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The Impact of Climate Change on the Food (In)security of the Siberian Indigenous Peoples in the Arctic: Environmental and Health Risks

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Abstract: Climate change represents a global challenge that impacts the environment, traditional lifestyle and health of the Indigenous Peoples in the Arctic zone of Western Siberia and threatens their food security. Reindeer are an important food source for this population since reindeer herding products are used as traditional nutrition and effective preventive means and remedies for adapting to the cold and geomagnetic activity in the High North. Longer off-season periods, high summer and winter temperatures, melting ice, and forest and tundra fires have a significant impact on the trampling and degradation of reindeer pastures. These effects may lead to massive reindeer losses and changes in the traditional diet of the Indigenous Peoples in the Arctic, which result in increases in the prevalence of respiratory diseases, overweight and hypertension. This study applied a multidisciplinary approach based on ecological and medical research methods with the inclusion of socioeconomic analysis. The primary sources included data on the longitudinal dynamics of air temperature as a climate change indicator and reindeer livestock populations (1936–2018), consumption of reindeer products and physiological impacts on the Yamal Indigenous population collected during expeditions to the Arctic zone of Western Siberia in 2012–2018.

Keywords: climate change; food security; reindeer herding; reindeer losses; overgrazing; traditional nutrition; health risks; Arctic Indigenous Peoples; Yamal-Nenets Autonomous Okrug

1. Introduction

Food security, health and well-being of the Arctic Indigenous communities depend on reindeer herding. There have been rapid social, economic, and political changes in the Russian Arctic during the last half of the twentieth century. It has impacted Indigenous traditional livelihoods, community social networks, and their lifestyle. Furthermore, the Indigenous Peoples are increasingly exposed to risks associated with climate change [1–3] which is presenting challenges for reindeer herders in the Arctic. In recent decades, Arctic and subarctic regions have experienced significant warming trends [4–7], which can have devastating environmental impacts [8]. The dynamics of the increase in the average annual temperature in the Arctic has, on average, an effect that is two times greater than that in the temperate latitudes [9]. By the end of the twenty-first century, the global mean temperature is expected to rise 1–5 °C [9]. This increase in temperature has already affected reindeer herding activities [10–13], traditional lifestyle, well-being and health of the Indigenous Peoples in Scandinavia and the Russian Arctic [1,2,14]. Adaptive capacity [15,16] and coping strategies [17] for changes in the terrestrial ecosystem caused by climate change are urgently required [14,18,19].

A growing number of studies are providing insights into how climate change is being experienced in the Arctic, by northerners, beyond the variables included in climate change models, and how Arctic people are being affected [18,20,21]. Human dimensions of climate change have been enriched with the studies of vulnerability which are increasingly considering the multiple variables that drive exposure sensitivities, and research on the interconnections between climate and non-climatic factors (industrial development of the Arctic, changing socio-ecological and economic policies, etc.) that have acted synergistically to affect individuals and communities [18,22–24]. The effect of the political context could be so large as to conceal the impact of other natural factors on reindeer populations such as climate change. However, a gradual increase of reindeer populations in the northern part of Russia in the 1960s can be associated with changes in atmospheric circulation patterns [25]. Therefore, in our research, we are mostly focused on the impact of climate change on reindeer herding practices. However, the importance of other non-climatic factors as socio-economic drivers has also been considered.

Climate change is expected to have both positive and negative impacts on reindeer herding [3,17,26,27]. Regarding the positive effects, climate change has increased the duration of the snowless season and temperatures during the growing season, which have positively impacted the productivity of plants and the growth of the reindeer's forage base [27,28]. In spring, early snowmelt and increased availability of fresh forage are favourable for lactating reindeer and the new-born calves [29–32]. These climatic changes have impacted the nomadic routes of reindeer herds and, ultimately, the traditional lifestyles of the local communities because of the decreased availability of their traditional food [33] for most of the year.

