer grazing areas in the mountains and winter pastures in the boreal forest; two districts, Slakka and Udtja, graze their reindeer year-round in the boreal forests.

Forestry, the service sector and reindeer herding are the main livelihoods of the Savukoski municipality. 90.9% of the land in the herding district in Savukoski is owned by the government; forest land, most of which is commercial forest, covers 70.9% of the total herding area (Kumpula et al. 2019). Savukoski attracts nature tourism, recreation, and nature-based livelihoods, which are seen as ways to diversify the economic base in the municipal strategy (Savukosken kunta 2022). Jokkmokk has a very similar economic base with tourism being of local importance. The Sokli phosphate reserve was discovered in 1967 in Savukoski and since then, there has been on and off plans to open a mine in the area; the latest plans are for the extraction of rare earth metals (Sajari 2023). Within Jokkmokk, the Swedish Government gave its approval for a mining permit in March 2022 for an iron ore mine, which has been in the plans since 2006 and creates friction within the community and wider society (Fjellborg et al. 2022; Wilson and Allard 2023).

Survey design

We collected the local perceptual data on environmental changes through an online participatory mapping survey platform, Maptionnaire (www.maptionnaire.com), during February–May 2022 in Savukoski and May–September 2022 in Jokkmokk. The survey introductory page included description of the research objectives, data usage, and the privacy policy. Respondents were asked to tick a box declaring that they understand the objectives and give consent to use their responses in the research project. The survey included structured questions about respondent background, perceived environmental changes (both structured and open-ended), and a possibility to mark the changes on a map using both point and polygon map markers (see Supplementary Material 1). Also, open-ended questions were asked about negative and positive impacts of changes and adaptation measures undertaken by the respondents. Adaptation measures were defined as changes to one's life or livelihoods that the person has made in order to adapt to the impacts of environmental change. The survey included questions about future landscape preferences; however, the analysis of these is beyond the scope of this article. The link to the online survey was advertised in regional and local email lists, via focal points of local associations and the reindeer herders' associations, County Administration Boards, social media (e.g., local Facebook groups), and in Finland also in the regional newspaper. The survey was self-administered. In the Finnish case study in Savukoski, the main author collected responses in a facilitated manner during four days in April 2022; additionally, phone call interviews were conducted with two respondents. The dataset from Jokkmokk is more limited as we did not facilitate survey responses. In Savukoski, the survey received 107 respondents representing 12% of the total population and in Jokkmokk 87 respondents representing only 2% of the total population. The number of respondents per each survey question is indicated by the *n*-values among the text.

The spatial extent of the survey followed roughly the municipal borders; however, the delineation was not strict as people's living environment does not necessarily follow administrative boundaries. Thus, we chose to use the term region (i.e., Savukoski region, Jokkmokk region) in the survey and its advertisement. The target group for the survey was people living or practicing their livelihood in the municipalities or otherwise well-familiar with the environment of the regions. We defined environmental changes in the survey as changes resulting from natural processes or direct human impacts and provided a short list of examples identified beforehand as probing and cues. We used the concept of environmental change because it is more holistic and does not entail as strong uncertainties, personal beliefs, and political discourses as does the climate change concept (Shi et al. 2015; Sambrook et al. 2021). We asked people to describe changes they have observed within their life time, as a certain predefined time range might deter people from answering and since human memory is not precise.

Collection of secondary data on scientific evidence

Scientific evidence on environmental changes in the study regions were collected from peer-reviewed scientific literature and reputable gray literature. We did not conduct a systematic literature review because a lot of local level and regional instrumented data has been published in gray literature that is not indexed in academic research databases. Literature was sought for each change phenomenon which received more than one mention in the survey. This search was conducted using Scopus and Web of Science databases, existing publications known to the authors, national environmental report databases, and organizational websites. The resulting literature includes original research papers, environmental monitoring reports, and science communication papers by national or regional level environmental agencies. For evidence in Savukoski, the Värriö research station, which is situated within the municipality, was contacted to enquire any relevant published or unpublished work at the local level. The relevant literature was screened for corresponding evidence—either corroborating, contradicting, or inconclusive—on the phenomena observed by survey respondents. The evidence was documented in detail in a data matrix on Microsoft Excel. The data matrix is provided in a concise form as a Supplementary Material 2.

Analysis and knowledge integration

The survey data were analysed using descriptive statistics, qualitative content analysis, and spatial data analysis. Microsoft Excel was used to clean the data, run descriptive statistics, and conduct a content analysis (Flowerdew and Martin 2005) to iteratively identify, review, and name themes and subthemes inductively from the open-ended answers. Frequencies of mentions of each change phenomenon across the non-spatial and spatial open-ended answers were combined, since overall, they indicate the prevalence of perceptions regarding the same phenomenon. We conducted statistical analyses (Kolmogorov-Smirnov and Shapiro-Wilk tests of normality, Mann-Whitney *U*, and Pearson chi-square tests) on SPSS Statistics to study the relation of the respondents' demographic background and their environmental change perceptions, but no statistically significant differences were found. The spatial data on where the perceived environmental changes had been observed in the study areas were visualized with Esri ArcGIS software and area-based map markings specifically using the Count-overlapping-features tool. A visual interpretation of the spatial data results was done to indicate the spatial coverage of change perceptions. However, the spatial dataset in both case study areas was limited in the number of respondents and map markings: it only serves as indication of the spatial distribution of change perceptions.

The scientific evidence and the local perceptions are elaborated on and discussed together in the results section "Perceived environmental changes and related scientific evidence." We did not aim to scrutinize the validity of these different knowledge sets but present them alongside each other in order to highlight important insights from both and obtain a more nuanced understanding of the changes perceived locally. Regional level scientific studies often contain the caveat that there are marked differences within regions, e.g., in weather variables (Rasmus et al. 2020b) and thus caution is needed when utilizing regional and national level scientific evidence. We utilized scientific sources on changes in weather, vegetation, animal populations, and landscape features covering geographically as close an area as possible to the study regions. Yet, one needs to keep in mind the scale of the phenomena and of the scientific evidence when interpreting the results of this study.

Results and discussion

Characteristics of the respondents

The number of respondents in Savukoski was 107, which corresponds to 11.8% of the municipal population over 14 years of age. In Jokkmokk, there were 87 respondents which is 2.1% of the population over 14 years of age. In Jokkmokk, the gender ratio of respondents corresponds to that of the municipality and is more balanced than in Savukoski sample, where women are underrepresented (Table 1). The average age of respondents in Savukoski is 52.9 years (StD 17.6; min 16; max 91; $n = 107$); in the whole population, it is 51.3 years. In the Jokkmokk sample, the average age is 52.4 years (StD 12.6; min 17; max 76; $n = 86$), which is slightly higher than in the whole population namely 47.7 years. The various age categories are fairly well represented in the Savukoski sample except for the elderly population; in the Jokkmokk sample, both the young adults and elderly are underrepresented (Table 1). In both case study municipalities, most of the respondents (Savukoski 64.5%, $n = 107$; Jokkmokk 67.8%, $n = 87$) have grown up and still live in the area or have lived there more than 10 years (Fig. 2). Other relations to the study area, such as regular visitation, also feature among the respondents, but clearly less.

In Savukoski, the main livelihoods of the respondents are reindeer herding, municipal work, and retirement (17.8%, 16.8%, and 16.8%, $n = 107$). In Jokkmokk sample, the most common main livelihood is municipal work (25.3%, $n = 87$), followed by retirement (14.9%) and miscellaneous entrepreneurship (10.3%). Other livelihoods include among others transport and logistics, health care, forestry, and mining industry. In Jokkmokk, 9.2% of the respondents ($n = 87$) are reindeer herders, which indicates Sámi background and

Table 1 Gender ratio and age categories of the respondents compared to the municipal population

	Savukoski[a]		Jokkmokk[b]	
	Sample population ($n = 107$)	Municipal population ($n = 1009$)	Sample population ($n = 87$)	Municipal population ($n = 4760$)
Gender				
Male	62.60%	56.20%	49.40%	51.70%
Female	34.60%	43.80%	49.40%	48.30%
Prefer not to answer	2.80%	NA	1.10%	NA
Age by category over 14 years of age[c]				
15–24	9.30%	7.20%	2.30%	9.50%
25–44	19.60%	18.70%	24.40%	25.30%
45–64	43.90%	37.10%	57.00%	30.50%
65–	27.10%	37.10%	16.30%	34.70%

[a]Statistics Finland 2022; [b]Official Statistics of Sweden 2022; [c]percentage of age categories compared to population over 14 years of age; Savukoski 904 and Jokkmokk 4104 inhabitants, respectively

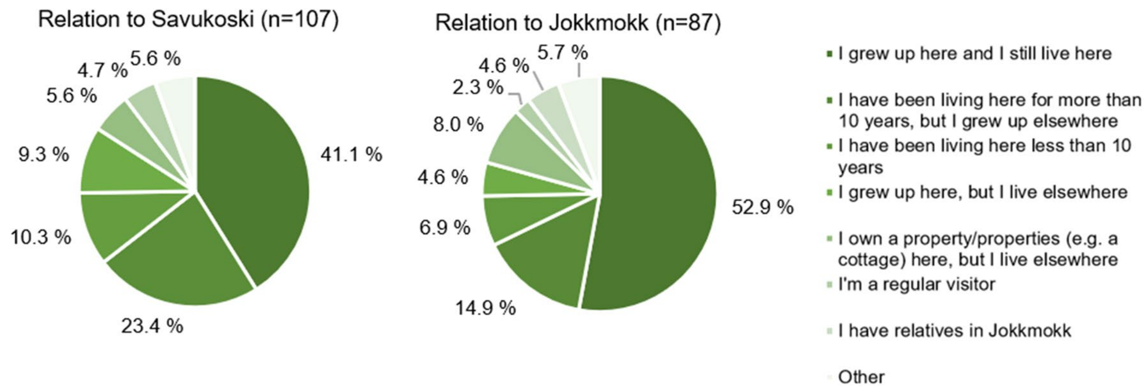


Fig. 2 Respondents' relation to the studied municipalities. Note the category "I have relatives in Jokkmokk" applies only to Jokkmokk and is 4.6%

self-identification. As the survey did not explicitly ask about indigeneity, we cannot exclude that several more respondents had a Sámi background but they did not indicate it. Most respondents in both case study areas characterize themselves as recreational users of nature (Savukoski 67.0%, $n=94$; Jokkmokk 79.5%, $n=83$) (Fig. 3). In both municipalities, more than half or nearly half of the respondents engage in hunting (Savukoski 60.6%, $n=94$; Jokkmokk 42.2%, $n=83$), fishing (Savukoski 59.6%, $n=94$; Jokkmokk 49.4%, $n=83$), and/or other nature-based activities (Savukoski 19.1%, $n=94$; Jokkmokk 54.2%, $n=83$). Some respondents state no nature-related characteristics relevant to them (Savukoski 12.1%, $n=107$; Jokkmokk 4.6%, $n=87$).

