Adaptive Strategies of Indigenous Nenets Reindeer Herders for Climate Change in Yamal

ALEXANDRA TEREKHINA, ALEXANDER VOLKOVITSKIY, FLORIAN STAMMLER, KARL MERTENS, VALERIY Y. IVANOV, PAVEL OREKHOV, COLIN D. WREN, BOQI TIAN, XIN SHEN, AYTALINA IVANOVA, DESHENG LIU, AND JOHN P. ZIKER

Abstract: Nenets reindeer pastoralists of Yamal in the Russian Arctic, successfully deal with rapidly changing climate and natural gas industrialization. We present results from our long-term ethnographic study (2001–present) on the adaptive strategies that Nenets nomadic households have employed over time, their tradeoffs, inherent risks, and social implications of these strategies. While some strategies limit the adaptive flexibility of herding, they simultaneously enable agency that keeps Nenets households on the land—critical for maintaining their nomadism. Rapid climate change in the Arctic, which could lead to increased icing of pastures, makes reindeer herding more vulnerable. We examine meteorological data from Yamal to better understand the climatic trends challenging reindeer nomadism. Our analysis is relevant for policymakers through understanding Nenets adaptation and interactions with ecological processes and institutions.

Keywords: Arctic, climate adaptation, climate change, decision-making, Indigenous peoples, migration, pastoralism, Yamal

Climate change is affecting the Arctic more rapidly and to a greater extent than the rest of the planet. A multi-dataset analysis of the mean temperature trends in the Arctic shows an increase at the rate of 0.73 degrees Celsius per decade, while for the globe as a whole it is only 0.19 degrees Celsius per decade, over the period 1979–2021. The maximum rate can be detected near the Novaya Zemlya region of Russia, where it exceeds 1.25 degrees Celsius per decade (Rantanen et al. 2022). As a result, Arctic peoples are experiencing disproportionate

exposure to the effects of climate change (Bennett et al. 2014). Reindeer husbandry, as a keystone of livelihood for many Indigenous peoples in northern Eurasia, is a significant topic in the Arctic climate adaptation literature (Rees et al. 2008; Tyler et al. 2007; Klokov and Mikhailov 2019). Of particular concern are the effects of rain-on-snow (ROS) events that impact reindeer's ability to forage (Serreze et al. 2021; Hansen et al. 2019; Krupnik 2018; Turunen et al. 2016; Rasmus et al. 2020). Earlier work has emphasized the role of both natural and social factors on the resilience of reindeer herding as part of a whole system which is explained as "capacity of a system to absorb disturbance and reorganize while undergoing change..." (Forbes et al. 2009; Pape and Loeffler 2012; Golovnev 2017; Rees et al. 2008). As such, resilience can be supported in numerous ways. Reindeer herders themselves stress the importance of factors such as subsidy regimes (Turunen et al. 2016), social benefits of industrial development (Forbes et al. 2009; Volkovitskiy and Terekhina 2020), and agency in the flexibility of their responses (Rees et al. 2008; Stammler and Ivanova 2020; Nakashima, Krupnik, and Rubis 2018; Kasten 2021).

The Nenets word *Num* means both "weather" and god. Nenets cosmology—like so many Indigenous peoples in Siberia and elsewhere—has no strict separation between the natural, social-spiritual, and built worlds (see Rasmussen 1927; Merkur 1983; Leduc 2007 on *Sila* Inuit conception). These worlds are connected and tightly interwoven through mutual dependencies and relationships. Thus, herders' own perceptions of environmental change have implications for the resilience strategies that they pursue (Roué 2018; Volkovitskiy and Terekhina 2021; Lavrillier and Gabyshev 2021; Terekhina and Volkovitskiy 2023; Laptander et al. 2023).

Building on the existing anthropological and interdisciplinary literature, this article advances discussions on Indigenous climate adaptation using a convergent science approach, bringing together cultural and earth systems perspectives (Ivanov et al. 2024). Convergence intends to blend scientific disciplines in a coordinated, reciprocal way, foster the robust collaborations needed for successful inquiry, and build and support creative partnerships and the creative thinking needed to address complex problems (Sharp and Hockfield 2017). We converged on the question of Nenets adaptive strategies from different disciplinary perspectives as a group of anthropologists interested in understanding climate change impacts on Yamal Nenets reindeer herding and a group of earth systems scientists interested in analysis of climate trends in different parts of Yamal to assess the risk of critical weather events to reindeer herding.

First, we provide an overview of the study area including recent developments and impacts of winter icing, or rain-on-snow events, on reindeer herds. Next, we discuss some of the relevant disciplinary contexts and methods of our project, which focused on a new analysis of our own existing records in both disciplines. By compiling and analyzing historical and ethnographic data, we identified 10 adaptive strategies employed by Nenets reindeer herders in the pre-Soviet period and modern times. We define these strategies along with their limitations, risks, and costs and benefits. Our analysis of adaptive strategies of reindeer herders finds that there are three groups of strategies: 1) changes to nomadic mobility; 2) intra-community relationships; and 3) extra-community relationships. We consider which of the traditional strategies have been kept or transformed, and which new ones have emerged. We pair the ethnographic data with long-term climate data from five meteorological stations on Yamal, which provides information on how climate change is affecting different subregions on Yamal over time. Finally, we bring together adaptive strategies and climate analysis to better understand the constraints and opportunities for Yamal Nenets reindeer herders.

Study Area

The Yamal Peninsula (see Figure 1) in northwestern Siberia is located in the Yamalo-Nenets Autonomous Okrug (YNAO). Yamal is the world's largest region of nomadic reindeer herding, where Nenets families live alongside their domestic reindeer on annual migration routes of up to 1,200 km using traditional technology such as conical hide covered dwellings and sledges harnessed to reindeer (see Figures 2 and 3).

The Yamal Peninsula is 200–220 km wide and extends 700 km northwards from the Arctic Circle. Yamal is a thermokarst Arctic plain divided into several tundra zones (southern, typical, sub-Arctic, Arctic), or subzones C, D, E, depending on the classification scheme (Walker, Raynolds, and Arve 2005). Administratively, the Yamal Peninsula is contiguous with the Yamalskii district of the YNAO. The total resident population is approximately 17,000 (as of 2020) with 12,700 Indigenous people, mainly Nenets. Yamal Nenets are one of the few remaining populations of fully nomadic reindeer herders in the Arctic (Stammler 2005). More than a thousand Nenets family households—approximately 6,000 people—are involved in reindeer herding, maintaining a nomadic lifestyle, living year-round in tundra in nomadic tents (*chumy*)

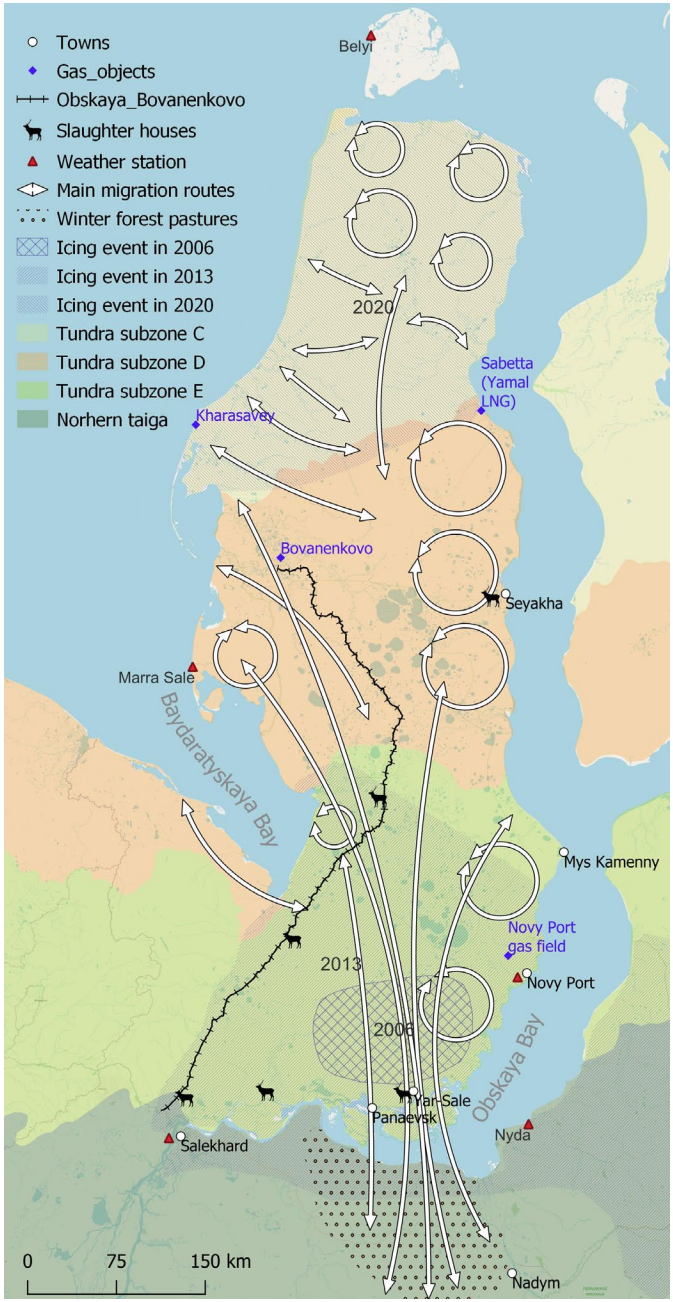

Figure 1. Map of the Yamal Peninsula and surrounding area, illustrating major settlements, infrastructure, biomes, spatial extent of major icing events, and a schematic of Nenets migration routes. Figure by the authors.