Regarding the negative impacts, warming can result in the potential re-emergence of anthrax associated with historic livestock burial sites [33–36], biological pollution, more severe insect harassment, epizootics and more frequent parasite epidemics [3,37–42]. It increases the risk of forest and tundra fires [43] (dry lichen represents an extreme fire hazard). The expansion of the taiga tick has caused the border of tick-borne encephalitis and borreliosis to move north. Longer warming periods in shallow water bodies and the thawing of cesspools previously located in the permafrost can lead to outbreaks of intestinal infections [36,44].

Warmer winters with "varying temperatures and events like rain-on-snow or thaw-freeze may lead to more frequent icing of snow and basal ice" [45], which make it difficult for reindeer to access ground lichens [3,46,47]. Warm autumns can also result in the growth of mycotoxin-producing microfungi (moulds) below the snow in reindeer pastures [3,47,48]. The lengthening of off-season periods and high summer temperatures contribute to the trampling (lichen becomes brittle when it dries) and degradation of reindeer pastures [49]. This damage results in less food being available to reindeer in winter and negatively affects the adaptive abilities of their bodies and their resistance to infections (brucellosis, mycobacteriosis, and anthrax), leading to increased losses during extreme weather and decreased offspring survival rates [50]. The trampled lichen takes a long time to recover and negatively impacts reindeer husbandry for several years. The increase in the occurrence of anomalous phenomena (winter thaws and rains, late spring with ice crust, high and prolonged heat) represents a significant threat, as it can result in massive reindeer losses [51,52] because of the decreased availability of pastures and ultimately placing an effect on the subsistence-based livelihoods of the Indigenous populations [53] jeopardizing the food security of the Indigenous Peoples.

Although climate change is projected to increase fish stocks in the Barents Sea capable of offering the availability of foods [54], the decrease of reindeer livestock is more likely expected. However, reindeer meat is a rich source of protein, minerals and essential fatty acids, and its consumption is culturally acceptable in these Arctic communities [55]. The loss of this food source increases the prevalence of chronic bronchitis [56,57], overweight [58] and arterial hypertension [59,60] because consuming reindeer meat, blood and liver helps to prevent these diseases [61–64] and increases the ability of the Indigenous population to adapt to the harsh Arctic living conditions [65–68]. The maintenance of a traditional diet is closely related to the maintenance of the traditional food system [69,70], which is "tightly interwoven with the culturally, socially and environmentally embedded practices of reindeer herding. Indigenous Peoples and their traditional food systems emerged in harmony with nature and contain knowhow on the sustainable use of natural resources in ways that contribute to their health" [71].

The environmental changes in the Russian North [72], and specifically in the Yamal-Nenets Autonomous Okrug (YNAO), have resulted in the melting of ice and the extension of the sea [73,74]. The ice crust formation in the winter of 2013–2014 and the outbreak of anthrax in the summer of 2016 have provoked a discussion on Nenets' reindeer husbandry "crisis", as evidenced by the overgrowth of herds and overgrazing [75,76]. Biologists and local governments emphasized the need to significantly reduce the Yamal reindeer population "for the sake of environmental safety". However, A. Golovnev presented an alternative approach focused on a system of movement: "skilful herd-navigation and quick manoeuvring is the basis of Nenets' traditional rule "*ya puna hayoda*" (land after us remains). Conversely, the consequences of sluggish and stationary behaviour, including huddling around camp for a long time, is reflected in another Nenets proverb: "*yadata habei*" (land is turned upside down)" [77]. These are examples of traditional coping strategies for dealing with the development of adverse weather and pasture conditions that have accumulated and been exchanged within the herding communities in different Arctic countries [78]. However, the rapidly changing Arctic environment and climatic challenges have made these coping strategies ineffective, requiring the development of new methods [46,79].

