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Climate change and reindeer management in Finland: Co-analysis of practitioner knowledge and meteorological data for better adaptation

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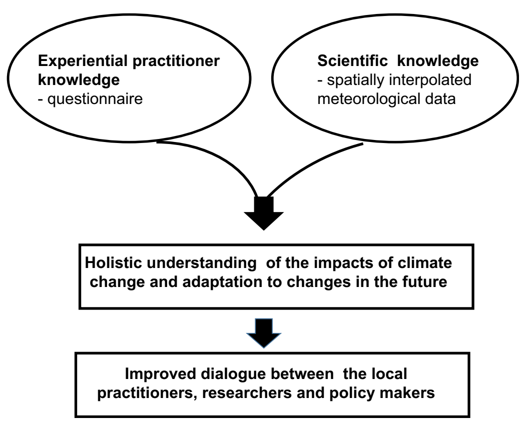
HIGHLIGHTS

- Systematically collected reindeer herder knowledge was combined to weather data.
- Practitioner knowledge was mainly in line with the long-term meteorological data.
- Changing seasonal climate affects reindeer condition and herding practices.
- Adaptation requires development of work practices and the governance of herding.
- Our approach can ease the dialogue between the practitioners and policy makers.

GRAPHICAL ABSTRACT



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ABSTRACT

We studied interannual variability and changes over time in selected climate indices in the reindeer management area (RMA) in northern Finland. We present together the knowledge possessed by reindeer herders with information from meteorological measurements over three decades. The practitioner knowledge was gathered via a survey questionnaire addressing herder observations of long-term changes (approximately during the past 30 years) in climatic conditions and their impacts on herding during the four seasons. A set of temperature-, precipitation- and snow-related indices relevant for herding within the RMA was derived from spatially interpolated daily meteorological data (1981–2010). Climatic changes detected based on the measurement data were mainly consistent with earlier studies, and practitioner knowledge was generally in line with the meteorological data. The herders had experienced the largest number of changes during the winter, and the smallest number of changes during the summer. The herders reported various impacts of changing seasonal weather on reindeer condition and behavior, and on herding practices. Adaptation to the changing conditions requires adoption of various coping strategies by the herders in their everyday work, continuous development of professional techniques and practices, as well as support received from the governance of reindeer management. We conclude that holistic understanding of the impacts of climate change and adaptation to changes in the future requires simultaneous analyses of data from different sources, more research co-defined with local practitioners, and co-

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planned governance solutions. The approach presented in this work can ease the dialogue between the local practitioners, researchers and policy makers.

1. Introduction

Knowledge sets gained outside the scientific communities such as *indigenous knowledge (IK)*, *traditional ecological knowledge (TEK)* or *practitioner knowledge* are often defined as contextual, local knowledge, typically passed on from one generation to the next, and often attributed to a particular ethnic group inhabiting a given area. This knowledge has been used as a basis for local level decision-making within a given livelihood and community (Agrawal, 1995; Ingold and Kurttila, 2000; Menzies and Butler, 2006; Berkes, 2008; Buchanan et al., 2016). Its use for scientific purposes has been criticized for lack of systematic approach to data collection, uncertainties and potential bias within the dataset, missing common terminology, and for being incommensurate with the spatial and temporal scales of observational data (Couzin, 2007; Monastersky, 2009; Alexander et al., 2011; Huntington, 2011). Nevertheless, during the 21st century, the value of local knowledge is being increasingly acknowledged, particularly in the sparsely populated areas where observational data may be scarce or seasonally biased and the time-series length insufficient (Couzin, 2007; Alexander et al., 2011; Huntington, 2011; IPCC, 2019).

Arctic and subarctic regions have shown significant warming trends during the recent decades (AMAP, 2017; Kivinen et al., 2017; IPCC, 2018; Marshall et al., 2018). Experiences of northern communities of changing climate have been collected in different parts of the circumpolar area (e.g. ACIA, 2004). Reindeer herders in northern Fennoscandia and Russia have extensive knowledge on weather. Weather conditions can strongly affect reindeer pastures, reindeer condition, reproduction, and mortality, and increase the workload and costs of reindeer husbandry (Heggberget et al., 2002; Kumpula and Colpaert, 2003; Helle and Kojola, 2008; Kumpula, 2012; Turunen et al., 2016). Herders thus need to continually monitor the grazing conditions during different seasons (e.g. Helle, 1984; Ryd, 2001; Eira et al., 2013).

Climate change, manifesting itself as long-term warming and changes in precipitation and snow conditions, is expected to have both positive and negative impacts on herding (Moen, 2008; Turunen et al., 2016). For example, on one hand, warmer early winters with varying temperatures and events like rain-on-snow (ROS) or thaw-freeze may lead to more frequent icing of snow and basal ice, which can hinder reindeer access to ground lichens (Rasmus et al., 2016, 2018; Eira et al., 2018). Warm autumns may also result in the growth of mycotoxin-producing microfungi (molds) below the snow in reindeer pastures (Kumpula et al., 2000; Rasmus et al., 2018). On the other hand, warmer winter weather can help reindeer keep fit, and early snowmelt and increased availability of fresh forage in spring are favorable for lactating reindeer and the new-born calves (Kumpula and Colpaert, 2003; Mårell et al., 2006; Helle and Kojola, 2008; Turunen et al., 2009; Tveraa et al., 2013). Warmer summers with increased precipitation may lead to more severe insect harassment and more frequent parasite epidemics (Soppela et al., 1986; Soppela, 2009; Laaksonen et al., 2007, 2010; Härkönen et al., 2010). Further, cold summers with heavy rains are considered harmful to young calves (Helle and Aspi, 1984; Helle and Kojola, 1994; Hagemoen and Reimers, 2002; Weladji et al., 2003; Turunen et al., 2016).

Both indigenous Saami and non-Saami Finns practice reindeer husbandry in Finland, unlike in Sweden and Norway where it is mainly an exclusive right of the Saami (Helle and Jaakkola, 2008; Soppela and Turunen, 2017). We consider the knowledge of herders as *practitioner knowledge* (Ingold, 2000). Practitioner knowledge widens the scope of IK or TEK to acknowledge the non-ethnic nature of knowledge gained in certain livelihoods by spending time on the land, developing skills, and evolving knowledge through practice and experience. Practitioner knowledge on reindeer and the environment possessed by the herders is acquired since childhood and passed on from one generation to the next (Forbes, 2006; Forbes and Stammler, 2009; Vuojala-Magga et al., 2011). Reindeer herders traditionally have various coping strategies to deal with adverse weather and pasture conditions. These strategies are based on context-situated learning where new knowledge about new situations and new practices adopted is accumulated and exchanged within the herding community (Turunen and Vuojala-Magga, 2014). Today, in the rapidly changing Arctic environments, unprecedented challenges related to adverse weather conditions may emerge, and no coping strategies operate for them exist thus far (Peltonen-Sainio et al., 2017; Eira et al., 2018).

In previous studies, collection of reindeer herder knowledge has been rather localized in space and time (Helander, 2004; Vuojala-Magga et al., 2011; Turunen et al., 2016; Jaakkola et al., 2018), systematic collection of herder knowledge for research purposes has been rare, and relating such local knowledge with scientific observations even rarer. We anticipate that relating practitioner knowledge of herders and meteorological measurements gives more in-depth understanding of the environmental changes in northern regions, also of aspects like experiences, impacts and coping. In this article, we examine the changes in climate conditions in the reindeer management area (RMA) in northern Finland during the past 30 years using knowledge of reindeer herders together with information originating from meteorological measurements. Rather than compare, nor validate either of the knowledge sets in detail, we aim at presenting the knowledge sets together to bring out the most important outcomes of both. We also review which coping strategies the herders use in their daily herding work and what kinds of governance level adaptation strategies exist. The objectives of this paper are to:

1) Study reindeer herder observations of changes in seasonal weather characteristics and their consequent impact on herding in forest and fell regions during the past 30 years.
2) Examine the inter-annual variability and changes over time of various climate indices relevant for herding, using high-resolution daily meteorological data covering approximately the same period;
3) Give an overview of the strategies to cope with difficult weather conditions, both from the viewpoint of everyday herding work and regarding policies that govern the reindeer management in Finland;
4) Discuss how these different knowledge sets can be used together, to create new understanding of the effects of climate change on the nature-based livelihoods, such as reindeer management, and to support decision-making on adaptation to climate change.

2. Materials and methods

2.1. Reindeer management area

In the Finnish reindeer management area (RMA) covering 36% of the country (Fig. 1, Supplementary text S1, Fig. S1 and Table S1), the semi-domesticated reindeer (*Rangifer tarandus tarandus*) has, in principle, a free grazing right. The RMA is divided into 54 herding districts, the organization and activities of which are guided by the Reindeer Husbandry Act (848/1990). The 21 northernmost districts