Figure 2. Winter migration of Nenets reindeer herders. An elderly man and his small grandson sit together on a reindeer sledge. Photo credit: Alexander Volkovitskiy.

Figure 3. Summer migration. Spatial flexibility in choosing one's migration route, including spontaneous changes, remains a key adaptation mechanism to unforeseen events—be they weather-related or socioeconomic. Photo credit: Florian Stammler.

with reindeer, and regularly migrating between different seasonal pastures. In addition to the permanent residents, another twenty-five thousand or more people reside in Yamal temporarily, including fly-in, fly-out workers in the gas industry and in infrastructure construction. While they are not considered in official statistics, these shift workers leave a significant footprint in the socioecological system (Forbes 2008; Kumpula et al. 2012).

Changes in post-Soviet Yamal Nenets reindeer herding concern economy and ownership more than the way of life itself. Since the 1990s, the share of state-owned reindeer decreased, while the number of independent, private households and their herds increased—almost the only such case among the reindeer herding regions of the former Soviet Union (Stammler 2005: 78; Klokov 2020). Today, only about 10 percent of the total two hundred thousand Yamal reindeer population belong to the state-managed reindeer herding enterprise. The forms of private herding operations include independent private households, reindeer herding communities (*obshchina*), and peasant-farming households. Regardless, each private household plans its own migration route and schedule according to informal (traditional) rights. Seasonal movement patterns vary widely between the conditions in different parts of the tundra, climatic variation, and individual needs in the herding camps.

Nenets adaptation to climatic change is conditioned by both social and ecological needs. Therefore, the complex adaptive strategies of the Nenets, which we consider below, also imply the responses of nomadic households to changing grazing conditions associated with tundra pastures. As a rule, herders try to preserve lichen pastures for grazing during the snow-covered season, due to slow pasture recovery (see Figures 4 and 5). During the rest of the year, their herds feed on green plants. As the entire livelihood is sensitive to pasture quality, a lot of the yearly mobility follows the growth of green biomass northwards in spring, and its retreat in the fall. During Soviet times, recovery periods for winter pastures were institutionalized as pasture rotation for the state-owned herds. Today, Nenets herders actively manage local pasture quality through their control of reindeer movement on pastures on a daily, sometimes hourly basis. High herd mobility reduces the cumulative footprint, as less biomass per pasture is consumed by a moving herd in comparison to a stationary herd. This grazing pattern enables a high number of animals on the peninsula. This article does not specifically address the problem of the quality of pastures on the Yamal Peninsula, which is contested among herders and herbivory

Figure 4. Forest lichen–rich pastures. Numerous households migrate here in winter, traveling hundreds of miles and crossing the wide Obskaia Bay. Photo credit: Alexandra Terekhina.

Figure 5. Campsite of a private reindeer herding household staying in the tundra for the winter. Photo credit: Alexandra Terekhina.

biologists. As all the recent cases of reindeer losses on Yamal have been associated with their starvation on ice-encrusted areas after winter ROS events (Forbes et al. 2022), not animals' starvation on poor pastures, we consider the combined effects of development and global climatic change pressures on the system.

Infrastructure and Industrial Development

In recent decades, Yamal reindeer herding has been at the same time both constrained and actively supported by the rapidly developed hydrocarbon production infrastructure. Exploration of gas and oil deposits on the Yamal Peninsula reaches back to the 1970s. After a period of stagnation in the late 1990s, development intensified, and large infrastructure projects were built on and between the main deposits (Bovanenkovo, Kharasavei, Novyi Port, Sabetta), including gas production facilities, pipelines, workers' camps, quarries, airports, seaports, roads, and a trans-peninsula railroad (Forbes et al. 2009; Kumpula et al. 2011; Stammler 2011; Terekhina and Volkovitskiy 2020; see Figure 6). All of these large-scale industrial facilities have taken over land tradition-

Figure 6. Herder crossing the Gazprom Obskaia-Bovanenkovo railroad, which has become an obstacle for many migrating households. Photo credit: Alexandra Terekhina.

ally used as reindeer pasture or important fisheries, and they continue to impact migration routes for Nenets households whose migration routes or camps historically utilized those areas, creating bottlenecks in preferred migration zones (Degteva and Nellemann 2013). The existence of these industrial facilities impacts the traditional order of movement in the tundra on a broader basis across the peninsula, especially during construction. Concurrently, industrial activity contributes to the economic growth of the region, which also positively benefits the development of reindeer herding by providing subsidies and access to markets for reindeer products.

Climate Change, Icing Events, and Reindeer Mortality

Nenets elders recall that major icing events caused by ROS or sudden thawing previously happened once in a generation (Golovnev 2017; Stammler and Ivanova 2020). In the twenty-first century, their frequency has rapidly increased. The most significant winter icing events after ROS led to mass reindeer mortality in 2006–07, 2013–14, and 2020–21 (see Table 1 and Figure 7). The social consequences of the last two events were the most severe, with many nomadic households forced to camp near the outskirts of the Indigenous settlements on the peninsula. This process is known as "sedentarization" and leads to economic challenges that are difficult to overcome and return to herding (Ziker 2021). Yamal Nenets elders have reported that it used to take approximately seven years until a herd could be restored after a major icing event. It follows that the frequency of events is important and must be considered alongside their severity (Stammler and Ivanova 2020; Forbes et al 2022; Terekhina and Volkovitskiy 2023; Hanssen-Bauer et al. 2022; Laptander et al. 2023). After one particularly bad winter, as one herder put it, "If the next winter is the same, then it is an end to us all." In order to understand the full trajectory of herd loss and reconstitution, it is crucial to consider data compiled over decades rather than that based on a single year of fieldwork or distinct research periods. Our hydrometeorological data analysis provides an empirical context to the new conditions Nenets herders are navigating both climatically and within the constraints on their movements due to the expanding built environment.

Table 1. Critical Icing Events and Reindeer Mortality, 2002–2022

Year	Subregion of Yamal	Characteristics	Reindeer Mortality
2006–07	Southern and central	Ice crust formed by 2 ROS on 7–9 November 2006, repeated in January 2007, and freezing after thaw in April 2007 (Bartsch et al. 2010)	Several thousand reindeer; total demographic losses estimated by some households amounted to 25% of the animals (Bartsch et al. 2010)
2013–14	Southern and central	Ice crust after ROS on 8–9 November 2013 (Sokolov et al. 2016; Forbes et al. 2016)	Total demographic losses amounted to 43.2 thousand animals, leaving dozens of households without reindeer (Perevalova 2015)
2018, spring	Southern, central and partly northern	Icing caused by freeze after thaw at the beginning of spring migration (Volkovitskiy and Terekhina 2020)	Official data indicates the losses at 2% of all the Yamal reindeer. Losses of two reindeer herding enterprises (Yar-Sale and Panaevsk) amounted to 40%, while the Seiakha enterprise went bankrupt (personal communication with Yar-Sale enterprise staff).
2019, spring	Northern (locally) and mid-western Yamal	Icing caused by freeze after thaw	Several thousand reindeer dead (personal communication with herders)
2020–21	Northern	Large-scale icing above 71° N after a series of ROS events in November and on 5 December, 2020, followed by harsh freeze (Volkovitskiy and Terekhina 2021)	Up to 15 thousand reindeer dead and lost (personal communication with officials)

Figure 7. Reindeer—victim of the 2021 icing in Northern Yamal. Photo credit: Alexandra Terekhina.