Climate change and the extensive exploitation of reindeer pastures have resulted in overgrazing [80]. This has caused the Indigenous Peoples to change their nomadic routes (i.e., some reindeer herders in the Priuralsky district of the YNAO have moved to the Laborovskay tundra, which is still rich with lichen). Nomadic reindeer herders of the Tazovskaya, Tanamskaya, Gydanskaya and Yuribeyskaya tundras have experienced the reduction of winter reindeer pastures: there are significantly damaged pastures next to the slaughterhouse in the Antipayutinskaya tundra, near the trading posts ("faktoria") Yuribey and Tanama, surrounding the settlements of Antipayuta and Gyda and near fishing sites on the coast of Ob Bay (north of the settlement of Antipayuta, on the western shore of Yambuto lake, on the coast of Gydan Bay, in the area of oil and gas deposits of the Messoyakhinskaya group) [27]. Thus, climate change has had a strong influence on the Arctic ecosystems and jeopardized the Indigenous Peoples' food security and their wellbeing [81,82]. In this study, we focused on analysing the longitudinal trends in the climatic parameters, reindeer livestock population and consumption of traditional reindeer products and the physiological impacts on the Yamal Indigenous population. These analyses can provide relevant information about the sustainability of reindeer herding and the Indigenous communities in the Arctic zone of Western Siberia.

2. Materials and Methods

2.1. Setting: The Yamal-Nenets Autonomous Okrug (YNAO): Geography, Population and Ethnic Structure

The YNAO, the geographic focus of our research, is an important region for the Indigenous Peoples of Russia, and it is located in the circumpolar northwest of West Siberia. It has a population of 544,008 [83] who live in an area of 769,250 square kilometres [84] with a population density of 0.71 people per square kilometre. The location of the YNAO (more than half of its territory is above the Arctic Circle) significantly influences the traditional livelihoods in this region. It is a unique territory because almost half of the minority Indigenous population of the Russian Arctic (about 45,000 people) reside there, including the Nenets, Khanty, Selkups and Komi-Zyryans. A total of 14,600 Indigenous Peoples are nomadic, living in tundra areas [85]. The culture, health and social well-being of Indigenous Peoples are strongly linked to their traditional lifestyle and traditional livelihoods (reindeer herding, fishing, etc.), which are essential for meeting Indigenous Peoples' vital needs and helping them to survive in the severe Arctic areas.

2.2. Study Design

In this paper, we present the results of a quantitative analysis of the impacts of climate change on the reindeer livestock population and consumption of traditional reindeer products and of a follow-up analysis of the increased risks of physiological health effects faced by the Siberian Indigenous Peoples in reindeer herding communities living and practicing nomadism in the remote territories of the YNAO. The objectives of our study were to determine (1) if the longitudinal dynamics of air temperature has impacted reindeer livestock populations in the YNAO in 1936–2018 and (2) if the dynamics of the reindeer livestock population has affected the consumption of reindeer products and the health of Indigenous Peoples in the Yamal Indigenous population in 2012–2018. Non-climatic factors could be also considered to explain the results.

2.3. Measurement Tools, Methodology and Study Population

The study applied a multidisciplinary approach based on ecological and medical research methods with the inclusion of policy and socioeconomic analysis. The primary sources included data on the longitudinal dynamics of air temperature as a climate change indicator, reindeer livestock population, consumption of reindeer products and physiological impacts (prevalence of arterial hypertension) on the Yamal Indigenous population.

The data on the average daily, average monthly and average annual air temperatures for the period from 1936 to 2018 were obtained from the open-source platforms of the Federal Service for Hydrometeorology and Environmental Monitoring in the Russian Federation (Roshydromet) [86]. We used data collected from three meteorological stations in the following locations in the YNAO: in the city of Nadym in the Nadymsky district (65.53333: 72.51667), in the settlement of Novy Port in the Yamalsky district (67.4100: 72.5600) and the settlement of Antipayuta in the Tazovsky district (69.06667: 76.83333). The data on the number of reindeer in the YNAO for the period from 1930 to 2018 were obtained from the Department of Agroindustrial Complex of YNAO [87].

First, the correlation between air temperature and the reindeer population was studied. Spearman's rank correlation coefficient was used to determine the strength of the link between the sets of data. Due to the seasonality observed in the time series, seasonal differencing was applied to eliminate the seasonal component with the use of an autoregressive integrated moving average (ARIMA) model [88,89]. Short-term forecasting (5 years) was carried out using the Almon distributed lag method. Second, a forecasting model of the dynamics of the reindeer population was developed. Third, the correlation between the reindeer livestock population and consumption of reindeer products (reindeer meat, liver and blood) with a follow-up correlation between the consumption of these products and the prevalence of arterial hypertension (as the main reason for mortality [59]) in the Yamal Indigenous population was studied.