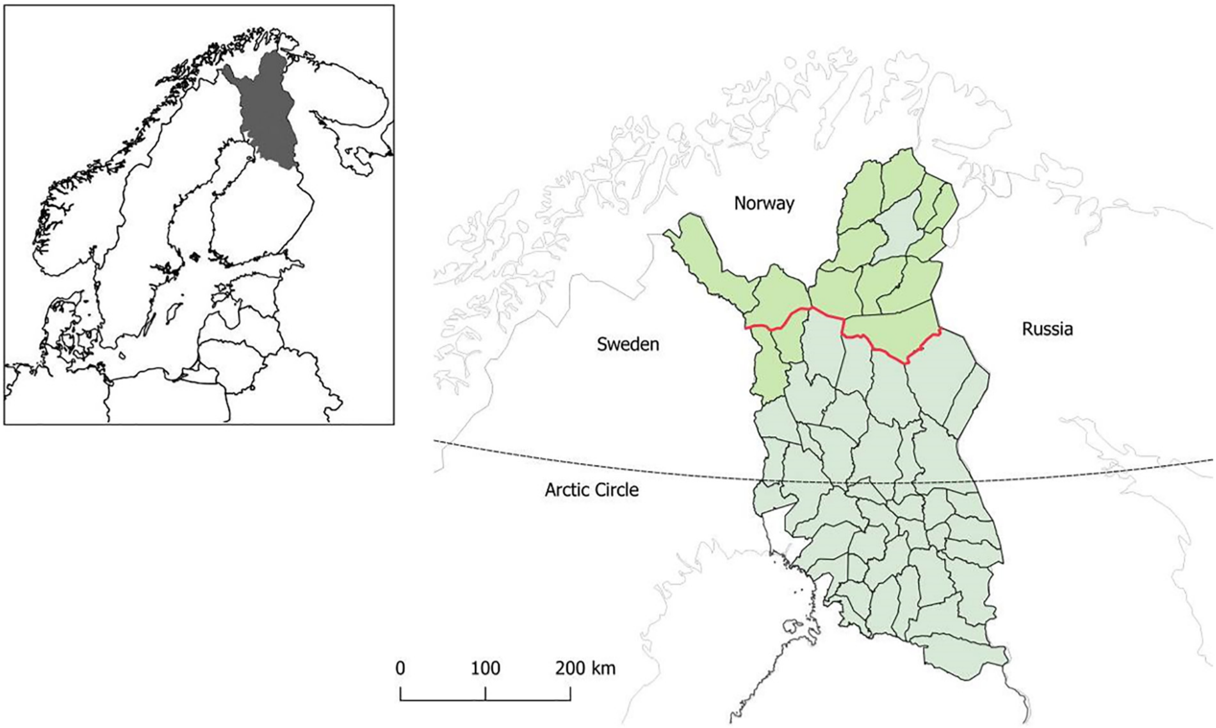

Fig. 1. The reindeer management area (RMA) of Finland. The thin black lines show borders of herding districts. Green and gray shading indicate fell and forest reindeer husbandry regions, respectively. The border between the regions generally follows the southern border of the Saami Homeland area in Finland (red line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

belong to an area specially intended for reindeer husbandry,[1] and 13 of these are located within the Saami Homeland area. The maximum allowed number of reindeer over one-year-old (the winter stock) is currently 203,700 within the whole RMA. About 100,000 calves are born in the spring, and 80,000 calves and 20,000 over one-year-old reindeer are slaughtered in the autumn (RHA, 2018).

We have divided the RMA into two major study areas, which differ from their environmental conditions, reindeer herding practices and culture: 1) forest reindeer husbandry region and 2) fell reindeer husbandry region (Fig. 1, Table 1). Forest reindeer husbandry region is situated within the boreal forest zone and fell reindeer husbandry region within the mountain birch woodland zone. The border between the forest and fell reindeer husbandry regions generally follows the southern border of the Saami Homeland area as well as southern timberline of spruce (Franke et al., 2015). In the Saami Homeland, reindeer herds are generally larger and herding is more commonly the main source of livelihood, whereas in southern districts, herding is traditionally more often combined with other livelihoods, particularly forestry and tourism (Soppela and Turunen, 2017; Jaakkola et al., 2018).

2.2. Survey on the practitioner knowledge possessed by reindeer herders

Practitioner knowledge of reindeer herders was gathered via a survey which was planned in collaboration with Metsähallitus, Reindeer Herders' Association, Finnish Environment Institute (SYKE), the University of Lapland and the University of Jyväskylä (see also Markkula et al., 2019). The survey was part of the assessment of threatened habitat types in Finland in 2018 (Pääkkölä et al., 2018). It was conducted in the form of a questionnaire using the Webropol survey tool. The survey was open from 13 October 2016 to 28 February 2017 (Supplementary text S2). The survey was distributed systematically to all herding districts through the information services of the Reindeer Herders' Association using its Internet page, Facebook page, electronic mailing list and the professional journal *Poromies* which, in theory, reaches every reindeer owner in Finland.

The questionnaire comprised of 26 arguments that addressed changes in climate on a seasonal basis and their impacts on herding during the past 30 years (approximately from the 1980s to the 2010s). Young herders who participated in the survey were instructed to consider the changes they had experienced during their whole life. The arguments were formulated using existing knowledge on projected climate change in northern Finland (e.g. Ruosteenoja et al., 2015, 2016) and knowledge of the impacts of weather conditions on reindeer well-being and herding (e.g. Vuojala-Magga et al., 2011; Turunen et al., 2016; Supplementary text S1). The arguments were formulated to express the changes generally associated with warming climate. Because of this, some framing effect cannot be ruled out.

The respondents were asked to express their level of agreement/disagreement with the arguments on a five-point scale, coded as follows: 1) I have observed a change in this feature into the direction of the argument 2) I have observed some change in this feature into the direction of the argument 3) I have not observed any change in this feature 4) I have observed some change in this feature, but into the opposite direction 5) I have observed a change in this feature, but into the opposite direction. Respondents also had the possibility to describe the observed changes and their impacts on herding in more detail in a free-form text field in the questionnaire.

For this study we define a person as a herder if he/she owns reindeer, practices herding either full-time or part-time, and earns at least part of the income through practicing herding - and most importantly, defines himself/herself as a herder. It is estimated that there are approximately 2000 active reindeer herders in Finland (RHA, 2018). A total of 90

[1] When referring to reindeer as a livelihood, we use the term "reindeer husbandry". "Herding" refers to day-to-day practices (and it also appears in the term "reindeer herding district"), whereas husbandry considers reindeer as a resource and is related e.g. to the profits, breeding, and social mechanisms. "Reindeer management" is related to all of the practices pertaining to the keeping of reindeer, including governance (Forbes, 2006).

Table 1
Main characteristics of fell and forest reindeer husbandry regions.

	Fell reindeer husbandry region	Forest reindeer husbandry region
Vegetation zone[a]	Mountain birch woodland, treeless heaths, boreal forest (Scots pine)	Boreal forests (Scots pine, Norway spruce)
Total area (km^2)[b]	37,221	85,600
Climate		
Mean annual temperature (°C)[c]	−1.3	0.3
Mean annual precipitation (mm)[c]	486	581
Mean maximum snow depth (cm)[c]	86	85
Reindeer management		
Number of reindeer[b]	82,745	115,576
Number of reindeer owners[b]	1383	3047
Reindeer/owner[b]	70.4	37.4
Supplementary winter feeding[d]:		
-in enclosures (% of reindeer)	8.5	76.5
-in the field or to support herding (%)	65.2	17.4
-no supplementary winter feeding (%)	26.4	6.1
Pasture rotation in use (% of districts)[d]	100	21

[a] Oksanen and Virtanen (1995) and Virtanen et al. (2016).
[b] During a herding year 2016–2017; approximately one third of reindeer owners are women, and 10–15% are under-aged (RHA, 2018), reindeer owners belonging to these groups are less involved in the daily practices of herding.
[c] During 1981–2010 (Pirinen et al., 2012).
[d] During 2004–2015 (RHA, 2018).

reindeer herders from 42 herding districts responded to the survey. This gives us a response rate of 4.5%.

Responses were received from nine out of 14 districts of the fell reindeer husbandry region (henceforth fell districts), and from 33 out of 40 districts of the forest reindeer husbandry region (henceforth forest districts). About 44% of respondents had herding as their full-time job and 56% as a part-time job. The average age of respondents was 51 years. Based on the age distribution of respondents, we estimate that at least 80% of the respondents have at least 30 years of experience on practicing the livelihood. Respondents gave altogether 160 in-depth descriptions of the seasonal weather changes (41 for summer, 39 for autumn, 36 for winter and 44 for spring) and 194 descriptions of consequent effects on herding (46 for summer, 47 for autumn, 50 for winter and 51 for spring).

The reindeer herder responses were analyzed separately for the fell and forest districts in Fig. 1. We classified the replies as agreements (values 1–2; change observed into the direction of the argument), neutrals (3; no change observed) and disagreements (values 4–5; change observed into opposite direction). The key findings of the study are presented in the form of maps, while more detailed results are shown as column charts in the Supplementary material (Figs. S2–S9).

Adaptation actions performed in response to climate changes were not explicitly addressed by the survey, but, in their free-form comments, many respondents explained the coping strategies they had adopted in their everyday herding work (altogether 62 references). The free-form comments are presented in full in the Supplementary material (Tables S2–S9) and some excerpts of this material are presented in this article to illustrate the effects of the ongoing climate change on the nature-based livelihoods from a more holistic perspective.

2.3. Climate indices

Alongside analyses of the herder observations and perceptions, a suite of seasonal and annual climate indices were calculated on the basis of information from meteorological measurements during the period 1981–2010. A total of 14 temperature-, precipitation- and snow-related indices relevant for reindeer herding were considered (Table 2). Three of the indices (ID, R1d, RR10) belong to the core set of extreme indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI; e.g. Sillmann et al., 2013). The snow-related indices were selected from a set of indices examined by Luomaranta et al. (2019). The indices for prolonged warm and wet periods (Warm1w and Wet2w) were originally defined by Peltonen-Sainio et al. (2016a) and used in studies on weather risks in agriculture (Peltonen-Sainio et al., 2016b, 2016c).

For calculating the indices, seasons were defined as JJA (summer), SON (autumn), DJF (winter) and MAM (spring). The number of rainfall days (Rain-d) was set equal to the number of wet days having daily minimum temperature equal to or above zero. When the number of rain-on-snow days (ROS-d) was calculated, a condition of at least 1 cm snow depth was added to this definition. In northern Finland, the day is generally regarded as hot if the daily mean temperature is higher than 20 °C, and cold if it is lower than −25 °C. The number of hot days (Hot-d) and cold days (Cold-d) were defined accordingly (Table 2).