Disciplinary Contexts and Methods

We consider Nenets adaptive strategies within the framework of the concepts of uncertainty and risk, discussed both for any pastoral communities living in conditions of nonequilibrium systems and in general for the Indigenous peoples of the Arctic in facing climate change (Behnke, Scoones, and Kerven 1993; Scoones 1995; Niamir-Fuller and Turner 1999; Roué 2018; Ulturgasheva and Bodenhorn 2022; Istomin and Vakhtin 2022). Regarding the widely recognized increased vulnerability of the livelihoods of northern Indigenous peoples, we share the central message of the volume edited by Douglas Nakashima, Igor Krupnik and Jennifer Rubis (2018) that these communities do not position themselves as passive victims of climate change, but instead have high adaptive capacities. We would like to complement previous research that has highlighted the hazards of climate change for Arctic reindeer herders (Mathiesen et al. 2018; Tonkopeeva et al. 2022) by analyzing particular Nenets adaptive strategies and practices. Here we assess the internal potential of the Nenets pastoralist community's resilience to climate

change, flexibility in reactions to modern transformations (Salick et al. 2018), as well as the influence of external government institutions. Our approach in comparing ethnographic observations of migration decisions with climate data is inspired by the convergence approach described in Ivanov et al. (2024).

We derive data on pre-Soviet reindeer herder strategies on Yamal using historical sources (Evladov 1992; Zhitkov 1913) that describe the Yamal Nenets before the socialist reforms, ethnographic literature (Volzhanina 2012), along with oral histories of elders gathered during our fieldwork from 2001 to 2022. We deliberately exclude information from the Soviet era because, at that time, reindeer herding was organized in large, state-managed, and territorially bounded reindeer herding enterprises. Instead, we focus our assessment on periods when private households have dominated Yamal reindeer herding, with the caveat that some echoes of the Soviet model are still visible in contemporary Yamal reindeer herding. Based on our ethnographic work with Nenets reindeer herders conducted from 2001 to 2022 and our analysis of the literature, we identify and define ten adaptive strategies, along with limitations and risks in their implementation, and main costs and benefits.

In addition, we assembled a collection of records for 28 reindeer herding households. This is a subset of all households with whom the authors have worked, as we included only households that had two or more observations over time with the same kinds of data. Observations occurred at irregular intervals over those two decades. There are 62 observations in our collection, providing data on household demographics, migration routes, and reasons for changes in these routes from the previous year. The sources for this collection include surveys, participant observation, and more recently, digital communication with herders. We coded reasons for changes in migration patterns and identified factors that influence these choices.

Regional Weather Trends

The formation of ice crusts that impact reindeer's ability to forage is usually associated with wet precipitation (ROS and other events) or thaws. Rains followed by snow thaws at the beginning of winter or in early spring occur almost every year, and these events do not necessarily lead to the appearance of ice impenetrable for reindeer. However, the increasing frequency of rains and thaws during winter increases

the risks for reindeer herding. According to Nenets reindeer herders, the rate of losses of reindeer in winter periods also depends on the body condition of the animals at the beginning of winter. These characteristics are determined by grazing conditions in summer and autumn. Extreme summer heat has a mainly negative impact on reindeer weight gain and health in general, because on hot, windless days with increasing insect harassment the animals cannot fully forage, leaving themselves without the fat deposits which are needed for survival in the winter (Makeev et al. 2014).

Since we know that reindeer herds are impacted by warmer weather in summer and winter, we analyzed meteorological data from five stations located in YNAO (relevant for Yamalskii district) from 1966 through 2021 for changes in the number of days of surface icing, icy rain, and wet snowfall (Bulygina et al. 2023). We also examined summer heat using frequency of summer temperature peaks above +20 °C. The data includes two important intervals: 1966–1990, which covers most of the climatological standard normal accepted in meteorology (1961–1990); and 1991–2022, a period of intensifying climate change. Our analysis of these data uses trend assessment (Mann-Kendall test), estimation to indicate the slope of the time series (Sen's linear trend slope magnitude and direction), and LOESS smoothing to dampen interannual variability for visual illustration of linear trend presence or lack thereof. The resulting graphs show both climate trends and, depending on the location of the meteorological station, the areas of Yamal which have experienced higher frequencies of changing conditions.

Results

Nenets Adaptive Strategies

Responses to extreme weather events are extremely diverse and every household chooses a response depending on its exact location, the size of their herd, labor power available, financial resources, social networks, specific qualifications and skills of the household members, and individual preferences and character. Table 2 provides the ten Nenets adaptive strategies we identified with a short description, indicating their pre-Soviet and current use. In our discussion below, we have divided the strategies into three categories with groups of increasing social integration: 1) direct responses related to nomadic mobility (strategies 1–4); 2) strategies involving relationships within the

Table 2. Nenets adaptive strategies in pre-Soviet and modern periods.

Adaptive strategy	Description	Pre-Soviet Use	Current Use
1. Tactical change of the nomadic route	Temporary (seasonal) change of route due to ROS	+	+
2. Free grazing	Reduced control over herd without regular roundups; reindeer free to disperse and find forage broadly	?	+
3. Strategic change of the nomadic route	Planned long-term change of a late autumn and winter route because of increasing risks related to icing; opens up previously unused areas	+	+
4. Using snowmobiles instead of reindeer	Snowmobiles help herders to move greater distances and scout out suitable pastures	–	+
5. Transition from reindeer herding to fishing	After losing reindeer, a household stays near a body of water where it could remain a fishing household, diversifying seasonal activities, or work to restore the herd (fish trade, making sledges or fur clothes for reindeer or cash) to return to reindeer herding	+	+
6. Transfer of reindeer by wealthy owners to families who have lost their herds	Different forms of leasing out reindeer by rich owners (free, loaning with pledge to return bulls trained to sledge, etc.)	+	+
7. Becoming a herder in a wealthy owner's household	Herders without reindeer work as a herder in a wealthy household on various labor agreements (i.e., for food, accommodation, and payment in reindeer)	+	–
8. Socialization in the village/urban setting	Sedentarization and employment (became possible since the Soviet period)	–	+
9. Education	Education as a way to change life strategy after losing reindeer	–	+
10. Support from government and industrial companies	Distribution of petrol, artificial feed, delivery of firewood; mostly financed by oil and gas companies; more recently the state purchased draft reindeer for households left with less than 100 reindeer and snowmobiles	–	+

The use of each strategy over time is indicated with a plus sign (+) for documented, minus sign (–) for not documented, and question mark (?) for likely but uncertain occurrence.

community (strategies 5–7); and, 3) strategies involving outside actors, such as the authorities or industrial companies (strategies 8–10).

Strategy 1: "Tactical" change of the nomadic route

We use "tactical" to describe temporary (single season) changes to migration routes in response to a specific ROS event. The main benefit of temporarily adjusting the migration route is to reduce the risk of reindeer mortality. Tactical changes often lead to occupying neighboring households' areas, increasing the competition for pastures with possible conflicts. Another risk of this strategy includes the possibility of mixing reindeer with neighbors' herds because of a lack of knowledge about the new territory. If herds of different households do mix, then this requires labor to separate the herds.

Strategy 2: Free grazing

Without regular roundups, "free grazing" reindeer disperse across a wide area to find forage, which can help survival rates after an ROS event. As a rule, they mix with neighboring herds, which requires herders' joint control and high labor costs for separating herds after the ROS event. The benefit of free grazing is the minimization of reindeer mortality, but a limitation is that some reindeer may not be found at all. A long-run potential benefit is the improvement of social contacts among neighbors that might occur through direct interaction and the mutual experience of hardship.

Strategy 3: Strategic change of the nomadic route

Longer-term "strategic" changes to migration routes due to increasing risks may either increase or decrease the distance traveled. This is more labor intensive than strategies 1 or 2, particularly when a household significantly increases their migration distance (from the peninsula to the southern forest zone, for example). More frequent camp moves are required to cover the longer distance, and this in turn implies a change in reindeer migration habits and knowledge of the land, which requires significant efforts over several years. Increasing migration route distance also involves investments from herders for reconnaissance of new grazing areas. A limitation of increasing migration distances is the lack of a sufficient number of draft reindeer and nomadic skills. In addition, there are more risky areas with low-quality pastures along a longer route that

herders will have to rely on. The benefits include better pastures at the end of the migration, meaning better nutrition for the animals, leading to an increase in calf survival, and better fitness for spring and summer migration. Conversely, a strategic decision to decrease the migration route distance in autumn might lead to a lack of firewood in the northern tundra and remoteness from social infrastructure. The benefits of shorter migration distances include reduced herders' labor needs in autumn and spring, and may improve reindeer fat deposition in better pastures, improving the rate of reindeer survival in winter.