The data on socio-demographic characteristics, consumption of reindeer products and health status were collected during expeditions to the Arctic zone of Western Siberia in 2012–2018. The fieldwork was conducted by researchers of the YNAO Arctic Scientific Research Centre, the National Medical Research Centre for Rehabilitation and Balneology, the Northern Arctic Federal University and the Association of Reindeer Herders in YNAO (two of the researchers were Indigenous).

To study the basic patterns of consumption of traditional reindeer products, we initially conducted a cross-sectional screening with the participation of the Indigenous inhabitants of the Arctic zone of Western Siberia. The inclusion criteria for the respondents were as follows: be over 18 years of age, be of Indigenous origin, be an Indigenous language speaker, be involved in reindeer herding, live a nomadic or semi-nomadic lifestyle and have resided in the tundra or the settlements of the Arctic zone of Western Siberia for over five years. The sequence of the survey was as follows: during an expedition to the settlement between 2012 and 2018, respondents were invited to participate in the survey while undergoing a medical examination conducted by the YNAO Arctic Scientific Research Centre at health care institutions. After the aims and content of the research were explained and consent for participation was obtained, the name of each person invited to take the survey was recorded in a registry, and they were given a questionnaire. The questionnaire was developed in Russian using the methodological recommendations of the Russian Academy of Medical Science (RAMS) Nutrition Institute (1996, 2016) [90,91]. It collected information about socio-demographic factors and the consumption of reindeer products (reindeer meat, liver and blood). Data collection was performed by medical doctors who had been trained in the study procedures with the assistance of Indigenous nurses and researchers. All participants given the questionnaire were interviewed and underwent medical examinations at the beginning of the study by a general practitioner, pulmonologist and cardiologist. If a patient had been found to have severe somatic pathology, they would have been excluded from the survey, but no such cases were found. Participants filled out a confidential paper questionnaire. The consumption of reindeer products was analysed according to the following questions: “How many grams of reindeer meat did you consume over the previous 30 days?”, “How many grams of reindeer liver did you consume over the previous 30 days?”, “How many grams of reindeer blood did you consume over the previous 30 days?” The participants received information about the programme, both verbally and in writing, and they provided written informed consent. The consent form stated that participation was voluntary and that their confidentiality was assured. Participants’ personal data and their answers were anonymised, numbered and entered into de-identified databases.

An analysis of the traditional foods (reindeer meat, liver and blood) was carried out using frequency and survey methods [63,92]. The amount of food consumed was estimated using a catalogue graphically depicting a range of portions of foods and dishes [93]. The amount of traditional products consumed over the previous 30 days was estimated in the survey. The blood pressure of the participants was measured three times according to the Korotkov method, and the presence of arterial hypertension (AH) was established in accordance with the recommendations for AH [94,95].

Statistical analyses were performed using Microsoft Excel 2016 and Statistica for Windows, v. 8.0 (StatSoft Inc., Oklahoma, USA). Significant differences were defined at a p-value < 0.05.

2.4. Ethics Approval

The study was approved by the Ethics Committee of the Arctic Scientific Research Centre of YNAO, Salekhard, Russian Federation, on 16 January 2012 (approval protocol No. 01/1-13). The research has been done in accordance with ethical concerns of working with the Indigenous Peoples in the Russian Federation (Constitution of the Russian Federation, Article 69. 14 March 2020). Communication was initiated with the Associations of the Indigenous Peoples and with representatives from national Indigenous communities of the Nadymsky, Yamalsky and Tazovsky districts in YNAO early in research planning. This resulted in an expression of interest from their representatives in having the research conducted in their communities.