Perceived environmental changes and related scientific evidence

Overview of perceived environmental changes

Respondents in both municipalities reported very similar environmental changes. When the respondents were asked to select environmental changes, which they had observed during their life time from a predefined list, changes in snow conditions, vegetation, winter weather, wildlife, and lake and river ice conditions were chosen most frequently (Fig. 4). In Savukoski, changes in vegetation and fish stocks were more prominently mentioned than in Jokkmokk where changes in snow conditions, spring weather, and landscape features were predominantly mentioned. In the next sub-section, we focus on the detailed descriptions of these perceived changes (open-ended answers in Savukoski $n=85$ and Jokkmokk $n=43$) and juxtapose them with findings from scientific studies.

Changes in seasonal weather and snow and ice conditions

In both municipalities, respondents report less predictable weather patterns due to increased annual and daily weather variability (Savukoski 15.3%, $n=85$; Jokkmokk 27.9%, $n=43$). Most commonly, the variability has been observed in the winter—and in Jokkmokk also in the spring temperatures—as several respondents refer to low temperatures

Fig. 3 Nature-related characteristics and activities that the respondents identify with

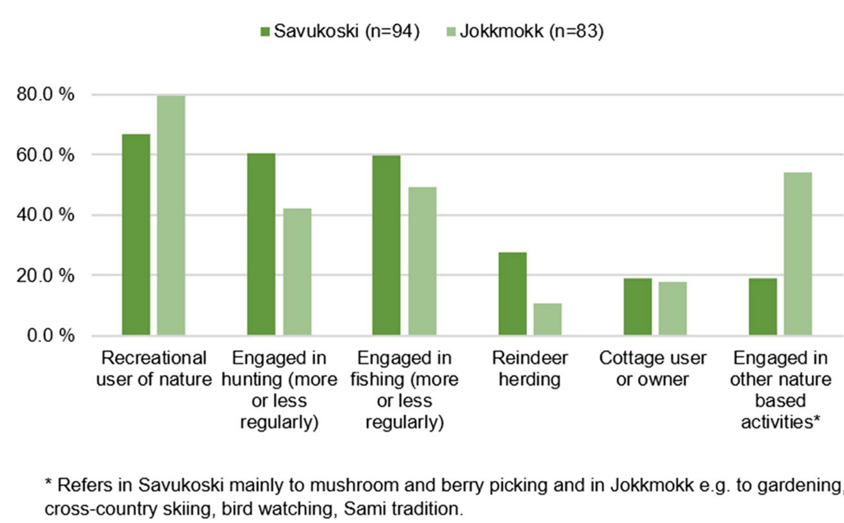
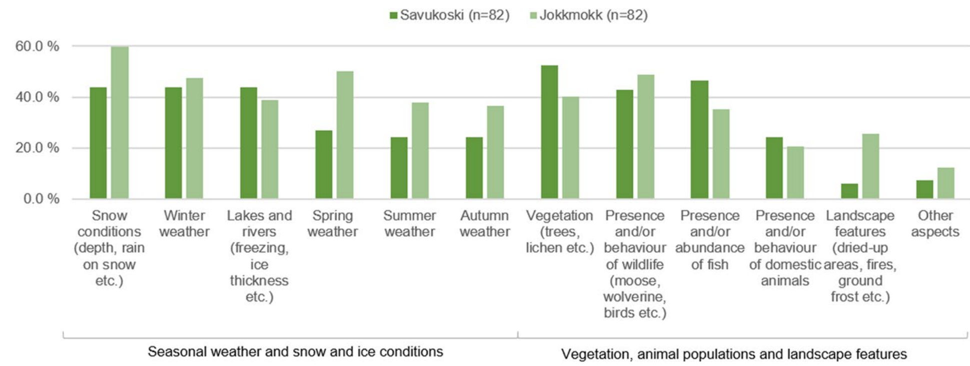


Fig. 4 Percentage of respondents who have observed particular types of changes in the environment during their lifetime in the case study municipalities



changing within a few days to plus degrees and back. Also, the amount of snow is reported to differ considerably between years. One respondent refers to an old Finnish saying that "winters are not brothers alike" (70-year-old man, Savukoski), meaning that even in the past winter conditions have varied. Spatially, changes in weather, ice, and snow are predominantly reported near the municipal settlements, but are also depicted to cover the whole municipality (see Supplementary Material 3). Regional climate measurements show large interannual variability in climate indices in Northern Finland and Northern Sweden (SMHI 2015; Rasmus et al. 2020b). Changes in weather variability or daily weather persistence have been studied very little (Rasmus et al. 2020b); however, local perceptions of increased variability in weather, especially in summer and winter, have been reported in some studies in Northern Finland (Markkula et al. 2019; Rasmus et al. 2020b).

In both municipalities, some respondents (Savukoski 9.4%; Jokkmokk 20.9%) perceive windiness to have increased in general and a few respondents note that wind blows nowadays unusually even during the cold periods of winter. In a study of Northern Sweden, increased seasonal mean wind speed trend has been detected for 1956–2013 (Minola et al. 2016). In studies of Northern Finland, in contrast, a decrease in mean wind speeds or no significant change was detected in records dating since late 1970s (Laapas and Venäläinen 2017; Gregow et al. 2021).

In Savukoski, autumns are noted to have become warmer and snow cover and proper ice on lakes and rivers forming later (16.5% of respondents): "Autumns are clearly warmer than before, there are fewer crisp autumn days, less sunny frost days and more often warm, foggy and rainy. You notice it when you're hunting, you've had to change your clothes and the dog is sweltering." (48-year-old woman, Savukoski); "In the beginning of the 90s, one could travel on a sled along the river ice already towards the end of November, in recent years it has not been possible to go on the river ice before the end of December/January." (47-year-old woman, Savukoski). Similar observations were reported by 16.3% of respondents in Jokkmokk describing warmer and longer autumn seasons. In the area close to Savukoski, no significant change in autumn mean temperatures has been detected but the number of autumn frost days has decreased in the past century, whereas in Northern Sweden, a warming trend in autumn mean temperatures has been recorded (SMHI 2015; Kivinen et al. 2017).

Several respondents indicate that the winter season has become shorter (Savukoski 18.8%; Jokkmokk 16.3%), while the snowless autumn season lasts longer and snow melt often starts earlier. However, not all respondents describe what they consider being the determinant of autumn or spring season and simply state the winter season as shorter. A decrease in snow season length has been detected in Savukoski region and in Northern Sweden, which is indicative to these perceptions of shortening of winter (Rasmus et al. 2014; SMHI 2015; Turunen et al. 2016; Luomaranta et al. 2019).

Twenty-nine point four percent of respondents in Savukoski and 37.2% in Jokkmokk state that winters are milder with shorter periods of subzero temperatures. They refer to less harsh minus temperatures as before, less events of extreme cold ("tulipalopakkanen" [fiery frost] in Finnish), or that the continuous week-long periods of subzero temperatures are now more frequently interrupted by thaw (a common observation in Jokkmokk): "Winters are rarely really cold these days. Long periods of severe cold are now completely gone." (69-year-old man, Jokkmokk). A warming trend in winter season temperatures has been detected over many decades in several studies in Northern Finland, a slight increase in winter temperatures has been recorded in northern Sweden, and in the whole of Sweden, thaw-freeze cycles have become more common since 1990s (Rasmus et al. 2014, 2020b; SMHI 2015, 2023; Kivinen and Rasmus 2015; Merkouriadi et al. 2017; Kivinen et al. 2017; Lépy and Pasanen 2017).

In Savukoski, 3.5% of respondents note that it rains more often during winter or at odd times: "It rained around Christmas which is not normal" (57-year-old woman, Savukoski). In Jokkmokk, 7.0% of respondents state that precipitation in general has increased. Research shows increased numbers of rainy days during winter in Savukoski and increase in mean annual precipitation in Northern Finland (Rasmus et al. 2014; Merkouriadi et al. 2017). In Northern Sweden, a slight increase in precipitation has been recorded (SMHI 2015).

Several respondents state that the waterbodies do not freeze properly as previously but ice remains fragile long into the winter months (Savukoski 15.3%; Jokkmokk 25.6%), there is less often clear ice and water rises above the ice intermittently during winter. One Savukoski respondent, a 60-year-old man, states, however, that the ice thickness has always varied over the years. There are no comprehensive studies of ice conditions in waterbodies in Northern Finland but the few indicative studies show some similar trends in ice build-up and thickness in lakes as mentioned in Savukoski survey (Korhonen 2006; Puro-Tahvanainen et al. 2019). Also in Sweden, comprehensive studies are lacking but deteriorating ice conditions are expected due to warming temperatures in the Northern latitude (Länsstyrelsen Norrbotten 2012).

The formation of ice layers in the snow during autumn and winter is reported to be more frequent and a detrimental phenomenon. In Jokkmokk, 16.3% of respondents describe icing events to have become more common, in which rain or thaw conditions cause the snow surface to freeze inhibiting, e.g., reindeer from grazing. In Savukoski, 9.4% of respondents describe that the first snow falls more commonly on unfrozen soil creating a situation in which the ground vegetation and soil become moldy and then freeze, melt and refreeze again during the winter with a similar consequence for reindeer grazing. One Savukoski respondent (57-year-old woman) notes that these basal ice events happened also in the 1970s and 1980s a few times but in the past 20 years they have become more frequent. There is very sparse scientific data on basal ice formation in Finland; however, one study based on local herders' observations shows a slightly decreased number of winters with basal ice formation in Savukoski in the 1983–2016 period compared to 1948–1982 (Rasmus et al. 2018). The above-mentioned more frequent thaw-freeze cycles in Sweden may indicate more frequent icing events but further studies are lacking (Päiviö 2006; SMHI 2023). Increased precipitation in winters is associated with mold formation underneath the snow and negative effects of icing events on reindeer grazing are commonly reported (Rasmus et al. 2018; Ocobock et al. 2023).

One particular phenomenon associated with warmer autumns and winters in Savukoski is that the peatlands are perceived to not completely freeze during winters as observed by two respondents (2.4%). "There is no more ground frost on peatlands. Peatlands are wet even during the winters and form crusty ice [paannejää] hindering traveling." (58-year-old woman, Savukoski). The other states that reindeer do not go to peatlands for this reason and it smells like soil there during winter (57-year-old woman, Savukoski). Studies of peatland ice conditions in Northern Finland are lacking; however, a study by Rasmus et al. (2020b) reports similar perceptions on ground frost among reindeer herders. In north-western Finland, significant degradation of permafrost has been reported during a 1959–2021 study period (Verdonen et al. 2023).