The climate indices were derived from FMIClimGrid, a daily gridded climate dataset covering Finland with a spatial resolution of 10 km × 10 km (Aalto et al., 2016). The dataset consists of daily values of seven climate variables, of which five were used in the present study: minimum, maximum and mean temperature, precipitation and snow depth (Table 2). FMIClimGrid is based on weather observations at meteorological stations in Finland and the neighboring countries (i.e., Sweden, Norway, Russia and Estonia). A kriging interpolation method was used for the gridding procedure (Matheron, 1963; Goovaerts, 1999). The effects of the geographical location of the weather stations, topography and water bodies (sea and lake effects) were taken into account in the interpolation routine used by Aalto et al. (2016). The uncertainties in the dataset were related to spatiotemporal inconsistencies in the station network, the incomplete sample of background data used as external predictors, inhomogeneity in the observation data, and the sensitivity of the interpolation model parameters. The dataset is fully documented in Aalto et al. (2016).

The climate indices are presented in this paper as 1) time series showing annual values calculated separately for the fell and forest districts, 2) maps showing the mean values (in Supplementary material), and 3) maps showing the temporal trend values for selected indices at 10 km resolution within the RMA. The trends in indices were calculated using the non-parametric Sen's slope method. The statistical significance of the trends was calculated using the Mann-Kendall trend test. These methods are generally considered as robust and reliable, except that in the case of rare events, the trend may appear significant even though it is, in practice, nonexistent. We also calculated the standard deviations of yearly values of annual and seasonal climate indices and compared these to time-mean average changes per decade in the regions of RMA where the trends were statistically significant. The purpose of this comparison was to support our interpretations regarding the questionnaire survey results (for a human observer it may be difficult to separate the possible change in a variable from interannual variation, when the standard deviation is of the same magnitude or larger than the decadal trend). Some of the indices corresponded directly to the arguments presented in the questionnaire survey, whereas other indices were rather discrete or stand-alone ones. Some of the arguments

Table 2
Climate indices calculated from the FMIClimGrid dataset for daily mean temperature (Tmean), daily maximum temperature (Tmax), daily minimum temperature (Tmin), daily precipitation sum (Prec) and snow depth (SN). The indices have been calculated for a 3-month season, unless marked with an asterisk (annual values used).

Index	Description	Unit	Season
Temperature			
Hot-d	Days with Tmean >20 °C	Nr of days	ANN
DD	Degree day sum for Tmean >5 °C	°C days	ANN
Cold-d	Days with Tmean < −25 °C	Nr of days*	ANN
ID	Days when Tmax ≤0 °C	Nr of days	SON, DJF, MAM
Zero	Zero-crossing days: Tmin <0 °C and Tmax >0 °C	Nr of days	SON, DJF, MAM
Warm1w	Periods of seven consecutive days with Tmean ≥ Tsea[a] +3 °C, and in at least six of them Tmean ≥ Tave[b] + 3 °C	Nr of periods	JJA, SON, DJF, MAM
Precipitation			
Rain-d	Days when Prec ≥1 mm and Tmin ≥0 °C	Nr of days	JJA, SON, DJF, MAM
R1d	Largest daily precipitation	mm/day	JJA
RR10	Days with Prec ≥10 mm	Nr of days	JJA
Wet2w	Periods with Prec2w[c] ≥ Pmon[d] and at least seven days with Prec ≥0.5 mm and at maximum two consecutive days with Prec <0.5 mm	Nr of periods	JJA
ROS-d	Days when Prec ≥1 mm, Tmin ≥0 °C and SN ≥ 1 cm	Nr of days	SON, DJF, MAM
Snow			
BEG	Snow cover formation date	Date*	ANN
SOD	Snow cover melt day, first snow free day after the winter maximum snow depth	Date*	ANN
MaxSN	Annual maximum snow depth	cm*	ANN

[a] Tsea = climatological mean temperature of a season.
[b] Tave = mean temperature of a 30-day period (moving average).
[c] Prec2w = precipitation sum during a 2-week period.
[d] Pmon = climatological monthly mean precipitation sum.

of the survey were difficult to translate into climate indices (e.g. more frequent mold/ice layer formation).

3. Results

Mean climatic conditions vary considerably within the RMA (Figs. S10–S13). Climate indices show also remarkable interannual variability, both in fell and forest districts (Figs. S14–S17). In this section, we present the changes in the seasonal weather as experienced by the herders, and as manifested through the climate indices calculated for the RMA for the period from 1981 to 2010. We start from the summer season, following the seasonal cycle in reindeer life and herding (Table S1 and Fig. S1). Also, the reindeer herder observations of the effects of these changes on herding practice are described. See Table 3 for the summary of the survey results and Supplementary material (Figs. S2–S9; Tables S2–S9) for further details not shown here.

3.1. Summer – warmer or wetter?

3.1.1. Herder experiences and meteorological observations of summer climate

In the questionnaire survey, nearly 80% of the herders reported that summer precipitation has increased, and over 70% reported that heavy rains have become more common. Instead, the herders had not generally observed any particular changes in the summer temperatures, although some divergent views on warming and more frequent heat periods were expressed (Table 3, Table S2). Present-day summers were perceived as warmer than before in some districts in the southern and northwestern parts of the RMA (Fig. 2a). The majority of the herders reported having observed greater variability in summer weather. They noted that variation in the summer temperature and precipitation is large not only interannually but also within the season. The views of the herders of the fell and forest districts concerning the changes in summer weather were mostly similar to each other.

Statistically significant increasing temporal trends in the annual number of hot days (Hot-d) were detected rather widely in the southern part of the RMA (Fig. 2b). In these regions, the increase was 1–1.5 days per decade and, on the other hand, the standard deviation of yearly values was 2–6 days. In only four districts located within these regions, a majority of respondents reported about warming summers (Fig. 2a). The annual degree day sum (DD) has significantly increased all around the RMA (Fig. 3b), most strongly in the southern and central RMA where the trend was 80–100 days per decade, the standard deviation being 110–130 days or locally more. This is not only related to warmer summers, but also to the lengthening of the growing season.

All precipitation indices had remarkable interannual and spatial variability (shaded areas in the Fig. S14). The number of rain days (Rain-d) increased significantly (by 4–6 days per decade) in some rather localized areas only (Fig. 4). In these areas the standard deviation of Rain-d was 3–5 days. Indices related to the heavy precipitation events also showed increasing trends in some northern locations: 3–6 mm per decade for the largest daily precipitation (R1d; Fig. 5a) and approximately 1 day per decade for the number of heavy precipitation days (RR10; Fig. 5b). The corresponding standard deviations for R1d and RR10 were mainly 5–10 mm and 3–4 days, respectively. For R1d, decreasing trends occurred in the southern areas, locally −2 to −4 mm per decade, standard deviation being 5–10 mm and locally up to 15 mm.

3.1.2. Effects of the changes in the summer climate on herding

According to the free-form comments of the herders of the fell districts (Table S6 in Supplementary material), a cold and rainy summer is worse for herding than a dry and warm one. Delayed and poor development of vegetation can have negative impacts on milk production of dams and growth of calves. A rainier but warmer and longer growing season may increase the growth of vegetation and availability of high-quality forage, e.g. mushrooms, for reindeer. On the other hand, rainy summers, wet ground and flooding rivers can make gathering and moving reindeer to the round-up sites with terrestrial vehicles more difficult. Interestingly, lack of insect harassment, which is dependent on temperature and precipitation, can hamper reindeer moving to the round-up sites. Only 11% of the respondents had not observed any impacts of changes in the summer weather on herding so far.

The herders of the forest districts reported that collecting and moving reindeer to the calf-marking round-up sites has become more difficult, because due to, e.g. short heat periods and lack of insect harassment, reindeer do not gather into herds as early as they

Table 3
A summary of the survey results. Agreements, i.e., changes observed into the direction of the argument (median values 1–2) are bolded. Percentages of responses with values 1–2 (change observed into the direction of the argument), 3 (no change observed) and 4–5 (change observed into opposite direction) are also given. NA means missing answers; no answers were missing from the fell districts. The category including the majority of the responses is shaded.

	Fell districts; n=18				Forest districts; n=72				
	Median	1-2 (%)	3 (%)	4-5 (%)	Median	1-2 (%)	3 (%)	4-5 (%)	NA (%)
SUMMER									
Increased precipitation	**1**	78	22	0	**2**	78	21	0	1
More frequent heavy rainfalls	**1**	72	28	0	**2**	74	25	0	1
More variable weather	**2**	72	28	0	**2**	83	17	0	0
More frequent sleet or hail precipitation	3	28	61	11	3	25	68	6	1
Warmer summers	3	39	33	28	3	21	61	17	1
More rare cold periods	3	22	56	22	3	22	58	17	3
More frequent heat periods	3	22	56	22	3	17	57	25	1
More frequent droughts	3	28	61	11	3	17	57	26	0
AUTUMN									
Delayed frost season	**1.5**	78	22	0	**2**	83	17	0	0
Delayed soil frost	**2**	78	22	0	**2**	72	15	0	3
Delayed snow cover formation	**1**	72	22	6	**2**	82	14	4	0
Less soil frost	**2**	67	33	0	**2**	76	22	0	1
More frequent mold formation on the pastures	3	44	56	0	**2**	68	29	0	3
Increased precipitation	3	39	50	11	**2**	58	39	1	1
WINTER									
Warmer winters	**1.5**	94	6	0	**2**	89	8	1	1
Decreased number of frost days	**2**	94	0	6	**2**	89	11	0	0
More variable weather	**2**	67	33	0	**2**	90	10	0	0
More snow-loads on trees	**1**	72	28	0	**2**	74	25	0	1
More frequent rainfalls	**2**	67	33	0	**2**	79	18	1	1
Increased windiness	**2**	56	44	0	**2**	78	22	0	0
More frequent formation of icy layers in the snow cover	2.5	50	50	0	**2**	85	14	1	0
More frequent formation of basal ice in the snow cover	2.5	50	44	6	**2**	75	25	0	0
Deeper snow	3	44	44	11	3	29	56	15	0
SPRING									
Earlier start of the growing season	**2**	72	28	0	**2**	78	19	1	1
Earlier snow melt and earlier snow-free patches	**2**	72	17	11	**2**	75	24	1	0
Earlier discontinuation of the frost season	**2**	67	11	22	**2**	83	15	0	1

did before. Many herders also pointed out that lack of long dry periods in the summer has led to difficulties in producing hay for supplementary winter feed for reindeer, and that hay is of worse quality than earlier. Some herders had observed that reindeer in the forest districts are in any case doing better due to lack of long heat periods and weaker insect harassment: "*Cool summer has helped reindeer keep fit… The heat periods have been relatively short.*" Some of the herders held the view that the changing summer weather is insignificant for reindeer herding.