3. Results and Discussion

Our main findings showed that climate change (increasing average air temperature) has impacted the reindeer population mostly in the central area of the Arctic zone of Western Siberia (Nadymsky district), as we found a weak correlation between the dynamics of average air temperature and reindeer livestock population in the northern areas (Yamalsky and Tazovsky districts). The weak correlation is explained with the stronger impact of non-climatic factors (i.e., the industrial development of the Arctic, changing socio-ecological and economic policies as well as tendencies of commodity production in the Indigenous reindeer herding communities). If the trend for increasing average annual temperatures continues at the same rate, the growth of the reindeer population in the YNAO will remain steady until 2025. After 2023, the dynamics of the reindeer population will slow down or become negative. Weather and extreme climatic events (the formation of an ice crust over large areas, freezing rain, heat waves) can cause catastrophic collapses in the reindeer population because many areas have insufficient reindeer pasture resources, which reduces the adaptive capabilities of the reindeer and the survival of offspring. Given the cyclical nature of these processes, the most dangerous period will be the spring of 2023–2024. However, these climatic effects and the reindeer population do not have direct impacts on food security, although the health status of the Indigenous population in the YNAO is strongly linked to the consumption of reindeer products.

The results of the correlation analysis of average air temperature and the reindeer population in three districts of the YNAO are presented in Table 1.

Table 1. Spearman rank-order correlations of average air temperature and the reindeer population.

District	Spear—R	*p*-Level
Nadymsky district	0.5	0.02
Yamalsky district	0.169278	0.126048
Tazovsky district	0.4	0.0001

The Nadymsky district located in the central part of the YNAO has different types of landscapes, including southern shrub tundra, forest-tundra and northern taiga. In this district, we found a direct strong statistically significant correlation between the average annual air temperature and the number of domesticated reindeer (rs = 0.5; p = 0.02). As the average annual temperature increased, the size of the reindeer herd increased, which is probably associated with the increase in the reindeer forage base because of the increase in the productivity of vascular plants in the warming climate. An increase in fodder naturally increases the adaptive reserves of animals, making it possible for them to endure unfavourable periods with fewer losses, increasing the survival of offspring and increasing the number of deer (Figure 1).

For the Yamal region, which is located above the Arctic Circle on the Yamal Peninsula, no reliable correlation was found between the reindeer population and air temperature (rs = 0.169278; p = 0.126048) (Figure 2).

For the Tazovsky region, which is located above the Arctic Circle on the Tazovsky, Gydansky and Yavay-Sale Peninsulas, only a weak direct correlation was found between the average annual air temperature and the number of domesticated reindeer (rs = 0.4; p = 0.0001) (Figure 3).