Among the respondents in both municipalities (Savukoski 23.5%; Jokkmokk 11.6%), the perceptions on the changes in snow depth vary between increased and decreased snow depth. Some respondents specifically note that there is a big annual difference in winter snow conditions. Variability in annual snow depth is confirmed by instrumented studies in Finland (Rasmus et al. 2014, 2016). Exceptionally high snow cover conditions have been reported in winter 2019–2020 in Northern Finland (Kumpula et al. 2020), which might affect current perceptions on trends. Interestingly, in Jokkmokk, an increased number of winter storms were reported by four respondents (9.3%), while in Savukoski, the only two respondents (2.4%) who spoke of winter storms stated that snow blizzards have become less common. Long-term records of winter storms are scarce. Climate models predict increased storm frequency in the Arctic region; however, the reduction of Arctic sea ice extent can affect the wind regimes and reliability of predictions (Gregow and Vihma 2012).

Changes in the start of spring season gather varied observations. In Savukoski, in contrast to some respondents observing that spring starts earlier and shortens the period of winter and snow cover (5.9%), there are opposite observations that spring seasons are colder and the snow cover lasts longer nowadays (7.1%). Similarly, in Jokkmokk, the spring weather has been observed to change abruptly more commonly and temperatures stay colder for longer, causing the snow to melt later than before (11.6%). Scientific studies show signs of earlier snow melt in Northern Finland during the last century and in the future (Turunen et al. 2016; Kivinen et al. 2017; Rasmus et al. 2020b) but the spring of 2020 featured exceptionally high snow cover (Kumpula et al. 2020). On average, spring temperatures in Northern Sweden have slightly increased (SMHI 2015), which is contrary to respondents' perceptions in Jokkmokk.

In Savukoski, 7.1% of respondents perceive that the melting of lake and river ice in spring is no longer the same—the ice melts gradually or might not have been as thick as before. Thus, there are fewer ice jams on rivers as in the past. Long-term records in the closest studied river, Torne river, indicate that the river ice breakup dates occur with significant annual variation (Norrgård and Helama 2022) whereas ice breakup in closest studied lake, Lake Inari, now sets in earlier and ice thickness in spring has undergone a statistically significant decrease in the past 60 years (Puro-Tahvanainen et al. 2019). The ice jam formation has not been recorded in the data used in these studies.

Summers are associated with more frequent extremes in both municipalities. On the one hand, summer seasons are noted to have more and longer dry spells and higher temperatures than before (Savukoski 11.7%; Jokkmokk 11.6%): "Extremely hot periods in summer. For several years, in Berghem, where I live, we have had over 30 degrees in the shade (30–34) and it doesn't get that hot in these areas" (69-year-old man, Jokkmokk). On the other hand, respondents observe that variability in temperatures and precipitation during and between summers has increased (Savukoski 2.4%) or that summers have become more humid and rainier than before (Jokkmokk 4.7%). A record for 100 years in Northern Finland exhibits an increasing trend of extremely high daily maximum temperatures during spring and autumn seasons, but not during summer (Kivinen et al. 2017) and the period 1981–2010 shows no significant change in annual number of hot days (Rasmus et al. 2020b). Thus, a clear increase of hot spells during summer is not supported by the studies; nonetheless, exceptionally high temperatures have been experienced in Finnish Lapland in recent years. In Northern Sweden, the number of consecutive summer days warmer than 20° has increased by a few days since the 1961–1990 reference period (SMHI 2015). No statistically significant change in monthly summer precipitation has been observed in Northern Finland in the past 100 years (Kivinen et al. 2017) but in Northern Sweden, a slight increase can be noticed in mean daily precipitation in summers between 1961 and 2013 (SMHI 2015).

Many observations align with existing scientific studies, such as warmer autumn temperatures, shorter and milder winters and increased precipitation especially in winter. However, there is less clarity regarding the views of participants on some weather-related trends due to insufficient scientific data, such as ice formation in rivers and on the ground. Some findings are supported by indicative scientific evidence, while others contradict previous studies, especially concerning colder spring temperatures, and increased wind speeds.

Changes in vegetation, landscape features, and animal populations

Changes in vegetation and animal populations are often described in relation to each other. Interlinkages with the changes in seasonal weather are also described. Changes in landscape features are less commonly described and when they are, they are perceived to be associated with other changes.

Perceptions of berry yields mostly concern their reduction, e.g., due to dryer summers (Savukoski 9.4%; Jokkmokk 4.7%). However, respondents also report that they see no particular change from the normal variation, which depends on the weather conditions of each summer (Savukoski 2.4%): "There are normal years, bad years and super good years when the climate is favorable" (59-year-old man, Savukoski). Finland does not carry out systematic berry inventories; a recent indicative study shows no clear trends but high interannual variability in berry yields (Turtiainen et al. 2015). Warmer climate and drought conditions have been shown to reduce berry yields but the effects are complex and species specific primarily causing shifts in species dominance (Markkula et al. 2019; cf. Forbes 1995).

Signs of Arctic greening were reported especially in Jokkmokk due to the mountains in the region. Several respondents (23.6%) have observed that the tree line is moving upwards and increased shrubification in the mountainous area (Supplementary Material 3), similar with reindeer herders' observations in a study by Horstkotte et al. (2017). In Savukoski, shrubification of fjelds and extending growth of hay have been noticed by 3.5% of respondents. In some parts of Northern Sweden, the tree line has risen altitudinally (approx. 200 m) since the early twentieth century (Kullman 2010), while it has remained stable in others (Van Bogaert et al. 2011). In Northern Finland, changes in species ratios have been documented (Pöyry and Aapala 2020) and in Savukoski, a marked increase in biomass of shrubs is evident during 2005–2018 (Kumpula et al. 2019). However, estimation of the magnitude of Arctic greening is complicated by vegetation dynamism and complexity in relation to climate, reindeer herding, and topoclimatic constraints (Kullman 2010; Van Bogaert et al. 2011; Markkula et al. 2019; Myers-Smith et al. 2020; Stark et al. 2021).

Increase of forestry activities is the most commonly perceived environmental change in Savukoski: it was noted by 40.0% of respondents. This includes forest harvest in form of clearcutting (7.1%) as well as decrease of old forests (7.1%). The loss of forest cover is associated with the drainage of peatland and heavy soil preparation in silviculture (15.3%). Together, these are perceived to have altered vegetation types, landscape features, waterbodies, and subsequently biodiversity, as exemplified in these quotes: "Forests have been cut down. Lands plowed. Waterbodies have become eutrophic. Forest drainage and soil preparation have ruined and dried up springs and streams." (65-year-old woman, Savukoski); "forest logging has increased – there are not many old forests, logging [occurs] already in the sapling stage. In restored areas, the forest has not grown back as it was thought it would. I criticized the actions of Metsähallitus [the Finnish state-owned forestry enterprise] that the management methods are not good" (65-year-old man, Savukoski). The forestry operations of Metsähallitus are directly criticized by five Savukoski respondents. In Jokkmokk, 18.6% of respondents report increased forest logging with effects on habitats: "Forests are gone apart from (too) small refugia, which is why tits and Siberian jay [Persioreus infaustus] and other resident birds are in a critical situation.

–. Also, fish (brown trout) have been strongly affected by forest harvest in the watershed." (72-year-old man, Jokkmokk). Forest logging is mapped to cover nearly the entire area of Savukoski apart from the northeastern corner which is protected (Supplementary Material 3). In Jokkmokk, logging affects the boreal forest zone outside of protected areas. In Finland, forest management has affected two-thirds of the reindeer herding district area and in Kemin-Sompio, the herding district in Savukoski, 17% of mature and old growth forests outside nature reserves have been harvested between 1995 and 2018 (Kumpula et al. 2019). No reliable data exists on the harvesting rate of old natural forests in Finland; however, most regeneration fellings in Northern Finland are estimated to have taken place in old natural forests and evidence exists of clearcutting in unprotected natural forests (Kröger 2018; Kumpula et al. 2019). In Northern Sweden, clearcutting of old forests has increased in extent since 2003 (Ahlström et al. 2022). Clearcutting and heavy soil preparation are a common practice in boreal forestry (Kumpula et al. 2019; Ahlström et al. 2022), which generally result in low biodiversity and ecological integrity in managed forests (Mönkkönen et al. 2022).

The siltation and eutrophication of waterbodies have been observed by 11.8% of respondents in Savukoski. Some respondents report anthropogenic alterations in rivers and rapids such as riverbed deepening, resulting in the decrease of natural river courses (4.7%). In Jokkmokk, these observations were not reported. The larger waterbodies in the Savukoski region are estimated to be in excellent or good condition (Finnish Environmental Institute 2019). Peatland drainage and conversion to other land uses in Finland was most intensive in the 1960s and 1970s and continued until the 2000s, after which they were reduced substantially (Kuusela et al. 2022). This reduction is clear also in the Savukoski area (Räinä et al. 2015, 2022). In Northern Finland, 23% of forest peatland has been drained since the 1950s due to forestry (Turunen and Valpola 2020). According to Räinä et al. (2022), ditch maintenance is the main drainage operation nowadays in the watershed in Savukoski, but—together with continued heavy soil preparation, including soil scarification (Kumpula et al. 2019)—the effects of these operations on waterbodies including disappearance of small water sources are considered as long lasting.

In Savukoski, terricolous and epiphytic lichens (genera *Usnea*, *Bryoria*, and *Alectoria*) have diminished or disappeared in many areas according to 18.8% of respondents—whereas one respondent says they are growing better than in the past. Forest logging, soil preparation, and the number of reindeer, which feed on lichens, are mentioned as causes for the reduction: "Due to forest felling, heath forests are greener and epiphytic lichen has disappeared in many places in commercial forests. Moss has then killed the terricolous lichen in dense sapling stands" (47-year-old man, Savukoski). Reindeer lichen (*Cladonia* ssp.) biomass has decreased by one-third between 2005 and 2018 in the Kemin-Sompio herding district (Kumpula et al. 2019). The reduction of epiphytic lichen abundance has been attributed to forestry practices, while climate warming and reindeer herding are shown to impact on understory vegetation and ground lichen biomass in Northern Finland (Jaakkola 2014; Stark et al. 2021). Related to the changes in seasonal weather, habitats, and lichens, changes in reindeer behavior were reported in Savukoski (7.1%)—movement in landscape is different and herds are more often scattered. Another three respondents (3.5%) perceive that there are too many reindeer in the area nowadays, two of which refer to overgrazing and none quantifying what they mean by "too many." Changes in pasture extent and conditions affect reindeer behavior in various ways, one of which is the wide dispersal of herds in case of poor grazing conditions (Jaakkola 2014; Turunen et al. 2016; Rasmus et al. 2020b).