Strategy 4: Using snowmobiles instead of reindeer

A relatively new strategy when used chiefly during emergencies, the primary limiting factor for snowmobile use is the initial prosperity of a household. Money is needed to cover the initial cost of snowmobiles, plus ongoing maintenance and fuel costs. Risks include acclimatization to use of snowmobiles, adoption of a sedentary herding regime, and resulting loss of traditional migration skills that have lower-cost adaptive flexibility. The benefit of using snowmobiles is the continuation of

Figure 8. Snowmobile migration: traditional sledges pulled to a new campsite. Photo credit: Alexandra Terekhina.

nomadic livelihood despite the loss of sufficient draft reindeer capable of carrying herders and supplies, and increased flexibility, range, and reduced time in choosing new campsites (see Figure 8). By staying in the tundra, a household improves their opportunities to grow their reindeer herd again after losses from an ROS event.

Strategy 5: Transition from reindeer herding to fishing

A very old strategy, known regionally as "sitting by the river," or turning to fishing and trade to accumulate funds to purchase reindeer and rebuild a herd, now has major legislative limitations (i.e., fishing quotas). Another limitation is the concentration of households around the best fishing spots. Paradoxically, the expansion of gas industry infrastructure that constrains the movement and pasture of reindeer has also provided new opportunities for fishermen, because the growth of informal trade in Bovanenkovo or Sabetta from thousands of new potential customers is not controlled by officials. The advantages of this strategy include avoiding sedentarization in villages, even in case of the complete loss of a herd (see Figure 9).

Figure 9. Traditional sharing of fish is an important adaptation mechanism for times where reindeer herd numbers fluctuate strongly. Photo credit: Florian Stammler.

Strategy 6: Transfer of reindeer by wealthy owners to families who have lost their herds

This strategy has become less frequent, but we still documented several forms of leasing reindeer among close relatives who have relationships of high trust. The wealthy side of the interaction has to trust that the poorer side will not cheat, while the poorer side has to trust that the wealthy side will not force them into exploitative conditions. The benefits of this strategy include avoidance of sedentarization, maintaining and developing herding skills and nomadic life, and keeping the next generation in herding.

Strategy 7: Becoming a herder in a wealthy owner's household

The costs of this strategy include development of exploitative patron–client relationships and social dependency on the better-off herders. This strategy might require the separation of families, with the women and children in a village or at a fishing spot, while the men go alone for herding work. The benefits are that connections to the tundra and nomadic livelihood are preserved, even though families may be separated temporarily. There is a good possibility of building up one's own herd again through work, and the preservation of self-esteem if that happens.

Strategy 8: Socialization in the village/urban setting

Sedentarization in a village or urban context may allow for other types of employment. One problem with moving to a village or urban area is the lack of housing. Tundra nomads have few to no opportunities to be paid fairly for their work because of their low educational level in boarding schools. Risks include psychological costs, health declines from alcohol and drug abuse, and associated long-term effects. If they are successful in becoming employed with a regular salary, then they can become part of the Indigenous urban community, but this outcome is less likely. Employment based on tundra skills is limited; typical jobs include working in a slaughterhouse, sewing fur clothing, and ethnotourism. Theoretically, savings could be used to buy reindeer for a new herd, but this is not likely, as daily life consumes most of the income.

Strategy 9: Education

Higher education to improve chances of new employment entails (at least temporarily) a separation from the family and nomadic life, but with effort some families have kept their connection. The problems are low levels of education in boarding schools and a lack of opportunity to invest in education for poor reindeer herders. Government programs to support Indigenous students do not reach everyone. Often, this strategy entails an eventual choice of lifeway: tundra or village/urban. However, we have examples of herders who returned to a nomadic life after completing their education. The benefit is that education provides new employment for children from low-income families.

Strategy 10: Use of support from government and industrial companies

Use of petrol, supplementary feed, or firewood mostly from oil and gas companies, or even state-purchased draft reindeer provides emergency relief from hardship (see Figure 10). This strategy is becoming more common with the expansion of the natural gas industry and increasing frequency of critical ROS events. External support increases dependency

Figure 10. Distribution of reindeer fodder pellets (supplementary feeding) among households during a 2021 icing event, organized by industrial company and administration. Photo credit: Alexandra Terekhina.

on companies and the authorities, who are in turn dependent on the external demand for Russian gas. As there is a lack of valid statistics on private reindeer herds, support is not necessarily directed to those with the greatest need, leading to mismatches. There are further difficulties in using artificial fodder in the open tundra when reindeer are dispersed in their search for natural forage. There is also a risk of increased dependency on artificial feeding, which can change reindeer behavior. Herders and their animals might start to rely on outside help and eventually change behavior permanently. As with some of the more traditional strategies, emergency support saves reindeer lives, and keeps nomads in the tundra, enabling them to recover their herds.

According to our long-term field data and interviews with 28 households (with 62 recorded observations of their migration changes), the most frequent response of Nenets to climate and other challenges is mobility. The most common reasons for the changes of nomadic routes were classified as pasture quality (21), climate (7), social reasons (7), industry (4), and a "weak" herd (2). Social reasons include wanting to migrate with or away from other people. The anonymized data for these descriptive statistics is available at the Arctic Data Center (Mertens et al. 2023). Most common are strategic migration shifts, followed by free grazing, and tactical shifts—all strategies that relate directly to nomadic mobility.

Climate Trends

As climate was one of the factors that herders most frequently mentioned, we felt an analysis of local climate trends on Yamal would expand our understanding of the development of climate pressure. Our analysis of data from five weather stations on Yamal from 1966 to 2021 indicates that forms of extreme weather are statistically becoming more common. However, the effects are heterogeneous across the region.

The weather stations that generated the data that we analyzed are located roughly on a north to south transect across the peninsula, as indicated in Figure 1. Belyi is in the north; Marre-Sale is midway on the west coast; Novyi Port is on the southeast corner of the peninsula on the north side of the Obskaia Bay; Nyda and Salekhard are south of the peninsula in or near the forest zone; Nyda is on the south coast of Obskaia Bay.

Figure 11 presents our analysis of meteorological data from five stations over 55 years. The stations are arranged in rows on the figure,

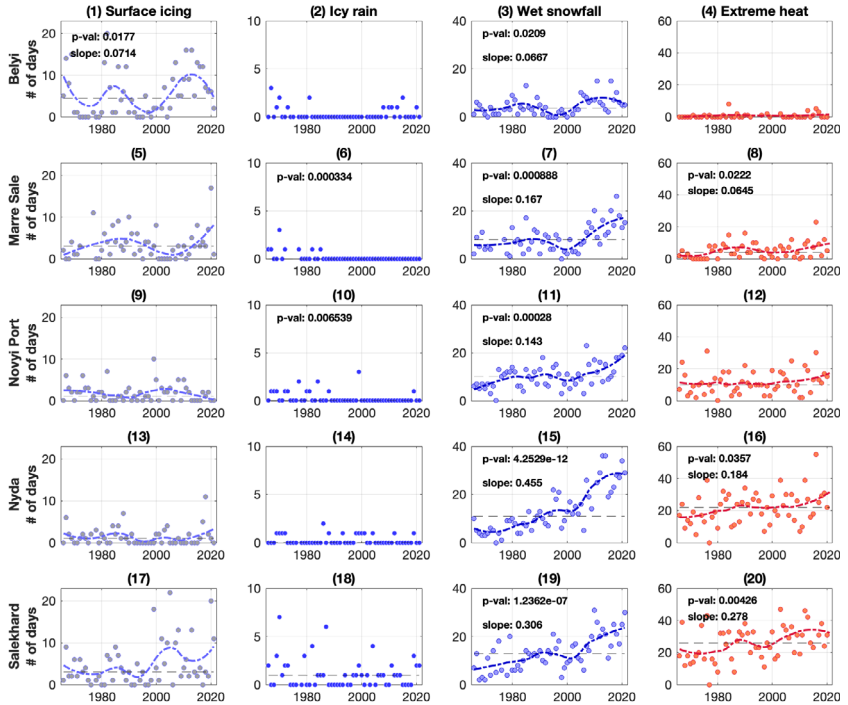

Figure 11. Atmospheric data from five weather stations on the Yamal Peninsula (locations are in Figure 1) illustrating the number of days of surface icing, icy rain, wet snowfall, and extreme summer heat, 1966–2021. Figure by the authors.

approximating the north to south arrangement of stations. The four types of measurement are arranged in the columns on the figure: surface icing, icy rain, wet snowfall, and extreme heat. Thus, each of the 20 graphs plots the number of days per year for the specific phenomena at each station by year. Significance figures and slope are reported only for those phenomena and stations where the Mann-Kendall test for a monotonic trend was statistically significant. The slope was calculated using Sen's estimator of slope. The trendlines were calculated using LOESS smoothing.