3.2. Longer and warmer autumn?

3.2.1. Herder experiences and meteorological observations of autumn climate

The herder views on delayed frost season in autumn and its consequent impacts on snow and ice phenomena are rather unanimous (Table 3, Table S3). Herders of the fell and forest districts had experienced a delayed onset of the frost period (subzero temperatures), later formation of the ground frost as well as ground frost being

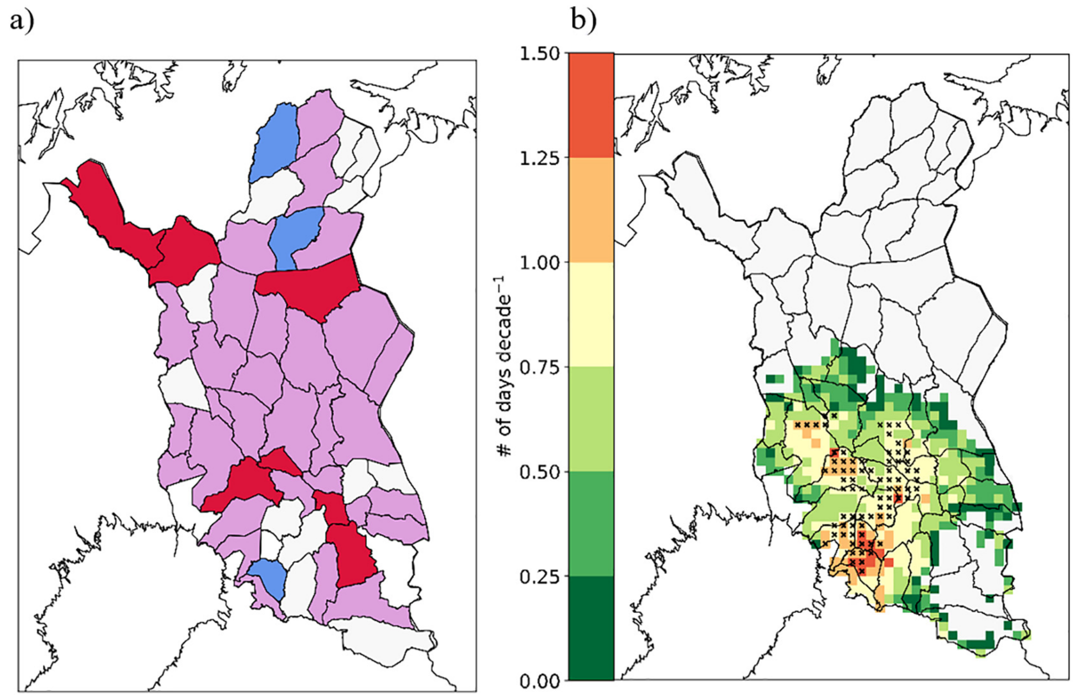

Fig. 2. a) Median values of answers by district to the argument "Summers are warmer than before" in the survey targeted to reindeer herders. Violet = no change observed (median 2.5–3.5); red = change/some change observed into the direction of the argument (median < 2.5); blue = change observed into the opposite direction (median > 3.5); white = missing data. b) The change in the annual number of hot days (Hot-d) per decade within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

shallower than before, and later formation of the snow cover. Experiences of autumn precipitation changes differed regionally. About 58% of the herders of the forest districts and only 39% of herders of the fell districts had observed increased precipitation in autumn. As many as 68% of the herders of the forest districts had observed increased formation of mold in the vegetation compared to 44% of the herders of the fell districts.

Meteorological data for 1981–2010 showed a tendency towards later snow cover formation dates, but the trends in BEG were significant only in some northern parts of the RMA (Fig. 6), locally 4–7 days per decade. In the same areas the standard deviation was 5–15 days. The number of ice days (ID) declined in the whole RMA, but the trend was not significant during the study period. Further, the number of zero-crossing days (Zero) and the number of rain-on-snow days (ROS-d), the indices considered among the main drivers of formation of icy foraging conditions, did not change significantly during the study period. It is nevertheless clear that there was large annual variability in the values of these indices (Fig. S15), and their number alone could not describe the occurrence of conditions favoring ice formation on the ground and the severity of icing on reindeer pastures.

3.2.2. Effects of the changes in the autumn climate on herding

According to the free-form comments of the herders of the fell districts (Table S7 in Supplementary material), reindeer, particularly calves, benefit from late formation of the snow cover through higher availability of forage. Herders of the fell districts also reported that variable and warm autumn weather may delay the timing and impair the intensity of the rut. Round-ups may be delayed even until January, and reindeer need to be collected and moved to the round-up sites by terrestrial vehicles instead of snowmobiles due to lack of snow or thin snow cover. Some herders of the fell districts pointed out that the need for supplementary winter feeding has increased due to an increased risk of poor digging conditions (risk of icing of the snow cover).

The herders of the forest districts reported that, due to warm autumn weather, reindeer stay longer in summer pastures. Foraging conditions in autumn have deteriorated because the frosts arrive later than before, soil does not freeze before the snow comes, mold may be formed on the vegetation and if it rains there is a risk of basal ice formation on the soil. Because of poor foraging conditions, reindeer may start roaming and the herds are dispersed, which may make the gathering of the herds difficult and delay the round-ups. Also, the rut can be weaker and delayed. Use of terrestrial vehicles (ATVs) has increased due to lack of frost periods and snow, and their period of usage has been extended. Lack of or a weak ice cover on the waterbodies and mires may increase the risk of reindeer drowning when they are moved to the round-up sites. Herders also reported that supplementary feeding needs to be started earlier in some regions than before. Reindeer tend to move to familiar feeding places and enclosures much earlier than 20–30 years ago. Furthermore, in particular the herders from the southernmost districts noted that warmer autumns have increased the occurrence of new parasites, such as the deer ked, (*Lipoptena cervi*), which worsens the condition of the reindeer. One herder pointed out that warm and moist autumn weather makes the reindeer more susceptible to diseases.

3.3. Warmer and wetter winters?

3.3.1. Herder experiences and meteorological observations of winter climate

The respondents were rather unanimous in their views of most of the arguments about the changes in winter climate presented in the survey (Table 3; Table S4). The herders from both the fell and the forest districts reported that winters have become warmer and the number of subzero days has decreased. The majority of the herders also reported that rainfalls during the winter have become more frequent. The argument about increased snow depth yielded somewhat divergent responses (Table 3). Many of the herders had not observed

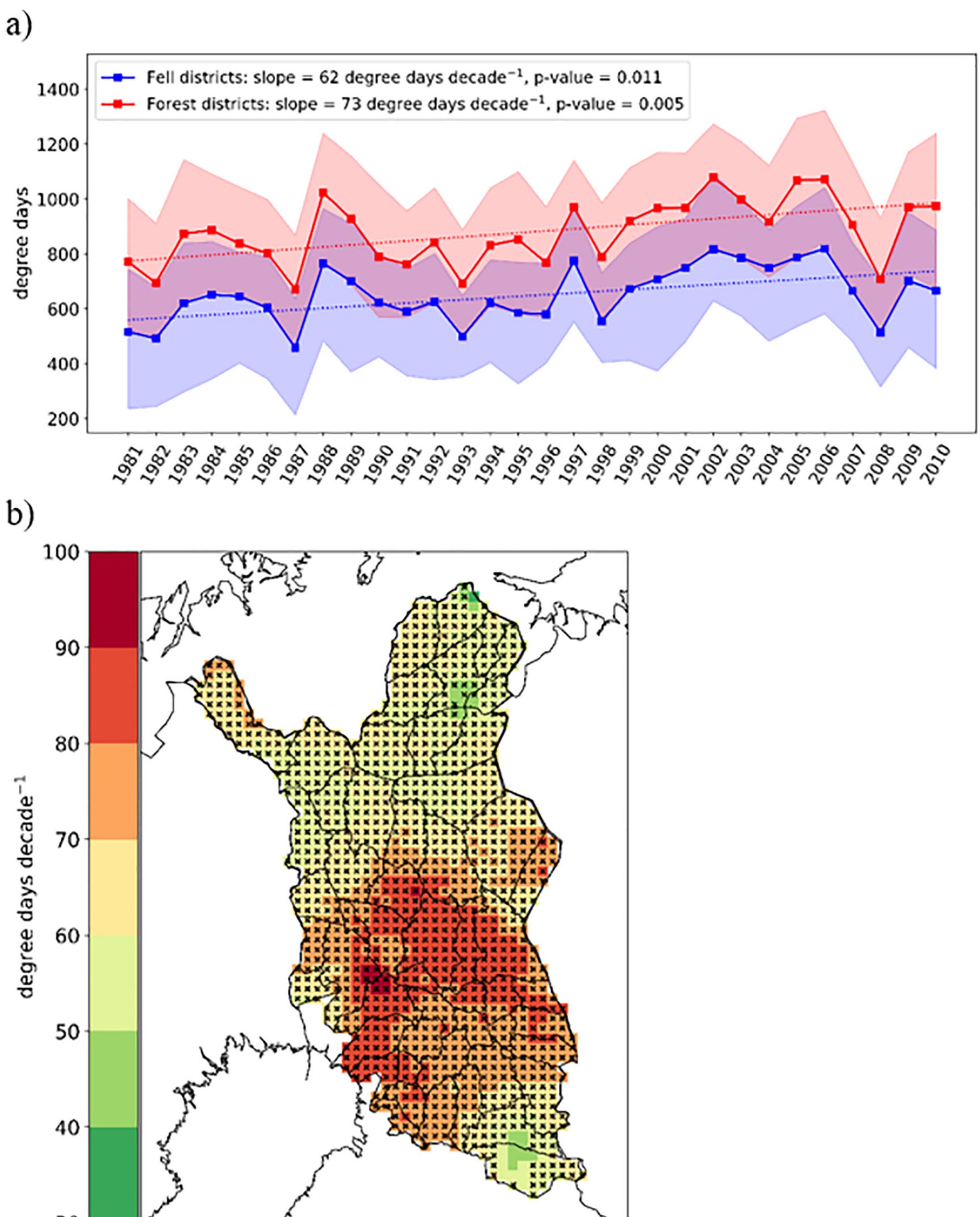

Fig. 3. a) The annual degree day sum (DD) as a function of time in fell and forest districts during 1981–2010, indicating significant increasing trends. The dots depict spatial averages and the shaded areas show the ranges (the highest and lowest annual values) across the grid boxes of the regions. b) The change in DD within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks.