Changes in fish abundance and species are commonly perceived phenomena (Savukoski 35.3%; Jokkmokk 20.9%, see also Fig. 4). Some respondents have very detailed perceptions of the fish stocks: "The amount of river trout [Salmo trutta fario] in streams today is about 15% of what it was before the draining of peatlands started in 1960. – The abundance of fish in Kemijoki, carp fishes [Cyprinidae] has increased slightly, grayling [Thymallus thymallus] populations have declined to only about 25% of what they were 60 years ago – (river track from Savukoski church to Kuosku, from where my knowledge is)" (69-year-old man, Savukoski). In both municipalities, there are similar perceptions of diminished, currently locally extinct, or proliferated fish species (see Supplementary Material 2). Some of these observations are lake- or river-specific, such as in the above quote. In Savukoski, particularly, most mapped changes were reported in the main channel of the Kemijoki (Supplementary Material 3). The changes in species were attributed to river dams, siltation caused by forest logging, and increasing water temperatures during summers. In inland waterbodies of Finland, according to statistics, the catch of common whitefish *Coregonus lavaretus* and river trout *Salmo trutta* (m. fario) has decreased, while catches of pike (*Esox lucius*), common perch (*Perca fluviatilis*), and salmon (*Salmo salar*) have increased between 1980 and 2021; European grayling (*Thymallus thymallus*) catches decreased between 2000 and 2021 (Natural resource institute of Finland 2023a). Except for salmon, all these trends are in line with local perceptions. Kemijoki watershed has dams, which likely explains the observations of nearly non-existent salmon stocks (Räinä et al. 2022). In Sweden, the mountainous areas have been modeled to provide refugia for Arctic char (*Salvelinus alpinus*) under warming temperatures and species interactions (Hein et al. 2012). However, according to four respondents (9.3%) in Jokkmokk, at least one of which is from the mountainous area, Arctic char has diminished because of pressure from other species and higher water temperatures, thus undermining the idea of refugia. Increased water temperature and browning and precipitation changes have been shown to affect fish survival (Karvonen et al. 2010; van Dorst et al. 2019; Saura and Kallasvuo 2023); in Sweden, brown trout (*Salmo trutta*) abundance is evidenced to depend also on the reservoir storage volume in waterbodies (Donadi et al. 2021).

Bird species observations (Savukoski 22.4%; Jokkmokk 16.3%) note the decrease of certain species, especially forest birds and cavity nesters due to habitat loss and increased hunting, and several new species extending their range into the regions. In Savukoski, especially Willow ptarmigan (*Lagopus lagopus*) among other grouses and Common starling (*Sturnus vulgaris*) are said to have diminished. Some of the mentioned new species are pigeons, doves (*Columbidae*), and Blue tit (*Parus caeruleus*). Studies of Northern Finnish bird populations show diminishing trends in forest birds and certain cavity nesters (Valkama et al. 2011; Markkula et al. 2019). Observations of the Värriö research station confirm this trend for Willow ptarmigan and Western capercaillie (*Tetrao urogallus*) but not for Black grouse (*Lyrurus tetrix*) which shows slight recent increase in numbers (personal communication, Mikko Sipilä, professor, Head of Värriö Subarctic Research Station, University of Helsinki, 07.04.2022). In Northern Sweden, contrary to respondents' observations, an increase in forest bird populations has been observed associated with increasing of dense forests and deadwood volume providing habitats to forest specialists (Ferry et al. 2020). In both countries, many southern bird species' breeding range has moved northward, which aligns with local observations (Brommer et al. 2012; Elmhagen et al. 2015).

Perceptions of the abundance and behavior of wildlife differ among the respondents especially in Savukoski. The change in abundance of large predators (16.5%), such as wolverine (*Gulo gulo*), wolf (*Canis lupus*), brown bear (*Ursus arctos*), and Eurasian lynx (*Lynx lynx*), gathered opposing observations—either increase or decrease—in Savukoski. One respondent refers to their disappearance close to residential areas: "Wolverines and bears have disappeared near the settlement. When I moved here in the 60s, they were right next to the settlement, you can't see them anymore. Out in nature further away they may be." (84-year-old man, Savukoski). In Jokkmokk, 7.0% of respondents note the decrease of animal populations, especially decrease of predators. Overall, the populations of large predators in the whole of Fennoscandia have increased in the past 50 years due to protection policies; however, there can be large annual variation on local level in the numbers, particularly of wolves (Rasmus et al. 2020a; Åhman et al. 2022; Metsähallitus 2023). In Sweden, wolves are restricted by policy to south of the reindeer herding area while wolverines mostly retreated to tundra areas, but in recent years have extended their range back into the forest zone (Elmhagen et al. 2015).

In Savukoski, the population of moose (*Alces alces*) is perceived to have decreased lately (9.4%), while roe deer (*Capreolus capreolus*) is a newly arrived species (2.4%). The game animal monitoring data of the region shows a slight decrease in moose populations since early 2000s (Natural resource institute of Finland 2023b). In the past 30 years, distribution of roe deer has extended to Finnish Lapland but the numbers vary according to snow conditions (Natural resource institute of Finland 2023c). Also, in Jokkmokk, the increase of roe deer as a new species has been noted (11.6%), which is in line with the current official distribution limit, which lies southeast of Jokkmokk (Elmhagen et al. 2015).

The presence of Nematocera such as mosquitos and blackflies was commented on by 7.1% of respondents in Savukoski and 7.0% in Jokkmokk—mainly to the effect that nowadays their season starts earlier but their numbers are less. There are no long-term records of insect populations available in Northern Finland and insect prevalence likely varies annually (personal communication, Jukka Salmela, conservation biologist, University of Lapland, 24.02.2023).

The increased human disturbance on animals was noted in both municipalities. In Savukoski, 10.6% of respondents consider that hunting by non-local hunters has increased, reducing the amount or altering the range and behavior of game animals. In Jokkmokk, increased scooter and snowmobile traffic and hunting activities were mentioned by 7.0% of respondents. There has been a marked increase in interest in non-local hunting licenses in Finnish Lapland in recent years and the tourist numbers in Northern Sweden have increased between 2008 and 2021 apart from the COVID-19 induced decline in 2020 (Metsähallitus 2022; Official Statistics of Sweden 2022b).

There is a clear correspondence between respondents' observations and scientific studies on phenomena such as changes in forests and peatlands, the dynamics of fish species prevalence, human disturbance on animals, and changes in lichen abundance and reindeer behavior. When it comes to changes in berry yields in Savukoski and the abundance of Nematocera in both municipalities, the correspondence cannot be evaluated because of the absence of sufficient scientific data. The only contradiction—a partial one—between the knowledge sets is found in the observations of forest birds.

What does experienced impacts of changes and adaptation strategies tell about the most pressing changes?

The human-induced pressures on and changes in animal populations and habitats are accentuated by the many reports of negative effects on traditional nature-based livelihoods such as fishing (Savukoski 26.5%, $n = 68$; Jokkmokk 8.6%, $n = 35$), reindeer herding (Savukoski 23.5%; Jokkmokk 14.3%), and hunting (Savukoski 14.7%), i.e., decreased catch or wellbeing of animals as well as in Savukoski, berry harvesting that is also conducted on commercial level (7.4%, $n = 68$). The human-induced changes together with increased unpredictability of seasonal weather, snow and ice conditions are also experienced to diminish opportunities for new nature-based livelihoods (Savukoski 10.3%; Jokkmokk 5.7%), especially in tourism: "Our mountain tours in spring and winter have been affected by the bad weather. – Partly we have had to cancel tours. A travel agency stopped cooperating with us after the forest company felled large areas around our base." (46-year-old man, Jokkmokk). These changes have a direct effect also on local people's seasonal experience and activities like winter sports (Savukoski 14.7%; Jokkmokk 17.1%). The vulnerability of tourism and reindeer herding under changing environment has been evidenced in numerous other studies of the region (Kaján 2014; Näkkäläjärvi et al. 2020; Rasmus et al. 2020b; Horne et al. 2021; Horstkotte et al. 2022b; Rosqvist et al. 2022). Furthermore, the most commonly mentioned adaptation measures, in both municipalities, are linked to the plight of nature-based livelihoods or activities (Savukoski 33.3%, $n = 48$; Jokkmokk 16.7%, $n = 30$). For example, people have reduced their catch in order to minimize effect on species populations, changed the location of activities to less affected areas, or adapted their practices. One reindeer herder refers to a new collectively initiated practice of reclaiming logging residues from forests as a response to forest harvesting and eutrophication caused by climate change which prevents reindeer from accessing food.

Anxiety over changes (Savukoski 7.4%, $n = 68$; Jokkmokk 20.0%, $n = 35$) and negative effects on nature experience such as enjoyment of the scenery, hiking, and relaxing in nature (Savukoski 17.6%; Jokkmokk 17.1%) reported by a number of respondents tell about the compound effects of numerous environmental changes and uncertainty of future. Anxiety is felt also by those who might not be otherwise affected: "They don't impact otherwise, but the bad feeling comes from the fact that people leave their mark on the landscape." (61-year-old respondent, Savukoski); "I worry more about children and grandchildren and their opportunities to find a meaningful existence in an increasingly desolate landscape." (72-year-old man, Jokkmokk). While some respondents state environmentally friendly attitude or behavioral change (Savukoski 6.3%, $n = 48$; Jokkmokk 16.7%, $n = 30$) such as increased respect for nature and greener choices in life—half of them exhibiting eco-anxiety-induced change (see, e.g., Kurth and Pihkala 2022)—others claim to simply persevere under the changes (Savukoski 8.3%; Jokkmokk 3.3%) and approximately a third of those who answered the question on adaptation (Savukoski $n = 48$; Jokkmokk $n = 30$) reported no adaptation measures. The urgency of experienced environmental changes due to their effects on human wellbeing has been increasingly reported in the Arctic (Nordic Council of Ministers 2014; Cunsolo Willox et al. 2015; AMAP 2021a).

In both municipalities, respondents recognize also positive impacts of the environmental changes, though not as frequently as negative ones. The most commonly reported positive effects are the benefits of changing seasonal weather conditions (Savukoski 39.5%, $n = 43$; Jokkmokk 31.8%, $n = 22$), such as milder winters, which, e.g., decrease the need of heating houses and removing snow, as well as the warmer, less rainy, and longer summers that respondents consider enjoyable. It is also noteworthy that a proportion of respondents (Savukoski, 7.0%; Jokkmokk, 4.5%) consider the forest, mining, and energy industry having positive effects in the municipalities, such as the planned mine in Jokkmokk providing employment and supporting the municipality economically. Similar local views on the impacts of extractive industries have been evidenced in other studies from Northern Fennoscandia and are seemingly competing with pro-environmental conservation views (Beland Lindahl et al. 2018; Kivinen et al. 2018; Komu 2019). Therefore, the level of concern about changing environment varies among the local community members while some worry about the ecological implications and others emphasize the economic opportunities that the changes are associated with.