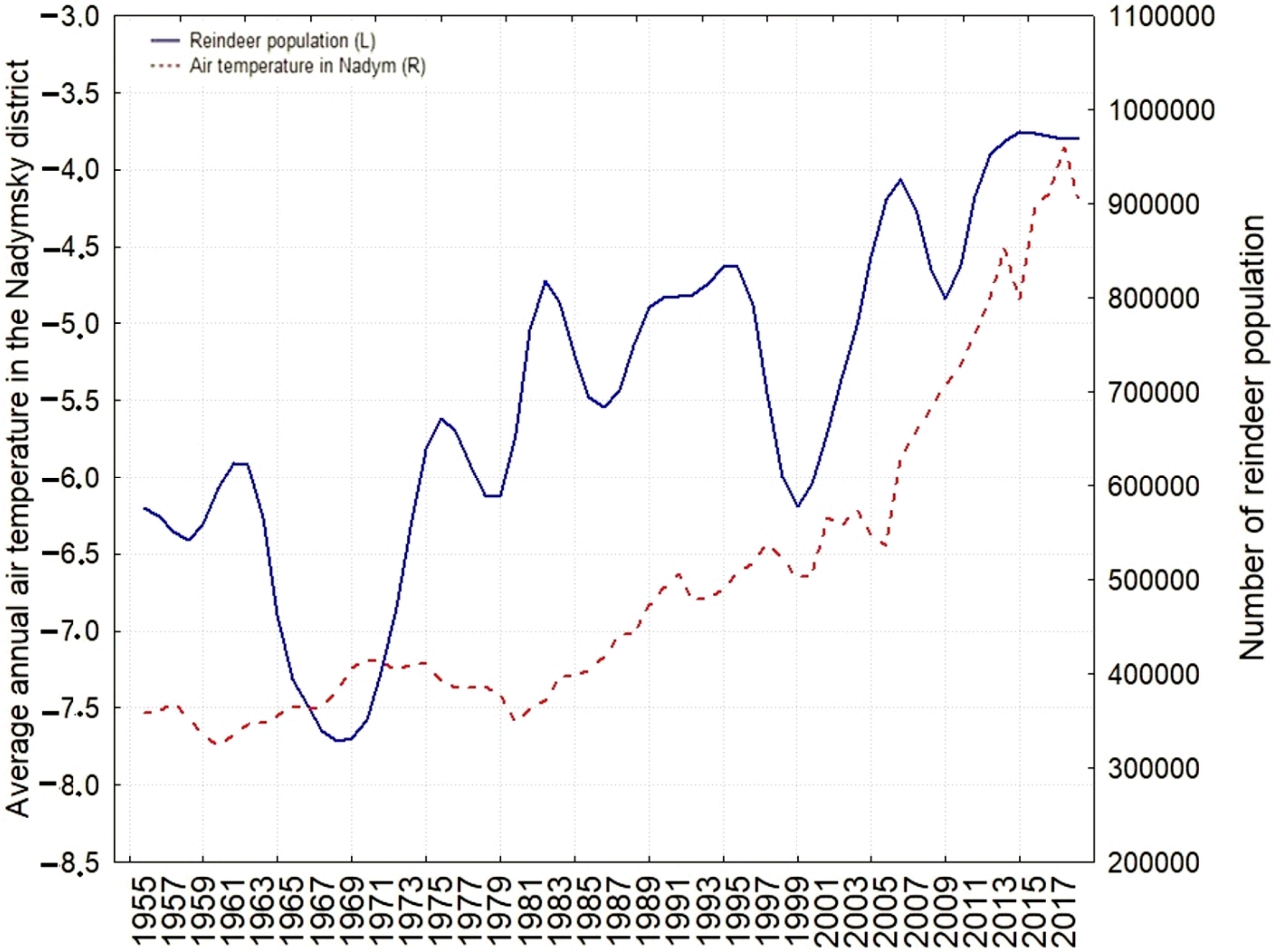

Figure 1. Correlation between the reindeer population and average annual air temperature in the Nadymsky district, 1960–2018.