changes in snow depth during the study period. However, deeper snow covers had been recently experienced in the northern part of the RMA in particular (Fig. 10a). The herders also pointed out that accumulation of snow and hard rime loads on tree branches ("*tykky*") has increased. The herders from the forest districts in particular reported that winters have become windier. They had also observed that winter weather has become more variable and that the formation of icy layers within the snow cover and basal ice has become more common (Table 3).

According to the indices calculated from the meteorological data, winter warming was evident in the whole of the RMA. The number of warm weeks (Warm1w) has increased (Fig. 7) in large areas, most strongly in the southern and central parts of the RMA (about 1 week per decade). The standard deviation in these areas was 1.5–2.5 weeks. The number of cold days (Cold-d) has decreased in parts of the RMA 2–4 days per decade (Fig. 8), standard deviation in these parts being mainly 6–10 days. There were also local increases in the number of rain days (Rain-d); most notably in the southern part of the area (Fig. 9) where the trend was 1–2 days per decade and standard deviation was 1–2 days. Annual maximum snow depth (MaxSN) had a decreasing trend of 5–10 cm per decade, or locally more, in the northern part of the RMA (Fig. 10b). The

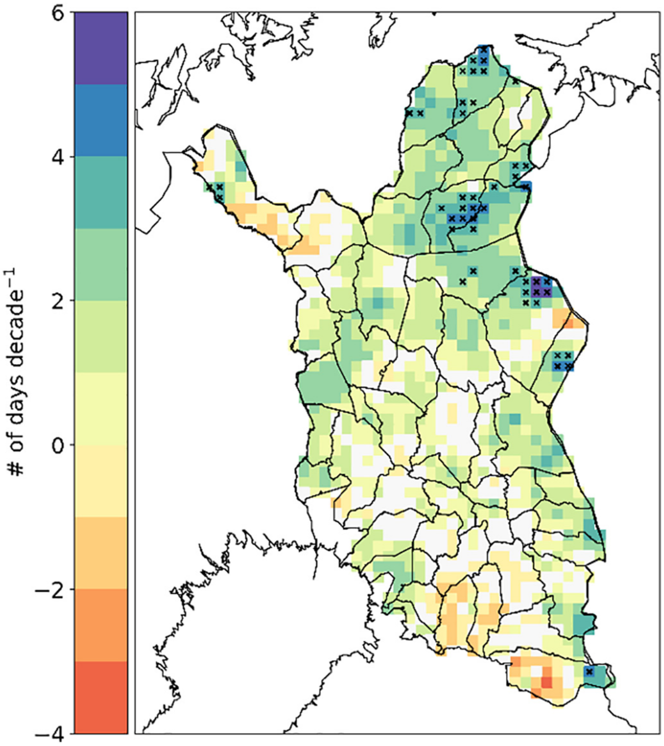

Fig. 4. The change in the number of rain days (Rain-d) in the summer season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

standard deviation of MaxSN in these regions was 10–20 cm. The region where the herders reported deeper snow covers (Fig. 10a) partly coincides the area with weak increases detected in the MaxSN. The trend was, however, not statistically significant during the study period.

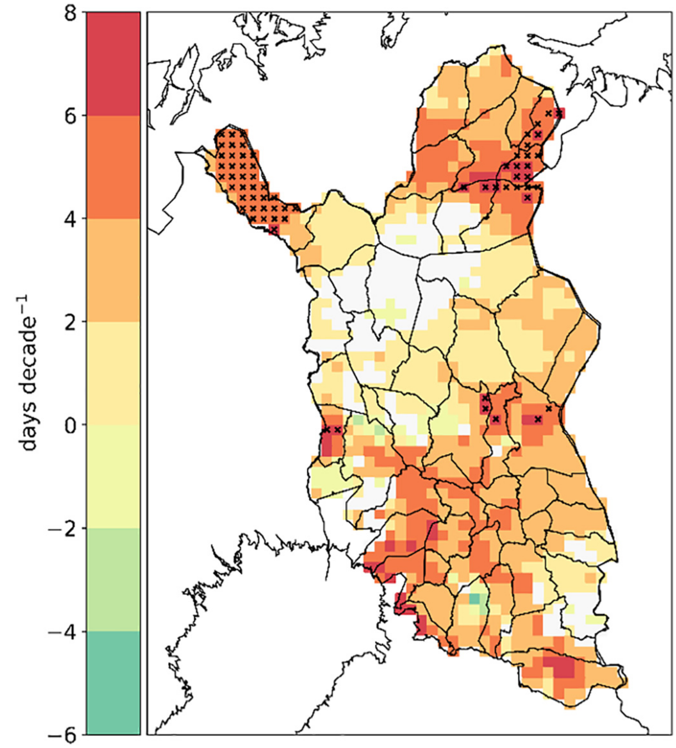

Fig. 6. The change in the snow cover formation date (BEG) within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

3.3.2. Effects of the changes in the winter climate on herding

There was a great local variation in the responses among the herders of the fell districts on how changing winter conditions affect herding (Table S8 in Supplementary material). Some herders reported that reindeer foraging conditions have been deteriorated

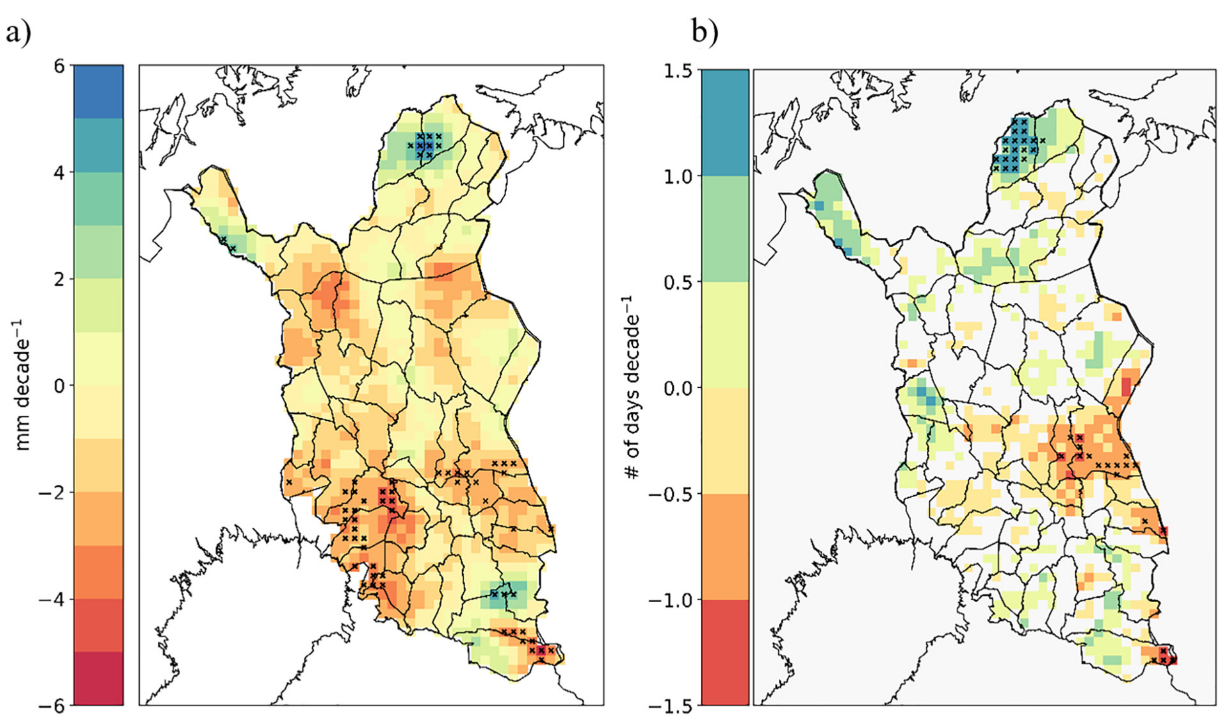

Fig. 5. a) The change in the largest daily precipitation (R1d) and b) the number of heavy precipitation days (RR10) in the summer season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