Implications to future scientific inquiry and policy formulation

Respondents in the two municipalities perceived similar changes in the climate, bio-physical environment, and animal populations, many of which are reported also in other local-knowledge-based studies in Finland and Sweden (Horstkotte et al. 2017; Markkula et al. 2019; Ritchie et al. 2021). Instability and daily variability of weather as well as warming of winters has been reported Arctic wide by local populations (Weatherhead et al. 2010; Herman-Mercer et al. 2016; Ksenofontov et al. 2017, 2019; Wyllie de Echeverria and Thornton 2019; Sansoulet et al. 2020). Furthermore, icing events are a phenomenon that some locals perceive to have increased in frequency in Siberia, Russia, similarly to our findings (Terekhina and Volkovitskiy 2023). Respondents in both of our case study municipalities experience a changing forest landscape. Vegetation shifts, reducing the area of open sites, are observed in both municipalities, but differ to some degree due to differences in topography. Vegetation shifts are commonly perceived phenomenon also in Siberia, Russia, among local communities (Ksenofontov et al. 2019; Terekhina and Volkovitskiy

2023). Our respondents associate various changes in boreal forest habitats to changes in waterbodies, and abundance of lichen, wildlife, and birds—a link which many respondents have recognized. The most frequently mentioned changes in Savukoski and Jokkmokk have pronounced effects on local people's nature-based livelihoods, ranging from herding to nature tourism. Forest logging and other human pressure effects on fish and terrestrial animal populations and consequently local livelihoods are causing more concern in both municipalities than climate change effects on species—a finding in line with several other studies in the Arctic (Arctic Council 2016; Ksenofontov et al. 2019; Kårtveit 2021; Rasmus et al. 2021).

Our results support the calls to utilize community-based monitoring of environmental conditions to supplement scientific monitoring and policy formulation with more locally relevant, context-sensitive, and small-scale phenomena observations (Huntington et al. 2019; Wheeler et al. 2019; Sawatzky et al. 2020; Eicken et al. 2021). While most of the local perceptions of change and the scientific literature are in line with each other, it is noteworthy that some of the perceptions are on such a local scale that they cannot be observed with instrumented studies aimed at broader generalizations. Similar to other studies that combine local perceptions of change to scientific instrumented data of the same phenomena, we conclude that there is a partial but valuable correspondence between these ways of knowing (Soriano et al. 2017; Williams et al. 2018; Forbes et al. 2019; Anisimov et al. 2019). Our study shows that the following phenomena and their effects require further scientific enquiry: changes in river and lake ice conditions, ground frost extent in peatlands of Northern Scandinavia, water quality, and fish species refugia in small waterbodies, Nematocera populations, and berry production.

While the scientific and perception-based knowledge clearly complement each other, both operate on different premises (Ingold 2000), producing specific and inherently incomplete representations of "reality." As to perception-based knowledge, previous experiences and expectations affect how one perceives the present (Clark 2013; Marsh, 2007; Sambrook et al. 2021). In Savukoski, perceptions of winter snow cover and increasingly cold springs may be explained partly by the abnormal conditions of the past few years affecting people's perceptions. Also, the type of the phenomenon observed causes a bias in perception: some phenomena are more easily noticed than others (Howe et al. 2015; Anisimov and Orttung 2019). In our study, many frequently perceived changes are tangible or visible in the landscape or relevant to a person's livelihood activities. For instance, the very detailed and long-time frame observations of fish stock changes are observed by respondents engaged in fishing. This emphasizes the potential of local specialist knowledge but it also implies that some phenomena may be missed. In addition to perceptions describing the same direction of change, there were a few respondents that had contradictory observations. These differences are inherent in experience-based knowledge but do not discount the complexity and location-specificity of change.

Our respondents are nearly homogenous in their relationship to nature—most practice nature-based activities—and our statistical analysis of the relation between demographic variables and perceptions yielded no significant differences. Thus, we need to acknowledge that the various discourses documented in Finland and Sweden related to Lapland, northern nature, and natural resource usage (Andersson 1994; Valkonen 2003; Beland Lindahl et al. 2017) may underlie some of the perceptions. The effects of individuals' worldviews on their observations of the surrounding environment are well documented (Nickerson 1998; Lavie et al. 2004).

Our study design has three limitations in its examination of environmental change observations. Firstly, we are unable to determine the timing of changes that have been observed, because of the implicit temporal definition—change perceived during one's lifetime. It needs to be emphasized that the direction, magnitude, and existence of changes depend on the time scale. A more precise timing of changes would require in-depth interviews. Secondly, using an online survey to collect data limits the respondents to those with digital skills. This limitation is pronounced when drawing conclusions from the Jokkmokk results because Jokkmokk had no facilitated data collection and fewer respondents as Savukoski. Consequently, variety and level of detail of descriptions of changes are less and the absence of mentions of a change does not necessarily mean that the change would not be present in Jokkmokk. Thirdly, the spatial data on the locations of observed changes may reflect the areas which respondents are most familiar with—as is the case in many participatory mapping surveys (i.e., spatial discounting [see Brown et al. 2020])—and not spatial distribution of the change.

Local people have adapted to changes in the environment when necessary. They have made changes reactively or proactively especially in their nature-based activities and everyday habits. However, some of them do not feel that they can make a difference in face of the external pressures and simply persevere. In fact, from our survey responses, it is evident that the multiple pressures on the environment decrease local people's opportunities to diversify their income base and nature-based livelihoods and to enjoy nature, thus undermining local resilience. A study in the Canadian Arctic likewise demonstrates multiple environmental stressors and pre-existing societal and financial barriers that influence climate change adaptation and trade-offs between coping strategies on community level (Lede et al. 2021). The authors highlight that vulnerability to stressors and adaptation strategies also vary among community members, e.g., based on gender and livelihoods (Lede et al. 2021). Many respondents of our case study reported environmental changes and their impacts, but fewer reported adaptation strategies or changes in behavior. Need for and barriers to adaptation and behavioral change should be further studied within these communities. A concern over changes requires people to first perceive the change (Bieling 2013; Anisimov and Orttung 2019), which can lead to a sense of urgency and action. However, this has not been shown in our data. Our data shows emotional connection to the environment, anxiety over change but also a sense of discouragement.

Formulation of policies and adaptation measures that benefit local and indigenous populations are recognized as important for ensuring environmental justice and mitigation of socioeconomic and ecological risks (Nordic Council of Ministers 2014; Friedrich 2023). There is a vast literature on concerns and adaptation of reindeer herders to environmental changes (e.g., Lépy et al. 2018; Näkkäläjärvi et al. 2020; Rasmus et al. 2021). By looking at the wider communities' response to change, we can identify that the concerns are similar among non-reindeer herders. But contradicting views and priorities also exist in local communities: warming climate entails positive impacts to everyday life and extractive industries, usually experienced as detrimental to nature-based livelihoods, have their local supporters and beneficiaries. A study by SarkkiXX et al. (forthcoming) in Northern Finland emphasizes that herders feel that the responsibility to adapt is not solely on them, but also state-based support and genuine participation of locals in land use planning are needed in the face of multiple external pressures on the environment and local ways of life. These calls resonate with the grievances of our study communities over state-led forestry operations, hunting and fishing licensing to outsiders, and fisheries and water catchment management, which ought to engage seriously with local knowledge and concerns to achieve more socially sustainable and resilient resource management. Among these grievances, also shared priorities among the wider community may be found.

Conclusions

Our study of locally perceived environmental changes in two municipalities in northern Fennoscandia shows similarities in and the variety of changes driven by climate change and land use pressure. The studied communities are sparsely populated and according to our respondents, land use pressure is mostly external, not driven by local needs. Most perceived changes are in line with scientific knowledge, while certain change phenomena can currently be traced through local perception but not (yet) via scientific data thus requiring further scientific enquiry. Substantial contradictions between the sets of knowledge were not found. Locally relevant changes in climate, habitats, and animal populations are felt but these concerns do not always translate into adaptation strategies but discouragement. Thus, instead they call for policy implications. For many people, the most impactful changes are the direct human activities in the landscape rather than climate change. Together, these multiple changes undermine local resilience such as diversification of income sources. Therefore, it is paramount that local perceptions of change as well as experienced and anticipated impacts inform regional and national land use policies and adaptation strategies in order to support community adaptation.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10113-024-02241-4.

Acknowledgements The authors would like to thank all the respondents to our survey as well as the various people and organizations, which kindly assisted us in advertising the survey among the local communities in Savukoski and Jokkmokk. We also thank Elina Paulus for assisting in the data collection in Savukoski.

Author contribution Salla Eilola: conceptualization, methodology, investigation, formal analysis, visualization, writing—original draft, writing—review and editing; Tim Horstkotte: conceptualization, investigation, formal analysis, writing—review and editing; Bruce C. Forbes: funding acquisition, writing—review and editing; Joachim Otto Habeck: funding acquisition, conceptualization, writing—review and editing; Teresa Komu: conceptualization, writing—review and editing; Sirpa Rasmus: funding acquisition, conceptualization, writing—review and editing; Nora Fagerholm: funding acquisition, conceptualization, methodology, writing—review and editing.

Funding Open Access funding provided by University of Turku (including Turku University Central Hospital). This research was funded by the European Union's Horizon 2020 Research and Innovation Programme under grant agreement no. 869471 (CHARTER).

Data availability The data is openly available at https://doi.org/10.23729/a36fe438-f2e3-4649-b916-1e44bd12b953.