Wet snowfall and extreme heat in summer are particularly visible at the stations in southern Yamal with significant increases from the 1990s. The number of days with surface icing increased significantly in the far north. However, there is significant interannual variability in surface icing across all locations that defies linear trend approximation.

In southern Yamal, there is a significant increase in the number of days with wet snowfall (3–5 days/decade), while in northern Yamal these changes are less conspicuous (up to 1 day/decade). There are similar trends for warm/hot weather during summer (number of days with temperature higher than 20 degrees C) in southern vs. northern Yamal. The significance of these changes in southern Yamal relative to the adaptive strategies of reindeer herders is discussed below.

Discussion

Pre-Soviet research on Yamal Nenets reindeer nomads lacks detailed accounts of critical weather events such as ROS, but they do contain references to sudden calamity followed by mass death of reindeer, connected to epizootic diseases such as anthrax (Evladov 1992; Zhitkov 1913). Even so, narratives of natural disasters are passed down orally across generations of herders. These narratives allow us to estimate that such disasters occurred approximately once in a generation (Golovnev 2017). The main problem associated with contemporary climate change is the increase in frequency of these severe events, cutting short nomads' ability to restore their herds before the next disaster comes (Stammler and Ivanova 2020). Indeed, according to previous studies, critical weather events (such as ROS) leading to mass reindeer mortality have become more frequent in the European and West Siberia tundra (Tyler et al. 2021). Our analysis of meteorological data from Yamal over the past 55 years confirms these concerns with more frequent icing in the north and wet snowfall and extreme heat in the south. We find that the degree of change increases further south on the peninsula—near Obskaia Bay and the Ob River—which are critical points on spring and fall migration routes.

Free grazing is a modern example of self-organization within the Indigenous community and mutual assistance among herders during icing of pastures (Volkovitskiy and Terekhina 2021). Reindeer disperse themselves in a free distribution relative to the resources they can find. As a result, reindeer from different households are allowed to mingle, although this mingling of animals from different herds creates the problem of sorting out the ownership of particular animals. As long-time observers of this strategy, we know that the solution to this problem requires trusting relationships between households. Herders and groups of households unite to jointly search for reindeer in the tundra and cooperate in separating the animals belonging to different

owners. In addition, under free grazing reindeer herders are not seen as breaking informal or formal rules about where they are pasturing their herds, since it is the animals themselves that are making those decisions. This is different from the herders leading their animals into someone else's pastures, which increases the likelihood of conflict. Free grazing is both a conflict management strategy and a survival strategy that depends on inter-household trust and reciprocity. However, climate change in the southern part of the region is putting pressure on this and other strategies. Herders mustering along the Obskaia Bay shore while waiting for freeze-up on the north side or thaw on south side puts many households in the same area for unpredictable periods of time.

In the pre-Soviet period, the Nenets did not expect external help or state support, so they developed internal social mechanisms to maintain a nomadic lifestyle (Volzhanina 2012). Some traditional strategies (see Figures 6 and 7, and Table 2) have greatly decreased, although there are still rare cases of temporal transfer of reindeer from wealthy herders to poorer households with an obligation to return trained draft bulls. We presume that these practices decreased in use during the Soviet era due to the state limiting the size of private herds and policies against "exploitation." After the collapse of the USSR and the emergence of a free market for reindeer products, the attitude toward reindeer, which became the main source of income for all nomadic Nenets households, has also changed. In addition to direct transfer, reindeer now also move from rich to poor households via the state, when herders willingly sell their reindeer to the state for later distribution among households who have lost reindeer during icing events. For this combination of strategies 6 and 10 to work, the monetary price for live reindeer must be higher than the income from selling them to a slaughterhouse. This market-based scheme excludes the patron–client relations in the tundra reported in earlier ethnographies (Evladov 1992), feeds forward to higher levels of social integration, and increases the role and reputation of state authorities among herders in those cases when reindeer transfer works well. However, climate change may exacerbate existing inequalities and social conflicts as herds mix and must be sorted out, with larger herd owners being at somewhat of an advantage.

A number of the traditional adaptive strategies depend on the maintenance of mobility. Mobility is essential to Nenets livelihood and cosmology—even the spirits migrate (Golovnev 2012). Most households have a sacred sledge, which hosts spirits that accompany people and reindeer on their yearly migration cycle. Many of the items in the

sacred sledges are in the form of wooden figures that represent mobile "copies" of the spirit host that resides on a sacred site. These sacred sites thus form anchor points for spiritual mobility. While industrial development and infrastructure construction on Yamal certainly create constraints on reindeer herder movement and availability of pastures, preferred campsites, and even sacred sites, industrial development also provides opportunities for herders to sell reindeer to markets and fish to shift workers, to travel more quickly to urban areas to deliver and retrieve children from schools, and to get to urban centers in cases of emergency. It also provides interactions with non-Indigenous workers, which broadens their social networks. Thus, the influence of industry continues to imply both opportunities and constraints for the herders (Stammler 2005) and social influence at the regional scale.

Support from industrial companies or the regional government to reindeer herders after critical weather events have the potential to reduce the severity of reindeer mortality. Help can come in the form of snowmobiles, petroleum products, firewood, and industrially produced animal fodder. In the short term, such aid is highly valued and helpful for reindeer herders. Many reindeer herding households in Fennoscandia have transitioned to imported hay and imported fodder to maintain herds in the context of centrally managed reindeer herding territories and global warming. However, Fennoscandian reindeer herders report problems stemming from the long-term use of imported fodder on reindeer health, behavior, and their ability to forage on their own (Turunen and Vuojala-Magga 2014). Furthermore, this strategy increases the dependence of reindeer herders on outside resources and supplies.

Local cultural practices and those coming from outside can offer solutions to new or recurring problems, or they can pose barriers (Pisor, Lansing, and Magargal 2023). We, like our colleagues working in other parts of the world, have observed that wealthy reindeer herders on Yamal—households with a thousand or more reindeer—do endure extreme ROS events better than households with small herds (Zuev 2020; Laptander et al 2023). A family with a herd of two hundred or fewer reindeer is more likely to lose all their reindeer in an extreme event. While the cumulative effects of growing herd sizes have raised concerns (Golovatin, Morozova, and Ektova 2012), there are limitations on this strategy. Few households have the opportunity to accumulate a large herd as it requires skill, significant additional labor input, cash, and *yab* (Nenets: "luck in reindeer"). At the same time, the size of a herd is far from fixed and is tied to management decisions among relatives:

five brothers uniting their herds of two hundred animals each also results in a herd of one thousand. Our research shows that throughout the twentieth century herds were always flexibly united and separated, both seasonally, as well as due to inheritance or life decisions. Climate adaptation science needs a science of culture so we can better understand how such strategies work within Nenets frames of reference. Combining this knowledge with empirical study of change, our work can also help to identify influences on decisions to adopt one or another strategy and to describe the social and environmental ramifications of those solutions on larger scales.

The three groups of strategies we identified earlier—direct responses involving nomadic mobility (strategies 1–4); strategies involving relationships within the community (strategies 5–7); and strategies involving outside actors, such as the authorities or industrial companies (strategies 8–10)—have differing sets of limitations and costs, particularly in light of the changing climate, which creates challenges at critical junctures of seasonal migration. All of these strategies ultimately help keep nomads on the land, which is necessary for maintaining the knowledge and skills for reindeer herding in the future. In addition, strategies 5–7 involve traditional social safety networks, which also reduces the need for outside subsidies. On the other hand, strategies 8–10 involving outside actors potentially create new opportunities for some household members, allowing for economic diversification, which is also a common risk-reducing strategy.

Conclusion

Nenets reindeer herders have been addressing the challenges of unpredictable weather due to climate change, expanding infrastructure development, and increased pressure on pastures using a suite of adaptive strategies, many of which have continuity over a century. Several strategies—centering on spatial flexibility in migration routes—can be implemented on the household level with minimal or moderate interaction with neighboring households. Another set of strategies involves more intensive relationships with other households and has greater potential for unfair situations to develop. A final set of strategies involves interactions with settled communities, the gas industry, or administrative relief. The increasing frequency of icing events against the backdrop of increased industrial infrastructure has more potential to increase dependency on external support, which can change the nature

of resilience among the Nenets communities. The adaptive capacity of reindeer herders is enhanced through a combination of new and old strategies, traditional and new methods. At the same time, herders need freedom of action to implement these strategies.