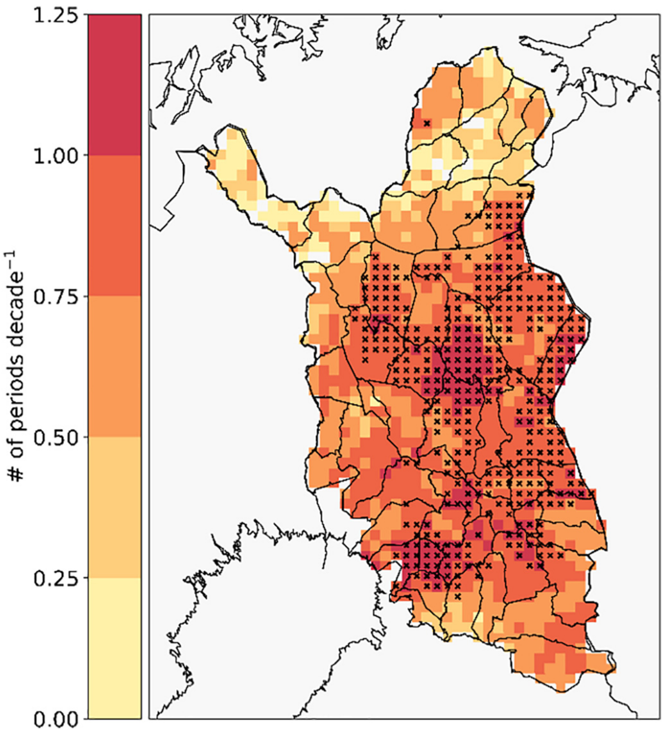

Fig. 7. The change in the number of warm weeks (Warm1w) in the winter season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

due to deep snow and ice formation, whereas others had experienced an improvement in winter conditions through less snow. Also, in forest districts, both positive and negative impacts of changes in winter conditions were experienced. Thinner snow

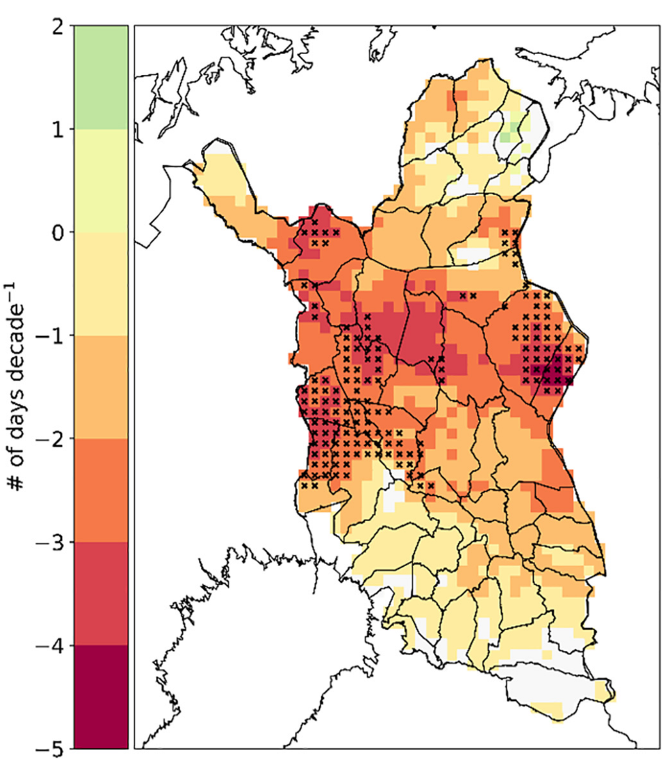

Fig. 8. The change in the number of cold days (Cold-d) within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

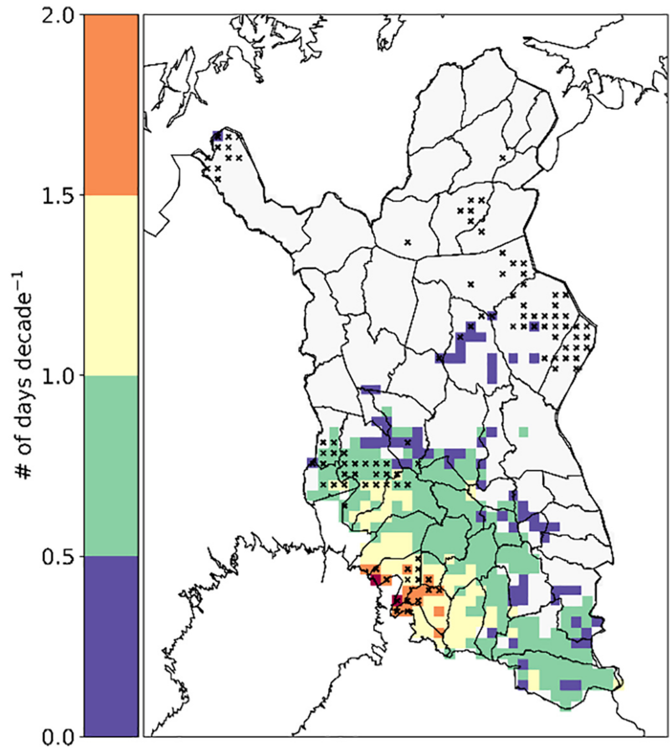

Fig. 9. The change in the number of rain days (Rain-d) in the winter season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

cover, milder weather and shorter periods of very low temperatures are favorable for reindeer, because reindeer stay more fit due to higher availability of forage and lower energy expenditure. Some herders reported that foraging conditions have been deteriorated due to hard snow and icy layers formed on the soil and snow cover resulting in declined availability of ground lichens for reindeer. Hard snow and rime accumulated on the branches of trees have also decreased the availability of arboreal lichens. As a consequence, reindeer herds can be dispersed and the animals move more than usual, which can present challenges to reindeer round-ups, leading to delays in them. Changing winter conditions have increased the need for taking reindeer into enclosures. Feeding reindeer in the enclosures have largely replaced feeding in the field, and supplementary feeding has to be started earlier than before. In some districts, the conditions were more favorable for the use of snowmobile over extended time periods.

3.4. Earlier and warmer springs?

3.4.1. Herder experiences and meteorological observations of spring climate

Most of the herders of both fell and forest districts reported that the frost period ends earlier in the spring, and some had experienced that the spring heat waves occur earlier than before (Table 3, Table S5). The growing season was found to start earlier and the development of birch leaves was more advanced when compared to the earlier decades. There was some divergence in the views of the herders from the fell districts (Table 3). Some experienced that the duration of the frost period during the spring has become longer, whereas most of the herders had experienced earlier discontinuation of the frost period. Most of the herders had experienced ice- and snowmelt occurring earlier, but some stated that snowmelt now occurs later than before. Some herders pointed out that the season of hard night frosts (affecting the snow hardness during the spring) is shorter than before, being over already before March. Some herders also noted that, due to evaporation of snow, spring flooding is not as strong as before.

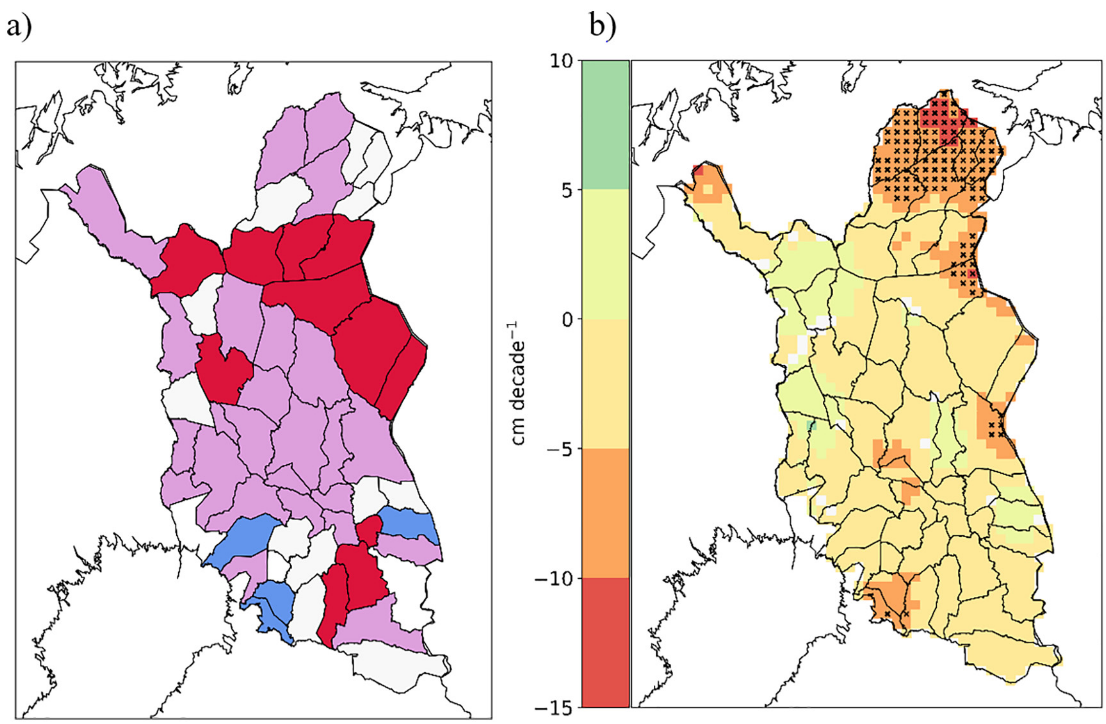

Fig. 10. a) Median values of answers by district to the argument "Snow cover is deeper than before" in the survey targeted to reindeer herders. Violet = no change observed (median 2.5–3.5); red = change/some change observed into the direction of the argument (median < 2.5); blue = change observed into the opposite direction (median > 3.5); white = missing data. b) The change in the annual maximum snow depth (MaxSN) within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

A decrease in the number of ice days (ID) in spring was found particularly in the northern part of the study area (Fig. 11), where it was locally 3–5 days per decade. The standard deviation of ID in these regions is 0.5–3 days. A trend towards an earlier snowmelt date (SOD), locally 3–5 days per decade, was statistically significant only in the southern part of the RMA (Fig. 12). The standard deviation of SOD