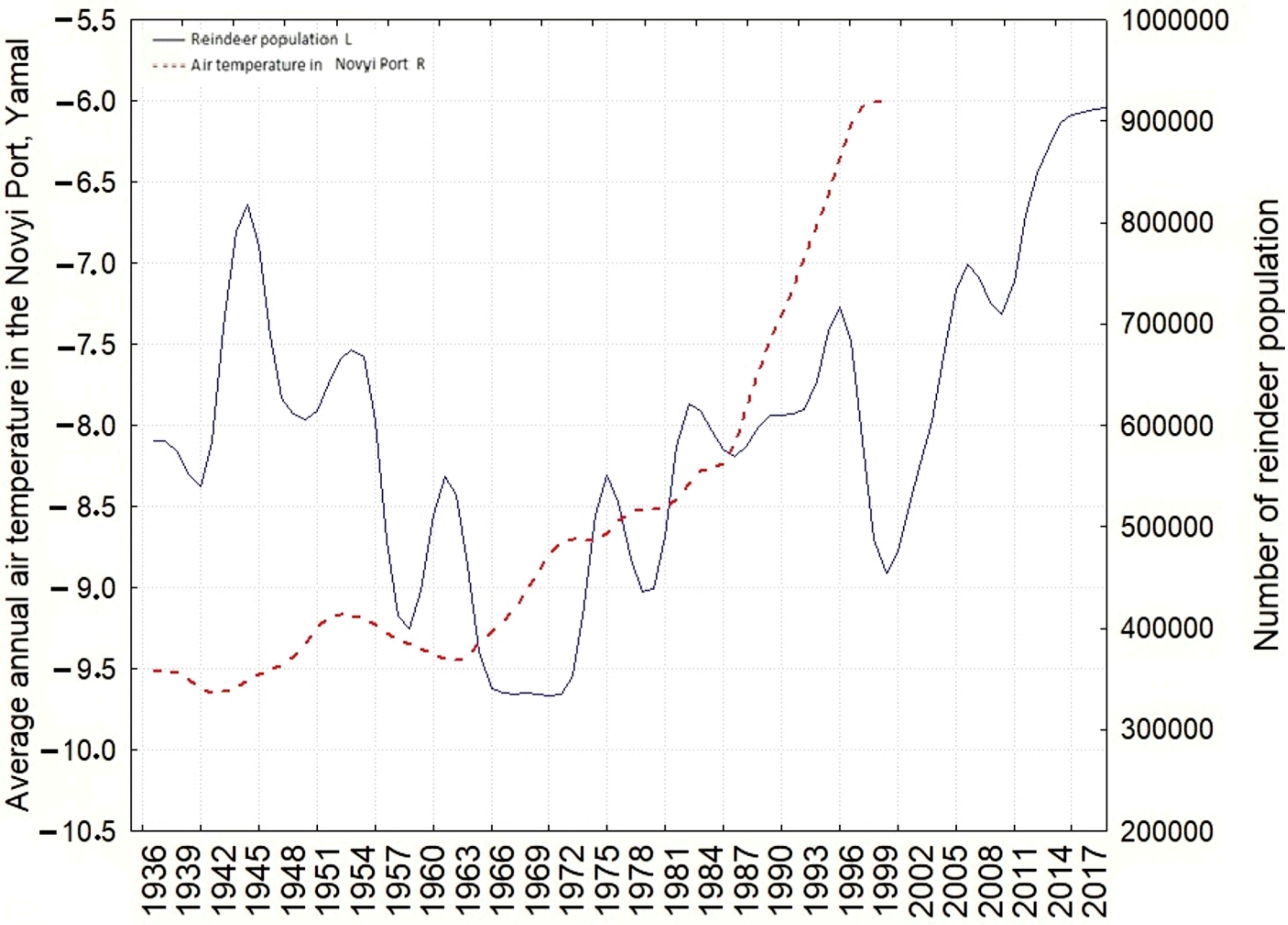

Figure 2. Correlation between the reindeer population and average annual air temperature in the Yamalsky district, 1936–2018.