We identify critical zones where climate change is having the strongest effects, supporting the need for development of forecasting measures and emergency response and support to buffer the immediate effects of climate change on reindeer pastoralism. Classical ethnographic methods combined with climate change analysis help us to understand the complexity of human life on Yamal. Our research has policy implications for utilizing the science of culture to understand the practicalities of Nenets adaptive strategies for climate change as well as the larger-scale feed-forward effects of these strategies. The problems we have considered are relevant for the entire circumpolar zone, where Indigenous peoples continue to practice traditional economic activities. As the Arctic is both a hotspot for climate change as well as for the advancement of industry to ever remoter areas, Indigenous livelihoods are under adaptation pressure not only on Yamal but also elsewhere in the Arctic. We have demonstrated how a deeper understanding of culturally embedded practices combined with scientific data leads to insights that can potentially boost the resilience of such livelihoods.

An obvious need for reindeer herding is the availability and accessibility of meteorological data for herders, as well as improved weather forecasting capabilities. Another important task for regional authorities (at least for the Russian Arctic) is to develop several options for responding to and supporting Indigenous communities after critical weather events. As one Yamal municipal official commented on the recent large-scale icing: "I understand, it's like COVID—now regular icing has become normal, we need to learn to live with it." In our view, the most optimal policy would be to support strategies that we broadly define as strategies involving "internal" and "outside" actors preserving the agency of Indigenous households. We have shown in this article that one, if not the most, important building block for this agency is the Nenets' freedom to move, as mobility is a key adaptation strategy. The more this mobility is restricted by external forces beyond the nomads' control, the more they may become dependent on external help in crises. In other words, a balanced system where reindeer herders can maintain economic independence and mobility without becoming used to a dependent model of dealing with crises should be found.

Acknowledgements

We are very grateful to the Yamal Nenets who help to improve our understanding of life on the Arctic. This research was supported by grants from the National Science Foundation 2126794 (Boise State University), 1725654, 1928014, and 2126792 (University of Michigan), 1724786, 1928040, and 2126798 (Ohio State University), and 2126799 (University of Colorado). FS an AI were also supported by a grant from the Research Council of Finland, 342462. AT, AV, and PO were supported by the State Program of the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences, No. 122021000089-9.

Alexandra Terekhina is a researcher at the Arctic Research Station of the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences.
Email: terekhina.yamal@gmail.com; ORCID: 0000-0002-2949-0520.

Alexander Volkovitskiy is a researcher at the Arctic Research Station of the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences.
Email: alvolkovitskiy@gmail.com; ORCID: 0000-0001-8767-0944.

Florian Stammler is a Research Professor of the Arctic Centre at the University of Lapland.
Email: florian.stammler@ulapland.fi; ORCID: 0000-0002-6243-773X.

Karl Mertens is a PhD student of the Department of Anthropology at Boise State University.
Email: karlmertens@boisestate.edu; ORCID: 0000-0002-2456-1262.

Valeriy Y. Ivanov is a Professor in the Civil and Environmental Engineering Faculty at the University of Michigan.
Email: ivanov@umich.edu; ORCID: 0000-0002-2456-1262.

Pavel Orekhov is a researcher at the Arctic Research Station of the Institute of Plant and Animal Ecology of the Ural Branch of the Russian Academy of Sciences.
Email: orekhov.eci@gmail.com; ORCID: 0000-0002-3154-5295.

Colin D. Wren is an Associate Professor in the Department of Anthropology at the University of Colorado.
Email: cwren@uccs.edu; ORCID: 0000-0003-4940-3997.

Boqi Tian is a student in the Civil and Environmental Engineering Faculty at the University of Michigan.
Email: boqitian@umich.edu; ORCID: 0000-0003-4695-8161.

Xin Shen is a student in the Civil and Environmental Engineering Faculty at the University of Michigan.
Email: xinsh@umich.edu; ORCID: 0000-0002-1734-4307.

Aytalina Ivanova is a researcher at the Arctic Centre of the University of Lapland.
Email: Aytalina.Ivanova@ulapland.fi; ORCID: 0000-0002-1831-7394.

Desheng Liu is a professor in the Department of Geography at The Ohio State University.
Email: liu.738@osu.edu; ORCID: 0000-0002-6088-5985.

John P. Ziker is a Professor and Chair of the Department of Anthropology at Boise State University.
Email: jziker@boisestate.edu; ORCID: 0000-0001-9059-5594.

References

Bartsch, Annett, Timo Kumpula, Bruce C. Forbes, and Florian Stammler. 2010. "Detection of Snow Surface Thawing and Refreezing in the Eurasian Arctic with QuikSCAT: Implications for Reindeer Herding." *Ecological Applications* 20 (8): 2346–2358. https://doi.org/10.1890/09-1927.1.

Behnke, Roy H., Ian Scoones, and Carol Kerven. 1993. *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas*. London: Overseas Development Institute.

Bennett, T. M. Bull, Nancy G. Maynard, Patricia Cochran, Robert Gough, Kathy Lynn, Julie Maldonado, Garrit Voggesser, Susan Wotkyns, and Karen Cozzetto. 2014. "Indigenous Peoples, Lands, and Resources." In *Climate Change Impacts in the United States: The Third National Climate Assessment*, ed. Jerry M. Melillo, Terese C. Richmond, and Gary W. Yohe, 297–314. Washington, DC: US Global Change Research Program. https://doi.org/10.7930/J09G5JR1.

Bulygina, Olga N., Valerii M. Veselov, Tatiana M. Aleksandrova, and Natalia N. Korshunova. 2023. "Opisanie Massiva Dannykh po Atmosfernym Iavleniiam na Meteorologicheskikh Stantsiiakh Rossii" [A Description of Mass Data on Atmospheric Phenomena at the Meteorological Stations of Russia]. Svitdeltel'stvo o Gosudarstvennoi Registratsii Bazy Dannykh No. 2015620081, 14 February 2023.

Degteva, Anna, and Christian Nellemann. 2013. "Nenets Migration in the Landscape: Impacts of Industrial Development in Yamal Peninsula, Russia." *Pastoralism* 3 (1): 1–21. https://doi.org/10.1186/2041-7136-3-15.

Evladov, Vladimir P. 1992. *Po tundram Iamala k Belomu ostrovu: Ekspeditsiia na Krainii Sever poluostrova Iamal v 1928–1929 gg.* [Across the Yamal tundra to White Island: The Expedition on the Northern Lands of the Yamal Penin-

sula in 1928–1929]. Tiumen': Institut problem osvoeniia Severa Sibirskogo otdelenniia Rossiiskoi Akademii nauk.

Forbes, Bruce C. 2008. Equity, Vulnerability and Resilience in Social-Ecological Systems: A Contemporary Example from the Russian Arctic. *Research in Social Problems and Public Policy* 15: 203–236. https://doi.org/10.1016/S0196-1152(07)15006-7.

Forbes, Bruce C, Timo Kumpula, Nina Meschtyb, Roza Laptander, Marc Macias-Fauria, Pentti Zetterberg, Mariana Verdonen, et al. 2016. "Sea Ice, Rain-on-Snow and Tundra Reindeer Nomadism in Arctic Russia." *Biology Letters* 12 (11): 4–8. https://doi.org/10.1098/rsbl.2016.0466.

Forbes, Bruce C., Timo Kumpula, Nina Meschtyb, Roza Laptander, Marc Macias-Fauria, Pentti Zetterberg, Mariana Verdonen, et al. 2022. "Coping with a Warming Winter Climate in Arctic Russia: Patterns of Extreme Weather Affecting Nenets Reindeer Nomadism." In *Resilience Through Knowledge Co-Production*, ed. Marie Roué, Douglas Nakashima, and Igor Krupnik, 217–232. Cambridge University Press. https://doi.org/10.1017/9781108974349.017.

Forbes, Bruce C., Florian Stammler, Timo Kumpula, Nina Meschtyb, Anu Pajunen, and Elina Kaarlejärvi. 2009. "High Resilience in the Yamal-Nenets Social-Ecological System, West Siberian Arctic, Russia." *Proceedings of the National Academy of Sciences of the United States of America* 106 (52): 22041–22048. https://doi.org/10.1073/pnas.0908286106.

Golovatin, Mikhail G., Ludmila M. Morozova, and Svetlana N. Ektova. 2012. "Effect of Reindeer Overgrazing on Vegetation and Animals of Tundra Ecosystems of the Yamal Peninsula." *Czech Polar Reports* 2 (2): 80–91.