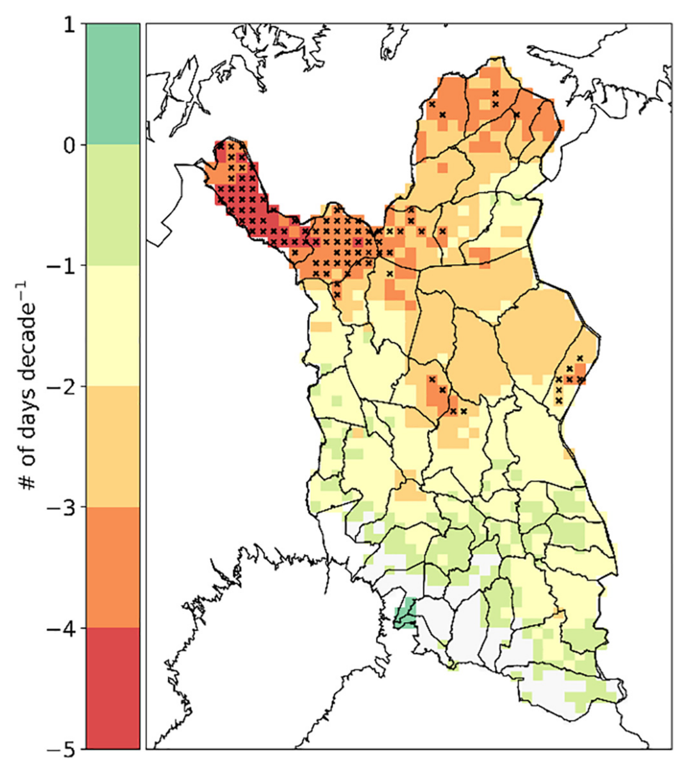

Fig. 11. The change in the number of ice days (ID) in the spring season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

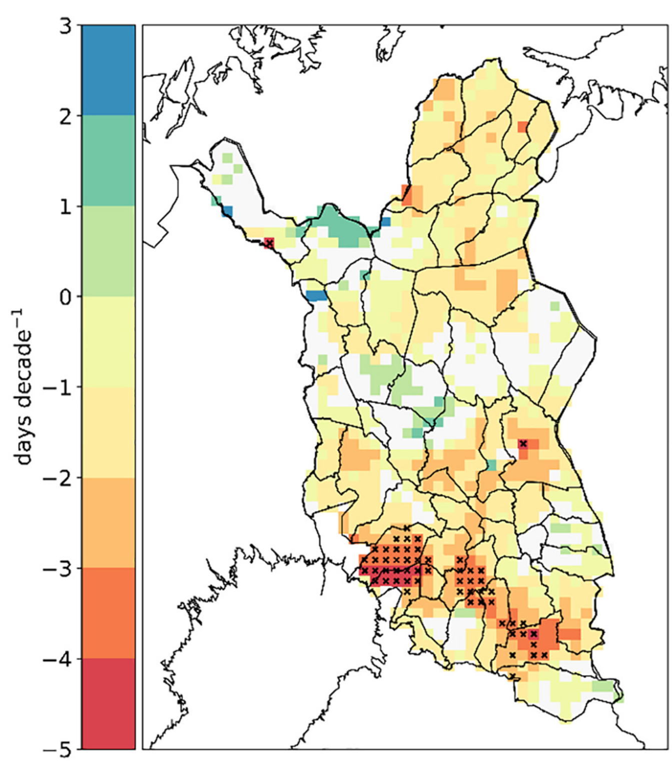

Fig. 12. The change in snowmelt date (SOD) within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

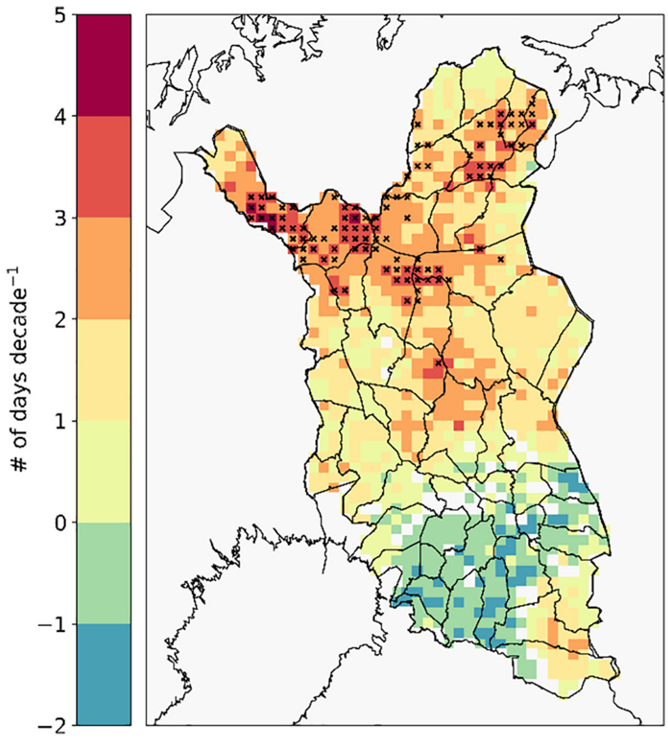

Fig. 13. The change in the number of zero-crossing days (Zero) in the spring season within the RMA in 1981–2010. Locations with significant trends (at 5% significance level) are marked with black check marks. The trend is zero in the white area.

was 9–12 days in these areas. The number of zero-crossing days (Zero) related to the night frosts showed an increasing trend of 3–5 days per decade in the northern parts of the region (Fig. 13) (standard deviation 6–8 days). Slight, local increases in the number of rain days (Rain-d) were found within the RMA, most clearly in its southern parts where the trend was 2–3 days per decade (map not shown). Standard deviation of Rain-d was 3–5 days in these areas. Precipitation in spring was not explicitly addressed in our questionnaire.

3.4.2. Effects of the changes in the spring climate on herding

According to the free-form comments of the herders of the fell districts (Table S9 in Supplementary material), earlier arrival of spring has had a positive impact on reindeer herding. Snow-free patches on the fells were available for reindeer grazing earlier than before. Due to advanced development of vegetation and the consequent higher availability of fresh forage plants for milk-producing dams and their calves, the calves will be fit by the time the calf marking period starts in the summer. Spring can also be a difficult time for herding on the fells: Start of the growing season is uncertain, it can snow heavily at calving time, and riverine flooding can be strong, which exposes the calves to accidents.

In the forest districts, as well, most of the herders reported that earlier spring can have positive impacts on herding. Due to earlier snowmelt, the risk of reindeer calving taking place in snowy conditions is nowadays smaller, and due to advanced emergence of spring vegetation, reindeer can feed on natural forage earlier than before. Early spring lowers the expenses of supplementary feeding. The winter feeding period is shorter because reindeer can be released from enclosures to the summer pastures much earlier than before. Some herders report that the interannual variation of spring conditions is great and that the arrival of spring has not advanced. A few herders reported that the earlier arrival of spring has not had any impact on reindeer herding. Some others list negative impacts related to early springs, such as strong flooding and increased predatory threat.

3.5. Coping strategies of herders

Gathering and moving reindeer to the calf marking round-up sites has become more difficult in the summer, because reindeer do not necessarily gather into herds due to e.g. short warm periods and lack of insect harassment (Table S6). Therefore, many herders have given up the summer calf-marking period and, instead, mark calves only during the autumn-winter round-ups or already in the spring in the case of enclosure calving. Rescheduling the calf marking was also reported as a way to cope with long heat periods and severe insect harassment during summer (see also Turunen et al., 2016). In the autumn, weather-related factors, such as mold or ice on pastures may cause herds to be dispersed over a wide area, which delays round-ups (Table S7). Due to lack of snow or thin or non-uniform snow cover, reindeer are collected and moved to the round-up sites increasingly by terrestrial vehicles, particularly ATVs, or helicopters instead of snowmobiles.

In winter, supplementary feeding plays an important role in adaptation of reindeer to the changing weather conditions (Table S8). The need for supplementary winter feeding of reindeer has increased, and in some regions, it needs to be started earlier than before. Many herders held the view that although supplementary winter feeding increases expenses, taking reindeer into enclosures is nowadays the only way to gain regular income from herding (see also Turunen et al., 2013; Turunen and Vuojala-Magga, 2014; Turunen et al., 2016). The majority of the herders of the forest districts reported that changing winter conditions have increased the need for taking reindeer into enclosures, and that feeding reindeer in the enclosures has largely replaced feeding of reindeer in the field. The herders of fell districts reported several strategies for coping with deteriorated foraging conditions. These included moving herds to lower elevations of fells with less snow or to wind-exposed habitats where snow cover is thinner; adjusting the time the herds (of a village or a siida) are kept together; moving the herds from one pasture to another with the aid of hay earlier in the spring; starting supplementary winter feeding; and monitoring ice formation in the snow cover more carefully. Some herders reported (Table S9) that supplementary feeding can be discontinued earlier in the spring because of early snowmelt, which reduces the expenses for feeding. Reindeer can also be released from enclosures to the summer pastures much earlier than before.

4. Discussion

Our findings of the trends in climate indices were mainly consistent with earlier studies in northern Fennoscandia. According to earlier studies, summers in northernmost Finland have become warmer in many locations, but the trends in the amount of summer precipitation are not clear (Virtanen et al., 2010; Lépy and Pasanen, 2017; Maliniemi et al., 2018). Warmer autumns have been reported in several earlier studies (Vuojala-Magga et al., 2011; Turunen et al., 2016; Kivinen et al., 2017; Lépy and Pasanen, 2017; Jaakkola et al., 2018) as well as shorter snow season with later formation of the snow cover (Rasmus et al., 2014; Luomaranta et al., 2019). Only local increases in autumn precipitation have been reported (Kivinen et al., 2017; Lépy and Pasanen, 2017). Our observations of increased winter temperatures are in accordance with earlier studies (Vikhamar-Schuler et al., 2010; Vuojala-Magga et al., 2011; Kivinen et al., 2012; Rasmus et al., 2014; Kivinen and Rasmus, 2015; Lépy and Pasanen, 2017). Winter precipitation has increased within the study region (Rasmus et al., 2014; Lépy and Pasanen, 2017). Increasing amount of mixed and liquid precipitation has also been reported (Luomaranta et al., 2019) together with more frequent and more intense rainy periods (Vikhamar-Schuler et al., 2016). Previous studies have not found any significant changes in thickness of the winter snow cover in the region (Rasmus et al., 2014; Lépy and Pasanen, 2017; Luomaranta et al., 2019). Increasing spring temperatures have been observed in previous studies (e.g. Kivinen et al., 2017; Lépy and Pasanen, 2017), as well as earlier snowmelt (Vikhamar-Schuler et al., 2010; Rasmus et al., 2014; Lépy and Pasanen, 2017) and thinner spring snow covers (Luomaranta et al., 2019).