References

Ahlström A, Canadell JG, Metcalfe DB (2022) Widespread unquantified conversion of old boreal forests to plantations. Earths Future 10:e2022EF003221. https://doi.org/10.1029/2022EF003221

Åhman B, Rasmus S, Risvoll C, Eilertsen SM, Norberg H (2022) Large predators and their impact on reindeer husbandry. In: Reindeer husbandry and global environmental change: pastoralism in Fennoscandia. Taylor and Francis, pp 118–130. https://doi.org/10.4324/9781003118565-9

Alessa L, Kliskey A, Gamble J, Fidel M, Beaujean, G et al (2016) The role of Indigenous science and local knowledge in integrated observing systems: moving toward adaptive capacity indices and early warning systems. Sustain Sci 11:91–102. https://doi.org/10.1007/s11625-015-0295-7

AMAP (2017) Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. Arctic Monitoring and Assessment Programme (AMAP), Oslo. https://oaarchive.arctic-council.org/handle/11374/2105

AMAP (2021a) Arctic climate change update 2021: key trends and impacts - summary for policy-makers. Arctic Monitoring and Assessment Programme (AMAP). https://oaarchive.arctic-council.org/handle/11374/2621

AMAP (2021b) Human health in the Arctic 2021 - summary for policymakers. Arctic Monitoring and Assessment Programme (AMAP). https://oaarchive.arctic-council.org/handle/11374/2624

Andersson T (1994) Ideals and conceptions of forest: an experimental study of conceptual deliberation. Comm Cogn 27:397–428

Anisimov OA, Zhil'tsova EL, Shapovalova KO, Ershova AA (2019) Analysis of climate change indicators. Part 1. Eastern Siberia. Russ Meteorol Hydrol 44:810–817. https://doi.org/10.3103/S1068373919120033

Anisimov O, Orttung R (2019) Climate change in Northern Russia through the prism of public perception. Ambio 48:661–671. https://doi.org/10.1007/s13280-018-1096-x

Arctic Council (2016) Arctic resilience report. M Carson and G Peterson (eds). Stockholm Environment Institute and the Stockholm Resilience Centre, Stockholm. http://www.arctic-council.org/arr

Armitage D, Berkes F, Dale A, Kocho-Schellenberg E, Patton E (2011) Co-management and the co-production of knowledge: learning to adapt in Canada's Arctic. Glob Environ Chang 21:995–1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Beland Lindahl K, Sandström C, Sténs A (2017) Alternative pathways to sustainability? Comparing forest governance models. For Policy Econ 77:69–78. https://doi.org/10.1016/J.FORPOL.2016.10.008

Beland Lindahl K, Johansson A, Zachrisson A, Viklund R (2018) Competing pathways to sustainability? Exploring conflicts over mine establishments in the Swedish mountain region. J Environ Manage 218:402–415. https://doi.org/10.1016/J.JENVMAN.2018.04.063

Bélisle AC, Asselin H (2021) A collaborative typology of boreal indigenous landscapes. Can J for Res 51:1253–1262. https://doi.org/10.1139/cjfr-2020-0369

Bieling C (2013) Perceiving and responding to gradual landscape change at the community level: insights from a case study on agricultural abandonment in the Black Forest, Germany. Ecol Soc 18. https://doi.org/10.5751/ES-05590-180236

Brommer JE, Lehikoinen A, Valkama J (2012) The breeding ranges of Central European and Arctic bird species move poleward. PLoS ONE 7. https://doi.org/10.1371/journal.pone.0043648

Brown G, Reed P, Raymond CM (2020) Mapping place values: 10 lessons from two decades of public participation GIS empirical research. Appl Geogr 116:102156. https://doi.org/10.1016/J.APGEOG.2020.102156

Chan MN, Beaudreau AH, Loring PA (2019) Exploring diversity in expert knowledge: variation in local ecological knowledge of Alaskan recreational and subsistence fishers. ICES J Mar Sci 76:913–924. https://doi.org/10.1093/icesjms/fsy193

Christie P, Sommerkorn M (2012) RACER: rapid assessment of circum-arctic ecosystem resilience. WWF Global Arctic Programme. Ottawa. https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/4fwihbrx76_racer_handbook.pdf

Clark A (2013) Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav Brain Sci 36:181–204. https://doi.org/10.1017/S0140525X12000477

Cunsolo Willox A, Stephenson E, Allen J, Bourque F, Drossos A et al (2015) Examining relationships between climate change and mental health in the Circumpolar North. Reg Environ Change 15:169–182. https://doi.org/10.1007/s10113-014-0630-z

Donadi S, Degerman E, McKie BG, Jones D, Holmgren K et al (2021) Interactive effects of land use, river regulation, and climate on a key recreational fishing species in temperate and boreal streams. Freshw Biol 66:1901–1914. https://doi.org/10.1111/FWB.13799

Eicken H, Danielsen F, Sam JM, Fidel M, Johnson N et al (2021) Connecting top-down and bottom-up approaches in environmental observing. Bioscience 71:467–483. https://doi.org/10.1093/biosci/biab018

Elmhagen B, Kindberg J, Hellström P, Angerbjörn A (2015) A boreal invasion in response to climate change? Range shifts and community effects in the borderland between forest and tundra. Ambio 44:39–50. https://doi.org/10.1007/S13280-014-0606-8

Ferry B, Rune H, Andersson U, Green M (2020) Increasing numbers of wintering forest birds in Swedish Lapland 1986–2017 show stronger correlations with forest development than with local weather. Ornis Svec 30:13–30. https://doi.org/10.34080/os.v30.19633

Finnish Environmental Institute (2019) Suomen pintavesien ekologinen tila-arvio 2019 [Estimate of ecological state of Finland's surface waters]. Finnish Environmental Institute, Finnish Natural Resource Institute. https://www.syke.fi/fi-FI/Ajankohtaista/Suomen_vesien_tilaarvio_Jarvien_ja_jokie(51384)

Finnish Meteorological Institute (2022) Etelä-Lappi – merellistä ja mantereista ilmastoa [Southern Lapland – marine and continental climate]. Ilmasto-opas.fi. https://www.ilmasto-opas.fi/artikkelit/etela-lappi-merellista-ja-mantereista

Fjellborg D, Lindahl KB, Zachrisson A (2022) What to do when the mining company comes to town? Mapping actions of anti-extraction movements in Sweden, 2009–2019. Resour Policy 75:102514. https://doi.org/10.1016/j.resourpol.2021.102514

Flowerdew R, Martin DL (2005) Methods in human geography: a guide for students doing a research project. Routledge, London. https://doi.org/10.4324/9781315837277

Flynn M, Ford JD, Pearce T, Harper SL (2018) Participatory scenario planning and climate change impacts, adaptation and vulnerability research in the Arctic. Environ Sci Policy 79:45–53. https://doi.org/10.1016/j.envsci.2017.10.012

Forbes BC (1995) Tundra disturbance studies, III: short-term effects of Aeolian sand and dust, Yamal Region, Northwest Siberia. Environ Conserv 22:335–344. https://doi.org/10.1017/S0376892900034901

Forbes BC, Turunen MT, Soppela P, Rasmus S, Vuojala-Magga T et al (2019) Changes in mountain birch forests and reindeer management: comparing different knowledge systems in Sápmi, northern Fennoscandia. Polar Rec 55:507–521. https://doi.org/10.1017/S0032247419000834

Friedrich D (2023) Climate justice and intersectionality in the Arctic. Sibirica 22:5–32. https://doi.org/10.3167/SIB.2023.220102

González-Puente M, Campos M, McCall MK, Muñoz-Rojas J (2014) Places beyond maps; integrating spatial map analysis and perception studies to unravel landscape change in a Mediterranean mountain area (NE Spain). Appl Geogr 52:182–190. https://doi.org/10.1016/j.apgeog.2014.05.010

Gregow H, Vihma T (2012) IPCC-seminaari: Ilmastonmuutos vaikuttaa sään ääri-ilmiöihin myös Suomessa [IPCC Seminar: Climate change will affect extreme weather phenomena also in Finland]. In: Finnish Meteorological Institute. https://www.ilmatieteenlaitos.fi/tiedote/512877. Accessed 11 Jul 2023

Gregow H, Mäkelä A, Tuomenvirta H, Juhola S, Käyhkö J et al (2021) Ilmastonmuutokseen sopeutumisen ohjauskeinot, kustannukset ja alueelliset ulottuvuudet [Climate change adaptation policy, costs