Golovnev, Andrei V. 2012. "Gods of Movement in the Nenets and Khanty Beliefs." *Religiovedenie* 4: 37–48.

Golovnev, Andrei V. 2017. "Challenges to Arctic Nomadism: Yamal Nenets Facing Climate Change Era Calamities." *Arctic Anthropology* 54 (2): 40–51.

Hansen, Brage B., Marlène Gamelon, Steve D. Albon, Aline M. Lee, Audun Stien, R. Justin Irvine, Bernt Erik Sæther, et al. 2019. "More Frequent Extreme Climate Events Stabilize Reindeer Population Dynamics." *Nature Communications* 10 (1): 1–8. https://doi.org/10.1038/s41467-019-09332-5.

Hanssen-Bauer, Inger, Rasmus E. Benestad, Julia Lutz, Dagrun Vikhamar-Schuler, Pavel Svyashchennikov, and Eirik J. Førland. 2023. "Comparative Analyses of Local Historical and Future Climate Conditions Important for Reindeer Herding in Finnmark, Norway and the Yamal Nenets Autonomous Okrug, Russia." In *Reindeer Husbandry: Adaptation to the Changing Arctic, Volume 1*, ed. Svein Disch Mathiesen, Inger Marie Gaup Eira, Ellen Inga Turi, Anders Oskal, Mikhail Pogodaev, and Marina Tonkopeeva, 187–222. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-17625-8_8.

Istomin, Kirill V., and Nikolai B. Vakhtin. 2022. "Faktor Neopredelennosti v Sovremennykh Soobshchestvakh Krainego Severa RF: Metodologicheskie

Podkhody k Izucheniiu" [The Factor of Uncertainty in Contemporary Northern Communities of the Russian Federation: Methodological Approaches to Study]. *Sotsial'naia Geografiia i Sotsial'naia Antropologiia* 68 (985): 420–436. https://doi.org/10.30758/0555-2648-2022-68-4-420-436.

Ivanov, Valeriy Y., Peter S. Ungar, John P. Ziker, Svetlana Yu. Abdulmanova, Gerardo Celis, Andrew Dixon, Dorothee Ehrich, et al. (2024). A convergence science approach to understanding the changing Arctic. *Earth's Future* 12: e2023EF004157. https://doi.org/10.1029/ 2023EF004157.

Kasten, Erich. 2021. *Mensch und Natur in Sibirien: Umweltwissen und nachhaltige Naturbeziehungen in Zeiten des Klimawandels. SEC Publications*. Fürstenberg/Havel: Verlag der Kulturstiftung Sibirien.

Klokov, Konstantin B. 2020. "Diversity of Regional Trends in Traditional Reindeer Husbandry in the Russian Arctic." In *IOP Conference Series: Earth and Environmental Science* 539: 1–8. Institute of Physics Publishing. https://doi.org/10.1088/1755-1315/539/1/012180.

Klokov, Konstantin B., and Vladimir V. Mikhailov. 2019. "Assessment of Climatic Conditions for Siberian Reindeer Herding on the Basis of Heat Balance Modelling." *Arctic* 72 (1): 28–42. https://doi.org/10.14430/arctic67916.

Krupnik, Igor. 2018. "'Arctic Crashes:' Revisiting the Human-Animal Disequilibrium Model in a Time of Rapid Change." *Human Ecology* 46 (5): 685–700. https://doi.org/10.1007/s10745-018-9990-1.

Kumpula, Timo, Anu Pajunen, Elina Kaarlejärvi, Bruce C. Forbes, and Florian Stammler. 2011. "Land Use and Land Cover Change in Arctic Russia: Ecological and Social Implications of Industrial Development." *Global Environmental Change* 21 (2): 550–562. https://doi.org/10.1016/j.gloenvcha.2010.12.010.

Kumpula Timo, Bruce C., Forbes, Florian Stammler, and Nina Meschtyb. 2012. Dynamics of a Coupled System: Multi-Resolution Remote Sensing in Assessing Social-Ecological Responses during 25 Years of Gas Field Development in Arctic Russia. *Remote Sensing* 4: 1046–1068. https://doi.org/10.3390/rs4041046.

Leduc, Timothy B. 2007. "Sila Dialogues on Climate Change: Inuit Wisdom For a Cross-Cultural Interdisciplinarity." *Climatic Change* 85 (3-4): 237–250. https://doi.org/10.1007/s10584-006-9187-2.

Laptander, Roza, Tim Horstkotte, Joachim Otto Habeck, Sirpa Rasmus, Teresa Komu, Heidrun Matthes, Hans Tømmervik, et al. 2023. "Critical Seasonal Conditions in the Reindeer-Herding Year: A Synopsis of Factors and Events in Fennoscandia and Northwestern Russia." *Polar Science* (November) 101016. https://doi.org/10.1016/j.polar.2023.101016.

Lavrillier, Alexandra, and Semen Gabyshev. 2021. "An Indigenous Science of the Climate Change Impacts on Landscape Topography in Siberia." *Ambio* 50: 1910–1925. https://doi.org/10.1007/s13280-020-01467-w.

Makeev, Viacheslav. M., Konstantin B. Klokov, Leonid A. Kolpashchnikov, and Vladimir V. Mikhailov. 2014. *Severnyi Olen' v Usloviiakh Izmeniaiushchegosia Klimata* [Reindeer in the changing climate]. Sankt-Peterburg: Gosudarstvennaia Poliarnaia Akademiia.

Mathiesen, Svein D., Mathis P. Bongo, Philip Burgess, Robert W. Corell, Anna Degteva, Inger Marie G. Eira, Inger Hanssen-Bauer, et al. 2018. "Indigenous Reindeer Herding and Adaptation to New Hazards in the Arctic." In *Indigenous Knowledge for Climate Change Assessment and Adaptation*, ed. Douglas Nakashima, Igor Krupnik, and Jennifer T. Rubis, 198–213. Cambridge University Press. https://doi.org/10.1017/9781316481066.015.

Merkur, Daniel. 1983. "Breath-Soul and Wind Owner: The Many and the One in Inuit Religion." *American Indian Quarterly* 7 (3): 23–39. https://doi.org/10.2307/1184255.

Mertens, Karl, John Ziker, Alexandra Terekhina, Alexander Volkovitskiy, Florian Stammler, Aytalina Ivanova, Valeriy Ivanov, et al. 2023. "Household Migration Decisions and Climate Variables of Nenets Reindeer Herders in Northern Siberia (Yamal Peninsula), 2001–2022." Arctic Data Center. https://doi.org/doi:10.18739/A2057CT96.

Nakashima, Douglas, Igor Krupnik, and Jennifer T. Rubis. 2018. *Indigenous Knowledge for Climate Change Assessment and Adaptation*. Cambridge University Press. https://doi.org/10.1017/9781316481066.

Niamir-Fuller, Maryam, and Matthew D. Turner. 1999. "A Review of Recent Literature on Pastoralism and Transhumance in Africa." In *Managing Mobility in African Rangelands: The Legitimization of Transhumance*, ed. Maryam Naimir-Fuller, 18–46. London: Intermediate Technology Publications. https://doi.org/10.3362/9781780442761.002.

Pape, Roland, and Joerg Loeffler. 2012. "Climate Change, Land Use Conflicts, Predation and Ecological Degradation as Challenges for Reindeer Husbandry in Northern Europe: What Do We Really Know After Half a Century of Research?" *Ambio* 41: 421–434. https://doi.org/10.1007/s13280-012-0257-6.

Pisor, Anne, J. Stephen Lansing, and Kate Magargal. 2023. "Climate Change Adaptation Needs a Science of Culture." *Philosophical Transactions of the Royal Society B: Biological Sciences* 378 (1889). https://doi.org/10.1098/rstb.2022.0390.

Perevalova, Elena. V. 2015. "Interv'iu c Olenevodami Yamala o Padezhe Olenei i Perspektivakh Nenetskovo Olenevodstva" [Interview with the Reindeer Herders of Yamal about the Loss of Reindeer and the Perspectives of Nenets Herders]. *Ural'skii Istoricheskii Vestnik* 2 (47): 39–49.

Rantanen, Mika, Alexey Yu. Karpechko, Antti Lipponen, Kalle Nordling, Otto Hyvärinen, Kimmo Ruosteenoja, Timo Vihma, and Ari Laaksonen. 2022. "The Arctic Has Warmed Nearly Four Times Faster than the Globe since 1979." *Communications Earth and Environment* 3 (1): 1–10. https://doi.org/10.1038/s43247-022-00498-3.