Reindeer herder observations of changes in seasonal weather characteristics, gathered via a survey questionnaire, were generally in line with the meteorological data. The observations of herders from the forest and the fell districts were mainly consistent with each other. Some regional differences were seen in the observations concerning the warming of summers, and changes in the autumn precipitation and snow depth. Local variation was seen in the responses among the herders when the arrival of spring was in question. The herders had experienced the largest number of changes during the winter, and the smallest number of changes during the summer. Furthermore, herders had experienced more variable weather, which has also been reported in earlier studies based on local knowledge (e.g. ACIA, 2004; Helander, 2004; Vuojala-Magga et al., 2011). Weather variability is a complex concept. Conclusions drawn in the scientific studies depend on the temporal scales and measures of variability used (Fischer and Knutti, 2014). If the variance of daily temperatures is considered as a measure of variability (or spread), it is evident that there is a general decreasing trend in variability in northern mid- and high latitudes, as cold days have warmed more than warm days (Screen, 2014; Lorenz et al., 2019). Furthermore, in the mid-latitudes the warming may cause weather patterns to move more slowly, increasing weather persistence (Overland et al., 2015). The replies in our survey may be interpreted as a common perception of a decrease, rather than an increase, in weather persistence from one day to the next, meaning rapid, intermittent change in the daily weather. To the knowledge of the authors, weather persistence of sub-arctic Scandinavia has not been explicitly studied, but there are several recent studies on high latitude cyclone activity. Changes in cyclone activity in the vicinity of our study area could lead to changes in weather persistence. Studies concentrating on Arctic cyclone activity during past decades observe no clear trends, or regional decreases or increases (Koyama et al., 2017; Wei et al., 2017; Zahn et al., 2018). According to Koyama et al. (2017), more intense cyclones have been experienced due to the increases in precipitable water in the atmosphere. Zhang et al. (2004) and Sepp and Jaagus (2011) also report on increase in the number and intensity of cyclones entering the Arctic from the mid-latitudes.

There were some interesting discrepancies between herder observations and the meteorological data. For example, warming of summers was seen more in the analysis of climate indices, than in the answers of the survey respondents. The herders had generally experienced an increase in summer precipitation and reported that heavy precipitation has become more frequent, while meteorological data showed only local increases in the indices related to the heavy precipitation events. The human memory is believed to emphasize recent and rare conditions. Our survey opened in autumn 2016, just after the summer during which record-breaking precipitation sums had been observed in several locations around the northern Finland (FMI, 2017). Both summer of 2016 and also 2015 had been relatively cool and rainy; autumns, winters and springs of these recent years had, on the other hand, been warmer than average. The use of climate data from the period of 1981–2010 (current three-decade normal period in use, not extending to the most immediate past) has most probably contributed to these discrepancies. Furthermore, for a human observer it may be difficult to separate the possible change from interannual variation (Figs. S14–S17). Standard deviations of climate indices were generally of the same magnitude or larger than the changes per decade. The detected decadal change was stronger than the standard deviation only for the number of rain days (Rain-d) in the summer, locally, and the number of ice days (ID) in the spring. For example, the decrease in the ID per decade in northwestern fell region was 3–5 days, standard deviation being 0.5–3 days. In this case, most of the herders from the fell districts had experienced discontinuation of the frost period in spring. Large interannual variability, together with a relatively short study period, may also mask trends possibly present in a longer time series.

Experienced impacts on herding and adaptation needs were rather consistent between the forest and fell districts, but more numerous and varied in the forest districts compared to the fell region. Local variation was seen in the herder views concerning the impacts of changing winter climate on herding. Reindeer management adapts to changing climatic conditions through adoption of various coping strategies in the everyday work of herders. Professional techniques and practices are also continuously developed, e.g. regulating the reindeer numbers and herd structure, or utilizing pasture rotation systems. The coping capacity of herding is dependent on the geographical space available for adaptation actions and facilitated by variations in topography, vegetation and herding practices (Tyler et al., 2007; Moen, 2008; Riseth et al., 2016; Turunen et al., 2016, 2019; Peltonen-Sainio et al., 2017). Large, diverse and peaceful pastures give herders more choice regarding the coping strategies available during various weather conditions. The fell and forest districts differ in terms of herding practices and pastureland types (Table 1) as well as are involved with different kinds of disturbance factors. Seasonal coping strategies of herders (Tables S6–S9) mirror these differences.

It is crucial that the coping strategies adopted in everyday herding work are supported by local, regional and national governance of reindeer management. When preparing adaptation strategies, governance level of reindeer management needs to understand the local impacts of seasonal changes, and to acknowledge that the coping strategies already in use are based on local practitioner knowledge – experiences and perceptions on what is normal and what can be expected. In Finland, national adaptation to climate change is guided by The National Climate Change Adaptation Plan 2022 (MAF, 2014). A separate adaptation plan does not exist for reindeer husbandry, although need for this has been acknowledged (MAF, 2005, 2014). Reindeer management in Finland has recognized the need for adaptation measures, impacts of climate change are known qualitatively, and some adaptation measures have been identified and are being planned (MAF, 2009, 2013; Peltonen-Sainio et al., 2017). Measures mentioned to mitigate the adverse effects of climate change are maintaining the uniformity and diversity of the pasture areas, improving reindeer health, limiting the expansion of invasive alien species, environment protection, considering reindeer management in the legislation regulating land-use planning, developing the financial instruments, and relevant research. Accordingly, adaptation to climate change requires consolidation of different land use needs and participatory planning approaches (Oinonen et al., 2014; RHA, 2014), consideration of sustainable development and socio-economic and cultural aspects in planning processes, and research and education on climate risks (Forbes, 2006; Hukkinen et al., 2006; Finland's Strategy for the Arctic Region, 2013; Soppela and Turunen, 2017). Furthermore, legislation has recently recognized the need of reindeer herding to cope with difficult weather events. Act on compensation of damages caused to reindeer herding (987/2011 and 655/2016) aims at supporting herders to cope with extensive and unexpected damages resulting from natural events like exceptional weather conditions. To our knowledge, at the time of writing this article, there have been no cases in which this legislation has been applied in practice. In the time of rapid change, it may be challenging to define what constitutes “normal”, “rare”, “exceptional” and “unexpected” weather conditions and set the corresponding compensation amounts.

Both meteorological observations and practitioner knowledge are needed for understanding of the effects of climate change on reindeer management, and to support decision-making on adaptation to climate change. To clarify the useful features of the knowledge sets, also critical evaluation is needed. Meteorological data are objective, systematical, and have full spatial coverage on the study area. However, fine-scale variability seen in the northern nature may cause errors and uncertainties into the interpolation of the climate data, even when a grid with high spatial scale is used. Also aspects like experiences, impacts on, and coping of local communities are missing. Herder experiences on seasonal weather are very much local in nature. On one hand this knowledge is unsystematic, spatially inconsistent and potentially biased (Couzin, 2007; Monastersky, 2009; Alexander et al., 2011; Huntington, 2011). There may, e.g. be seasonal bias causing the critical seasons to get disproportionate attention. On the other hand, herder observations provide valuable information on local conditions, the occurrence of extreme and harmful weather events and their consequences on the livelihood (see e.g. Rasmus et al., 2018).

Climate indices provide a quantitative ground which serves as an easy starting point for discussions on climate change and the adaptation actions it calls for. We aimed at using indices with a temporal scale that is comparable to human experience and easy to relate to the daily work of herding. High spatial resolution of the meteorological data and its full spatial coverage on the study area also enable bringing changing seasonal weather to the scale of the herder experiences as they move around and work in the landscape. Time series data and spatial visualizations of observed changes enable discussions on topics such as the regional differences in extreme events and the reasons for adopting different coping strategies. It should be noted that some of the indices could be easily connected with practitioner knowledge, whereas some of the arguments used in the questionnaire were difficult to translate into indices which could be derived from the data set used (more frequent mold/ice layer formation). The data set itself had some inherent limitations as e.g. humidity and wind data were not available.

5. Conclusions

Parallel examination of meteorological observations and practitioner knowledge can provide new insights into the temporal and spatial variability of the warming of the northern latitudes. In our work, relating the different knowledge sets enabled us not only to study the ongoing climate change in general, but also to examine its specific impacts on the northern environment with a particular focus on the nature-based livelihoods. We conclude that using different knowledge sets together will support decision making related to climate change adaptation. This view is shared also by IPCC (2019), who recently called for learning to relate different knowledge sets, as through this process new and relevant understanding for improved decisions and solutions can be created.

It is expected that, in the future, research problems will be increasingly co-defined and governance solutions co-planned with local practitioners. In these processes, new tools to present data and discuss the implications of observed changes are needed. Important features of these new tools are defining quantities, indices and observations relevant for all involved in the process, consideration of temporal and spatial scales when presenting the data, and genuine data fusion, where both local practitioner knowledge and scientific knowledge are treated with appreciation, acknowledging the strengths and weaknesses of both forms of knowledge. The approach presented in this work can facilitate the dialogue between the local practitioners, researchers and policy makers. Our study focused on reindeer husbandry, but the approach is applicable to other nature-based livelihoods (e.g. hunting, gathering, fishing and small-scale farming and forestry) facing adaptation needs caused by changing climate.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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