and regional scope]. The Finnish Climate Change Panel, report 2/2021. https://doi.org/10.31885/9789527457047
Hein CL, Öhlund G, Englund G (2012) Future distribution of arctic char Salvelinus alpinus in Sweden under climate change: effects of temperature, lake size and species interactions. Ambio 41:303–312. https://doi.org/10.1007/S13280-012-0308-z
Herman-Mercer NM, Matkin E, Laituri MJ, Toohey RC, Massey M et al (2016) Changing times, changing stories: generational differences in climate change perspectives from four remote indigenous communities in Subarctic Alaska. Ecol Soc 21. https://doi.org/10.5751/ES-08463-210328
Hitomi MK, Loring PA (2018) Hidden participants and unheard voices? A systematic review of gender, age, and other influences on local and traditional knowledge research in the North. Facets 3:830–848. https://doi.org/10.1139/facets-2018-0010
Horne L, De Urioste-Stone S, Daigle J (2021) Climate change adaptation and mitigation in the face of local uncertainty: a phenomenological study. Northeast Nat (Steuben) 28:108–128. https://doi.org/10.1656/045.028.s1107
Horstkotte T, Utsi TAA, Larsson-Blind A, Burgess P, Johansen B et al (2017) Human–animal agency in reindeer management: Sami herders' perspectives on vegetation dynamics under climate change. Ecosphere 8. https://doi.org/10.1002/ecs2.1931
Horstkotte T, Heikkinen HI, Næss MW, Landauer M, Forbes BC et al (2022a) Implications of norms and knowledge in customary reindeer herding units for resource governance. In: Horstkotte T, Holand Ø, Kumpula J, Moen J (eds) Reindeer husbandry and global environmental change: pastoralism in Fennoscandia. Routledge, London, pp 133–149
Horstkotte T, Holand Ø, Kumpula J, Moen J (2022b) Reindeer husbandry and global environmental change: pastoralism in Fennoscandia. Routledge, London
Howe PD, Mildenberger M, Marlon JR, Leiserowitz A (2015) Geographic variation in opinions on climate change at state and local scales in the USA. Nat Clim Chang 5:596–603. https://doi.org/10.1038/nclimate2583
Huntington HP, Carey M, Apok C, Forbes BC, Fox S et al (2019) Climate change in context: putting people first in the Arctic. Reg Environ Change 19:1217–1223. https://doi.org/10.1007/s10113-019-01478-8
Ingold T (2000) The perception of the environment: essays in livelihood, dwelling and skill. Routledge, London
Ingold T, Kurttila T (2000) Perceiving the environment in Finnish Lapland. Body Soc 6:183–196. https://doi.org/10.1177/1357034X00006003010
IPCC (2019) Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change
Jaakkola L (2014) Can learning from the past help to predict the future in the environmental impact assessment on reindeer husbandry? PhD, University of Jyväskylä
Kaján E (2014) Arctic tourism and sustainable adaptation: community perspectives to vulnerability and climate change. Scand J Hosp Tour 14:60–79. https://doi.org/10.1080/15022250.2014.886097
Karjalainen P, Habeck JO (2004) When "the environment" comes to visit: local environmental knowledge in the far north of Russia. Environ Values 13:167–186. https://doi.org/10.3197/0963271041159877
Kårtveit B (2021) Green colonialism: the story of wind power in Sápmi. In: Sørly R, Ghaye T, Kårtveit B (eds) Stories of change and sustainability in the Arctic regions. Routledge, Abingdon, Oxon, pp 157–177
Karvonen A, Rintamäki P, Jokela J, Valtonen ET (2010) Increasing water temperature and disease risks in aquatic systems: climate change increases the risk of some, but not all, diseases. Int J Parasitol 40:1483–1488. https://doi.org/10.1016/J.IJPARA.2010.04.015
Kivinen S, Rasmus S, Jylhä K, Laapas M (2017) Long-term climate trends and extreme events in northern Fennoscandia (1914–2013). Climate 5. https://doi.org/10.3390/cli5010016
Kivinen S, Vartiainen K, Kumpula T (2018) People and post-mining environments: PPGIS mapping of landscape values, knowledge needs, and future perspectives in Northern Finland. Land (Basel) 7. https://doi.org/10.3390/land7040151
Kivinen S, Rasmus S (2015) Observed cold season changes in a Fennoscandian fell area over the past three decades. Ambio 44:214–225. https://doi.org/10.1007/s13280-014-0541-8
Komu T (2019) Dreams of treasures and dreams of wilderness – engaging with the beyond-the-rational in extractive industries in northern Fennoscandia. Polar J 9:113–132. https://doi.org/10.1080/2154896X.2019.1618556
Korhonen J (2006) Long-term changes in like ice cover in Finland. Nord Hydrol 37:347–363. https://doi.org/10.2166/nh.2006.019
Kröger AM (2018) The global land rush and the Arctic. In: Finger M, Heininen L (eds) The global arctic handbook. Springer International Publishing, pp 27–43
Ksenofontov S, Backhaus N, Schaepman-Strub G (2017) 'To fish or not to fish?': fishing communities of Arctic Yakutia in the face of environmental change and political transformations. Polar Rec 53:289–303. https://doi.org/10.1017/S0032247417000134
Ksenofontov S, Backhaus N, Schaepman-Strub G (2019) 'There are new species': indigenous knowledge of biodiversity change in Arctic Yakutia. Polar Geogr 42:34–57. https://doi.org/10.1080/1088937X.2018.1547326
Kullman L (2010) A richer, greener and smaller alpine world: review and projection of warming-induced plant cover change in the Swedish Scandes. Ambio 39:159–169. https://doi.org/10.1007/S13280-010-0021-8/FIGURES/11
Kumpula J, Siitari J, Siitari S, Kurkilahti M, Heikkinen J et al (2019) Poronhoitoalueen talvilaitumet vuosien 2016–2018 laidunninventoinnissa: Talvilaidunten tilan muutokset ja muutosten syyt. Natural resource institute of Finland
Kumpula J, Jokinen M, Siitari J, Siitari S (2020) Talven 2019–2020 sää-, lumi-ja luonnonolosuhteiden poikkeuksellisuus ja vaikutukset poronhoitoon. Natural Resource Institute of Finland
Kurth C, Pihkala P (2022) Eco-anxiety: what it is and why it matters. Front Psychol 13. https://doi.org/10.3389/FPSYG.2022.981814
Kuusela S, Annala M, Kontula T, Leikola N, Määttänen A-M et al (2022) Kohti kattavaa suojelualueverkostoa: Luonnon monimuotoisuuden turvaamisen painopisteet Suomessa. Reports of Finnish Environmental Institute, 18
Laapas M, Venäläinen A (2017) Homogenization and trend analysis of monthly mean and maximum wind speed time series in Finland, 1959–2015. Int J Climatol 37:4803–4813. https://doi.org/10.1002/joc.5124
Lam DPM, Hinz E, Lang DJ, Tengö M, von Wehrden H et al (2020) Indigenous and local knowledge in sustainability transformations research: a literature review. Ecol Soc 25. https://doi.org/10.5751/ES-11305-250103
Länsstyrelsen Norrbotten (2012) Klimatsammanställning-Fjällkedjan
Lavie N, Hirst A, De Fockert JW, Viding E (2004) Load theory of selective attention and cognitive control. J Exp Psychol Gen 133:339–354. https://doi.org/10.1037/0096-3445.133.3.339
Lede E, Pearce T, Furgal C, Wolki M, Ashford, G et al (2021) The role of multiple stressors in adaptation to climate change in the Canadian Arctic. Reg Environ Change 21:1–13. https://doi.org/10.1007/S10113-021-01769-Z/FIGURES/2
Lépy É, Pasanen L (2017) Observed regional climate variability during the last 50 years in reindeer herding cooperatives of Finnish fell Lapland. Climate 5:81. https://doi.org/10.3390/cli5040081
Lépy É, Heikkinen HI, Komu T, Sarkki S (2018) Participatory meaning making of environmental and cultural changes in reindeer herding

in the northernmost border area of Sweden and Finland. Int J Bus Glob 20:203–221. https://doi.org/10.1504/IJBG.2018.089868
Luomaranta A, Aalto J, Jylhä K (2019) Snow cover trends in Finland over 1961–2014 based on gridded snow depth observations. Int J Climatol 39:3147–3159. https://doi.org/10.1002/joc.6007
Markkula I, Turunen M, Rasmus S (2019) A review of climate change impacts on the ecosystem services in the Saami Homeland in Finland. Sci Total Environ 692:1070–1085. https://doi.org/10.1016/j.scitotenv.2019.07.272
Marsh EJ (2007) Retelling is not the same as recalling: implications for memory. Curr Dir Psychol Sci 16:16–20. https://doi.org/10.1111/j.1467-8721.2007.00467.x
Meredith M, Sommerkorn M, Cassotta S (2019) Polar regions. In: Pörtner H-O, Roberts DC, Masson-Delmotte V (eds) IPCC special report on the ocean and cryosphere in a changing climate. Cambridge University Press, Cambridge, UK and New York, NY, pp 203–320
Merkouriadi I, Leppäranta M, Järvinen O (2017) Interannual variability and trends in winter weather and snowconditions in Finnish Lapland. Est J Earth Sci 66:47–57. https://doi.org/10.3176/earth.2017.03
Metsähallitus (2022) Metsästys- ja kalastuslupien kysyntä ylitti tarjonnan useilla alueilla [The demand for hunting and fishing licenses exceeded the supply in several areas]. In: Press release. https://www.metsa.fi/tiedotteet/metsastys-ja-kalastuslupien-kysynta-ylitti-tarjonnan-useilla-alueilla/. Accessed 6 Mar 2023
Metsähallitus (2023) Suurpedot.fi [largecarnivores.fi]. In: Metsähallitus [Finnish state-owned forestry enterprise], Natural resource institute of Finland. https://www.largecarnivores.fi/. Accessed 7 Mar 2023
Minola L, Azorin-Molina C, Chen D (2016) Homogenization and assessment of observed near-surface wind speed trends across Sweden, 1956–2013. J Clim 29:7397–7415. https://doi.org/10.1175/JCLI-D-15-0636.s1
Mönkkönen M, Aakala T, Blattert C, Burgas D, Duflot R et al (2022) More wood but less biodiversity in forests in Finland: a historical evaluation. Memo Soc Fauna Flora Fenn 98:1–11. https://journal.fi/msff/article/view/120306
Myers-Smith IH, Kerby JT, Phoenix GK, Bjerke JW, Epstein HE et al (2020) Complexity revealed in the greening of the Arctic. Nat Clim Chang 10:106–117. https://doi.org/10.1038/s41558-019-0688-1
Näkkäläjärvi K, Juntunen S, Jaakkola JJK (2020) SAAMI – Saamelaisten sopeutuminen ilmastonmuutokseen -hankkeen tieteellinen loppuraportti [Scientific report of the Climate change adaptation of the Sámi -project]. Publications of the Prime Minister's Office, 2020/25. http://urn.fi/URN:ISBN:978-952-287-930-1
National Land Survey of Finland (2023) Statistics. [WWW Document] URL https://www.maanmittauslaitos.fi/tietoa-maanmittauslaitoksesta/organisaatio/tilastot Accessed 10 April 2023
Natural resource institute of Finland (2023a) Kalalajitilastot [Fish species statistics]. In: Tilastohakemisto. https://www.luke.fi/fi/tilastot/tilastohakemisto?sector=Kala&classification=. Accessed 6 Jul 2023
Natural resource institute of Finland (2023b) Luonnonvaratieto: hirvi [Natural resource database: moose]. In: Helsinki. https://luonnonvaratieto.luke.fi/kartat?panel=hirvi-ja-sorkkaelaimet&lang=en. Accessed 6 Mar 2023
Natural resource institute of Finland (2023c) Talvilaskenta: metsäkauris [Winter monitoring: roe deer]. In: Helsinki. https://www.riistakolmiot.fi/raportit/metsakauris/. Accessed 6 Mar 2023
Nickerson RS (1998) Confirmation bias: a ubiquitous phenomenon in many guises. Rev Gen Psychol 2:175–220. https://doi.org/10.1037/1089-2680.2.2.175
Nilsson AE, Carson M, Cost DS, Forbes BC, Haavisto R et al (2021) Towards improved participatory scenario methodologies in the Arctic. Polar Geogr 44:75–89. https://doi.org/10.1080/1088937X.2019.1648583
Nordic Council of Ministers (2014) Arctic human development report - regional processes and global linkages. TemaNord 2014:567. https://doi.org/10.6027/TN2014-567
Norrgård S, Helama S (2022) Tricentennial trends in spring ice breakups in three rivers in northern Europe. Cryosphere 16:2881–2898. https://doi.org/10.5194/tc-2021-326
Ocobock C, Turunen M, Soppela P, Rasmus S (2023) The impact of winter warming and more frequent icing events on reindeer herder occupational safety, health, and wellbeing. Am J Hum Biol 35. https://doi.org/10.1002/ajhb.23790
Official Statistics of Sweden (2022a) Folkmängden efter region, civilstånd, ålder och kön. År 1968 - 2022. [Population by region, marital status, age and sex. Year 1968 – 2022]. [WWW Document] URL https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__BE__BE0101__BE0101A/BefolkningNy/ Accessed 31 May 2023
Official Statistics of Sweden (2022b) Gästnätter per anläggningstyp efter region. År 2008 – 2021 [Guest nights per facility type by region. Years 2008 – 2021]. https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__NV__NV1701__NV1701A/NV1701T6Ar/?rxid=5f706427-062f-47ad-9b96-c71587348c0b. Accessed 9 Mar 2023
Päiviö NJ (2006) Sirkas sameby–om konsekvenser av beitekatastrofer [Sirka Sámi village – about the consequences of grazing disasters]. Ottar 1:10–17
Pöyry J, Aapala K (2020) Lajit ja luontotyypit muuttuvassa ilmastossa [Species and habitats in changing climate]. Reports of Finnish Environmental Institute, 2
Puro-Tahvanainen A, Aroviita J, Dubrovin T, Kämäräinen J-P, Marttunen M et al (2019) Inarijärven tilan kehittyminen vuosina 1960–2017 [The development of conditions in Lake Inari 1960–2017]. Centre for Economic Development, Transport and the Environment
Räinä P, Liljaniemi P, Puro-Tahvanainen A, Pasanen J, Rautiala A et al (2015) Kemijoen vesienhoitoalueen vesienhoidon toimenpideohjelma pinta- ja pohjavesille vuoteen 2021. Centre for Economic Development, Transport and the Environment of Lapland
Räinä P, Lindholm A, Pasanen J et al (2022) Kemijoen vesienhoitoalueen hoitosuunnitelma vuosille 2022–2027. Centre for Economic Development, Transport and the Environment of Lapland
Rantanen M, Karpechko AY, Lipponen A, Nordling K, Hyvärinen O et al (2022) The Arctic has warmed nearly four times faster than the globe since 1979. Commun Earth Environ 3:1–10. https://doi.org/10.1038/s43247-022-00498-3
Rasmus S, Kumpula J, Jylhä K (2014) Suomen poronhoitoalueen muuttuvat talviset sää-ja lumiolosuhteet [The changing winter weather and snow conditions in Finnish reindeer husbandry area]. Terra 126:169–185. https://terra.journal.fi/article/view/107056
Rasmus S, Kivinen S, Bavay M, Heiskanen J (2016) Local and regional variability in snow conditions in northern Finland: a reindeer herding perspective. Ambio 45:398–414. https://doi.org/10.1007/s13280-015-0762-5
Rasmus S, Kojola I, Turunen M, Norberg H, Kumpula J et al (2020a) Mission impossible? Pursuing the co-existence of viable predator populations and sustainable reindeer husbandry in Finland. J Rural Stud 80:135–148. https://doi.org/10.1016/j.jrurstud.2020.08.017
Rasmus S, Turunen M, Luomaranta A, Kivinen S, Jylhä K et al (2020b) Climate change and reindeer management in Finland: co-analysis of practitioner knowledge and meteorological data for better adaptation. Sci Total Environ 710:136229. https://doi.org/10.1016/j.scitotenv.2019.136229
Rasmus S, Wallen H, Turunen M et al (2021) Land-use and climate related drivers of change in the reindeer management system in Finland: geography of perceptions. Appl Geogr 134:102501. https://doi.org/10.1016/J.APGEOG.2021.102501