Rasmus, Sirpa, Minna Turunen, Anna Luomaranta, Sonja Kivinen, Kirsti Jylhä, and Jani Räihä. 2020. "Climate Change and Reindeer Management in Finland: Co-Analysis of Practitioner Knowledge and Meteorological Data for Better Adaptation." *Science of the Total Environment* 710 (March). https://doi.org/10.1016/j.scitotenv.2019.136229.

Rasmussen, Knud. 1927. *Across Arctic America: Narrative of the Fifth Thule Expedition*. New York: G. P. Putnam's Sons.

Rees, Gareth W., Florian M. Stammler, Fiona S. Danks, and Piers. Vitebsky. 2008. "Vulnerability of European Reindeer Husbandry to Global Change." *Climatic Change* 87 (1-2): 199–217. https://doi.org/10.1007/s10584-007-9345-1.

Roué, Marie. 2018. "'Normal' Catastrophes or Harbinger of Climate Change? Reindeer-Herding Sami Facing Dire Winters in Northern Sweden." In *Indigenous Knowledge for Climate Change Assessment and Adaptation*, ed. Douglas Nakashima, Igor Krupnik, and Jennifer T. Rubis, 229–246. Cambridge University Press. https://doi.org/10.1017/9781316481066.017.

Salick, Jan, Anja Byg, Katie Konchar, and Robbie Hart. 2018. "Coping with Climate: Innovation and Adaptation in Tibetan Land Use and Agriculture." In *Indigenous Knowledge for Climate Change Assessment and Adaptation*, ed. Douglas Nakashima, Igor Krupnik, and Jennifer T. Rubis, 123–141. Cambridge University Press. https://doi.org/10.1017/9781316481066.010.

Scoones, Ian. 1995. *Living with Uncertainty: New Directions in Pastoral Development in Africa*. London: Intermediate Technology Publications.

Serreze, Mark C., Julia Gustafson, Andrew P. Barrett, Matthew L. Druckenmiller, Shari Fox, Jessica Voveris, Julienne Stroeve, et al. 2021. "Arctic Rain on Snow Events: Bridging Observations to Understand Environmental and Livelihood Impacts." *Environmental Research Letters* 16 (10): 105009. https://doi.org/10.1088/1748-9326/ac269b.

Sharp, Phil, and Susan Hockfield. 2017. "Convergence: The Future of Health." *Science* 355 (6325): 589.

Sokolov, Aleksandr A., Natalya A. Sokolova, Rolf A. Ims, Ludovic Brucker, and Dorothee Ehrich. 2016. "Emergent Rainy Winter Warm Spells May Promote Boreal Predator Expansion into the Arctic." *Arctic* 69 (2): 121–129. https://doi.org/10.14430/arctic4559.

Stammler, Florian. 2005. *Reindeer Nomads Meet the Market: Culture, Property and Globalisation at the "End of the Land."* Münster: Lit.

Stammler, Florian M. 2011. "Camps of the Tundra: Politics through Reindeer among Saami Pastoralists by Robert Paine." *Journal of Anthropological Research* 17 (2): 15–18.

Stammler, Florian M., and Aytalina Ivanova. 2020. "From Spirits to Conspiracy? Nomadic Perceptions of Climate Change, Pandemics and Disease." *Anthropology Today* 36 (4): 8–12. https://doi.org/10.1111/1467-8322.12589.

Terekhina, Aleksandra N., and Aleksandr I. Volkovitskiy. 2020. "The Railway across the Tundra: Yamal Reindeer Herders and Infrastructure." *Siberian Historical Research* 2020 (3): 48–61. https://doi.org/10.17223/2312461X/29/4.

Terekhina, Alexandra, and Alexander Volkovitskiy. 2023. "Climate Change through the Eyes of Yamal Reindeer Herders." In *The Siberian World*, ed. John Ziker, Jenanne Ferguson, and Vladimir Davydov, 166–178. New York: Routledge. https://doi.org/10.4324/9780429354663-13.

Tonkopeeva, Marina, Robert W. Corell, Nancy G. Maynard, Ellen Inga Turi, Inger Marie Gaup Eira, Anders Oskal, and Svein Disch Mathiesen. 2022. "Framing Adaptation to Rapid Change in the Arctic." In *Reindeer Husbandry: Adaptation to the Changing Arctic, Volume 1*, ed. Svein Disch Mathiesen, Inger Marie Gaup Eira, Ellen Inga Turi, Anders Oskal, Mikhail Pogodaev, and Marina Tonkopeeva, 15–35. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-17625-8_2.

Turunen, Minna T., Sirpa Rasmus, Mathias Bavay, Kimmo Ruosteenoja, and Janne Heiskanen. 2016. "Coping with Difficult Weather and Snow Conditions: Reindeer Herders' Views on Climate Change Impacts and Coping Strategies." *Climate Risk Management* 11: 15–36. https://doi.org/10.1016/j.crm.2016.01.002.

Turunen, Minna, and Terhi Vuojala-Magga. 2014. "Past and Present Winter Feeding of Reindeer in Finland: Herders' Adaptive Learning of Feeding Practices." *Arctic* 67 (2): 173–188. https://doi.org/10.14430/arctic4385.

Tyler, Nicholas J. C., Johan M. Turi, Monica A. Sundset, Kirsti Strøm Bull, Mikel N. Sara, Erik Reinert, Nils Oskal, et al. 2007. "Saami Reindeer Pastoralism under Climate Change: Applying a Generalized Framework for Vulnerability Studies to a Sub-Arctic Social-Ecological System." *Global Environmental Change* 17 (2): 191–206. https://doi.org/10.1016/j.gloenvcha.2006.06.001.

Tyler, Nicholas J. C., Inger Hanssen-Bauer, Eirik J. Førland, and Christian Nellemann. 2021. "The Shrinking Resource Base of Pastoralists: Saami Reindeer Husbandry in a Climate of Change." *Frontiers in Sustainable Food Systems* 4: 1–46. https://doi.org/10.3389/fsufs.2020.585685.

Ulturgasheva, Olga, and Barbara Bodenhorn. 2022. *Risky Futures: Climate, Geopolitics and Local Realities in the Uncertain Circumpolar North*. Studies in the Circumpolar North; Volume 6. New York: Berghahn Books.

Volkovitskiy, Alexander, and Alexandra Terekhina. 2020. "The Contemporary Issues of Yamal Reindeer Herding: Discussions and Perspectives." *Etnografia* 2020 (2): 152–169. https://doi.org/10.31250/2618-8600-2020-2(8)-152-169.

Volkovitskiy, Alexander I., and Aleksandra N. Terekhina. 2021. "'Ran'she po l'du Perevalivali': Izmeneniia Klimata v Vospriiatii Tundrovikov" ['Earlier We Crossed the Ice': Climate Change in the Perception of Tundra Dwellers]. In *Chelovek i Priroda v Sibiri—Ekologicheskie Znaniia i Ustoichivye Prirodnye Otnosheniia vo Vremena Izmeneniia Klimata*, ed. Erich Kasten, 39–66. Fuerstenberg/Havel: Kulturstiftung Sibirien.

Volzhanina, Elena. A. 2012. "Traditional Mechanisms of Supporting a Nomadic Life on Yamal in the First Third of XX Century." *Vestnik Arkheologii, Anthropologii i Ethnografii* 3: 131–140.Walker, Donald A., Martha K. Raynolds, Fred J. A. Daniëls, Eythor Einarsson, Arve Elvebakk, William A. Gould, Adrian

E. Katenin, et al. 2005. "The Circumpolar Arctic Vegetation Map." *Source: Journal of Vegetation Science* 16 (3): 267–282. https://doi.org/10.1658/1100.

Zhitkov, Boris Mikhaĭlovich. 1913. *Poluostrov Iamal*: *Zapiski Imperatorskago russkago geograficheskago obshchestva po obshcheĭ geografii* [The Yamal Peninsula: Notes of the Imperial Russian Geographic Society according to a General Geography]. Saint Peterburg: Tip. M. M. Stasiulevicha.

Ziker, John P. 2021. "The Revival of Reindeer Herding in the North Baikal Highlands." *Reports of the Laboratory of Ancient Technologies* 17 (3): 79–95.

Zuev, Sergey. 2020. "The 'Success Story' of Private Reindeer Husbandry in Iamal? A Look at Herders' Budgets 30 Years after." *Region: Regional Studies of Russia, Eastern Europe, and Central Asia* 9 (1): 83–115. https://doi.org/10.1353/reg.2020.0003.