Rasmus S, Turunen M (2015) Suomen poronhoitoalueen lumiolosuhteet ja niiden vaikutukset poronhoitoon. Reports of Arctic Centre 62, University of Lapland

Rasmus S, Kivinen S, Irannezhad M (2018) Basal ice formation in snow cover in Northern Finland between 1948 and 2016. Environ Res Lett 13. https://doi.org/10.1088/1748-9326/aae541

Reyes-García V, García-del-Amo D, Benyei P, Fernández-Llamazares Á, Gravani K et al (2019) A collaborative approach to bring insights from local observations of climate change impacts into global climate change research. Curr Opin Environ Sustain 39:1–8. https://doi.org/10.1016/J.COSUST.2019.04.007

Riseth JÅ, Tømmervik H, Helander-Renvall E, Labba N, Johansson C et al (2011) Sámi traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. Polar Rec 47:202–217. https://doi.org/10.1017/S0032247410000434

Ritchie M, Frazier T, Johansen H, Wood E (2021) Early climate change indicators in the Arctic: a geographical perspective. Appl Geogr 135. https://doi.org/10.1016/j.apgeog.2021.102562

Rosqvist GC, Inga N, Eriksson P (2022) Impacts of climate warming on reindeer herding require new land-use strategies. Ambio 51:1247–1262. https://doi.org/10.1007/S13280-021-01655-2/FIGURES/13

Sajari P (2023) Lapista paljastui maailmanlaajuisesti merkittävä harvinaisten maametallien esiintymä [Globally important deposit of rare earth metals found in Lapland]. In: Helsingin Sanomat. https://www.hs.fi/talous/art-2000009395994.html. Accessed 3 Jul 2023

Sambrook K, Konstantinidis E, Russell S, Okan Y (2021) The role of personal experience and prior beliefs in shaping climate change perceptions: a narrative review. Front Psychol 12:669911. https://doi.org/10.3389/fpsyg.2021.669911

Sansoulet J, Therrien M, Delgove J, Pouxviel G, Desriac J et al (2020) An update on Inuit perceptions of their changing environment, Qikiqtaaluk (Baffin Island, Nunavut). Elementa 8. https://doi.org/10.1525/ELEMENTA.025/112324

Saura A, Kallasvuo M (2023) Kalat ja poikkeukselliset säät [Fish and exceptional weather conditions]. In: Natural resource institute of Finland. https://www.luke.fi/fi/ajankohtaista/teemat-ja-kampanjat/poikkeuksellisten-saiden-vaikutus-luonnonvaroihin/kalat-ja-poikkeukselliset-saat. Accessed 21 Aug 2023

Savukosken kunta (2022) Savukosken kuntastrategia 2022–2025 [Municipal strategy of Savukoski 2022–2025]. Savukoski

Sawatzky A, Cunsolo A, Jones-Bitton A, Gillis D, Wood M et al (2020) The best scientists are the people that's out there: inuit-led integrated environment and health monitoring to respond to climate change in the Circumpolar North. Clim Change 160:45–66. https://doi.org/10.1007/s10584-019-02647-8

Serreze MC, Barry RG (2011) Processes and impacts of Arctic amplification: a research synthesis. Glob Planet Change 77:85–96. https://doi.org/10.1016/j.gloplacha.2011.03.004

Shi J, Visschers VHM, Siegrist M (2015) Public perception of climate change: the importance of knowledge and cultural worldviews. Risk Anal 35:2183–2201. https://doi.org/10.1111/RISA.12406

SMHI (2015) Framtidsklimat i Norrbottens län – enligt RCP-scenarier. Klimatologi 32, The Swedish Meteorological and Hydrological Institute

SMHI (2023) Nollgenomgångar. The Swedish Meteorological and Hydrological Institute. https://www.smhi.se/klimat/klimatet-da-och-nu/klimatindex/nollgenomgangar-1.22895. Accessed 6 Jul 2023

SMHI (2024) Klimat – statistik, forskning och vägledning [Climate – statistics, research and guidance]. https://www.smhi.se/klimat. Accessed 10 Apr 2024

Soriano MA, Diwa J, Herath S (2017) Local perceptions of climate change and adaptation needs in the Ifugao Rice Terraces (Northern Philippines). J Mt Sci 14:1455–1472. https://doi.org/10.1007/s11629-016-4250-6

Stark S, Ylänne H, Kumpula J (2021) Recent changes in mountain birch forest structure and understory vegetation depend on the seasonal timing of reindeer grazing. J Appl Ecol 58:941–952. https://doi.org/10.1111/1365-2664.13847

Statistics Finland (2022) Population structure. [WWW Document] URL https://stat.fi/tilasto/vaerak Accessed 20 April 2023

Takakura H, Fujioka Y, Ignatyeva V, Tanaka T, Vinokurova N et al (2021) Differences in local perceptions about climate and environmental changes among residents in a small community in Eastern Siberia. Polar Sci 27. https://doi.org/10.1016/j.polar.2020.100556

Tengö M, Brondizio ES, Elmqvist T, Malmer P, Spierenburg M (2014) Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. Ambio 43:579–591. https://doi.org/10.1007/s13280-014-0501-3

Terekhina A, Volkovitskiy A (2023) Climate change through the eyes of Yamal reindeer herders. In: Ziker JP, Ferguson J, Davydov V (eds) The Siberian world. Taylor and Francis, pp 166–178. https://doi.org/10.4324/9780429354663

Turtiainen M, Salo K, Saastamoinen O (2015) Mustikka- ja puolukkasatojen talteenotto [Collention of bilberry and lingonberry yields]. In: Salo K (ed) Metsä: Monikäyttö ja ekosysteemipalvelut. Natural Resource Institute of Finland, Helsinki, pp 121–130

Turunen MT, Rasmus S, Bavay M et al (2016) Coping with difficult weather and snow conditions: reindeer herders' views on climate change impacts and coping strategies. Clim Risk Manag 11:15–36. https://doi.org/10.1016/j.crm.2016.01.002

Turunen J, Valpola S (2020) The influence of anthropogenic land use on Finnish peatland area and carbon stores 1950–2015. Mires and Peat 26. https://doi.org/10.19189/MAP.2019.GDC.STA.1870

Valkama J, Vepsäläinen V, Lehikoinen A (2011) Suomen III Lintuatlas [Third Finnish bird atlas]. Luonnontieteellinen keskusmuseo ja Ympäristöministeriö. https://atlas3.lintuatlas.fi

Valkonen J (2003) Lapin luontopolitiikka: analyysi vuosien 1946-2000 julkisesta keskustelusta [Nature politics of Lapland: analysis of public debate during 1946-2000]. PhD dissertation, University of Tampere

Van Bogaert R, Haneca K, Hoogesteger J, Jonasson C, de Dapper M et al (2011) A century of tree line changes in sub-Arctic Sweden shows local and regional variability and only a minor influence of 20th century climate warming. J Biogeogr 38:907–921. https://doi.org/10.1111/J.1365-2699.2010.02453.X

van Dorst RM, Gårdmark A, Svanbäck R, Beier U, Weyhenmeyer GA et al (2019) Warmer and browner waters decrease fish biomass production. Glob Chang Biol 25:1395–1408. https://doi.org/10.1111/GCB.14551

Verdonen M, Störmer A, Lotsari E, Korpelainen P, Burkhard B et al (2023) Permafrost degradation at two monitored palsa mires in north-west Finland. Cryosphere 17:1803–1819. https://doi.org/10.5194/TC-17-1803-2023

Weatherhead E, Gearheard S, Barry RG (2010) Changes in weather persistence: insight from Inuit knowledge. Glob Environ Chang 20:523–528. https://doi.org/10.1016/J.GLOENVCHA.2010.02.002

Wheeler HC, Berteaux D, Furgal C, Cazelles K, Yoccoz NG et al (2019) Identifying key needs for the integration of social–ecological outcomes in arctic wildlife monitoring. Conserv Biol 33:861–872. https://doi.org/10.1111/COBI.13257

Williams P, Alessa L, Abatzoglou JT, Kliskey A, Witmer F et al (2018) Community-based observing networks and systems in the Arctic: human perceptions of environmental change and instrument-derived data. Reg Environ Change 18:547–559. https://doi.org/10.1007/s10113-017-1220-7

Wilson GN, Allard C (2023) Institutional determinants of mining projects in Canada and Sweden: insights from the prosperity and Kallak cases. Environ Manage 72:53–69. https://doi.org/10.1007/S00267-022-01679-8

Wyllie de Echeverria VR, Thornton TF (2019) Using traditional ecological knowledge to understand and adapt to climate and biodiversity change on the Pacific coast of North America. Ambio 48:1447–1469. https://doi.org/10.1007/s13280-019-01218-6

Zachrisson A, Beland Lindahl K (2013) Conflict resolution through collaboration: preconditions and limitations in forest and nature conservation controversies. For Policy Econ 33:39–46. https://doi.org/10.1016/J.FORPOL.2013.04.008