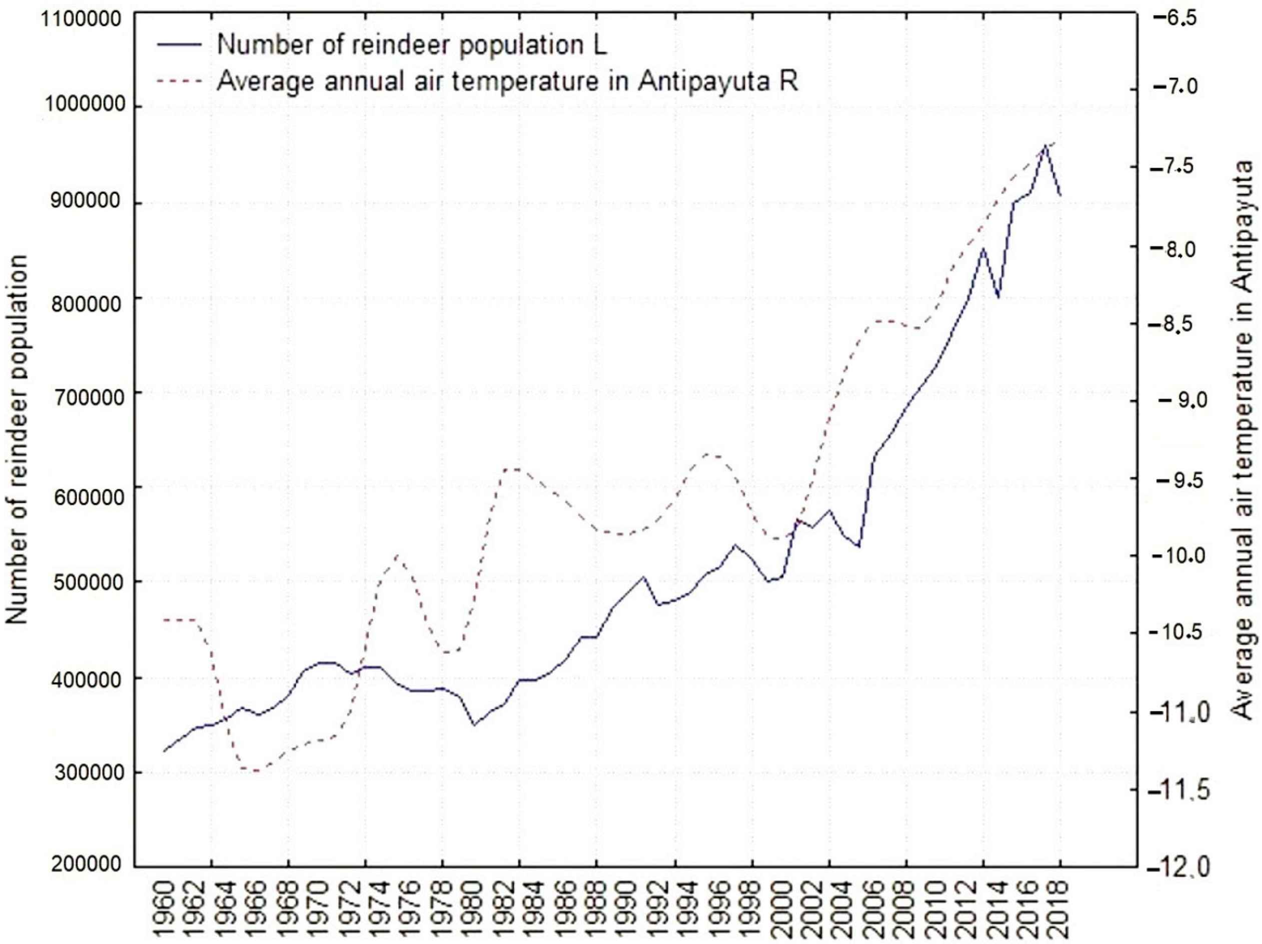

Figure 3. Correlation between the reindeer population and average annual air temperature in the Tazovsky district, 1960–2018.

Understanding of vulnerability of reindeer husbandry requires one assess at least three separate aspects: the external impacts on the social-ecological systems, the ability of these systems to cope and adapt to these impacts, and the extent to which environmental or societal conditions hinder herders in adapting to change [96]. Climate change is one of the important external impacts on reindeer herding. The differences in the impact of climate change on the reindeer population in the Nadymsky, Yamalsky and Tazovsky districts are partly connected with the thermal balance in the northern and central areas of the YNAO. Klokov K.B. et al. [97] stated that the areas for wintering with the best thermal balance are located in the northern (tundra) parts of the Nadymsky, Purovsky and Shuryshkarsky districts of the YNAO. In July–August, the optimal grazing conditions (without going beyond the thermoneutral zone) are in the northern part of the Yamal Peninsula. On the Gydansky and Tazovsky Peninsulas, the thermal balance sometimes goes beyond the thermoneutral zone.

The positive impact of climate change on the reindeer population can be explained by the increase in the snowless period and, consequently, the increased productivity of vascular plants in the warming climate. Finnish reindeer herders have also noted this favourable effect of climate change on increased forage: a rainier but warmer and longer growing season may increase the growth of vegetation and availability of high-quality forage, such as mushrooms, for reindeer [3,17]. Arctic areas are sensitive to such changes in forage conditions. In the Arctic zone of Western Siberia, reindeer consume more than 600 species of lichens, grasses, shrubs, trees and mushrooms [98], while in Chukotka and Alaska, there are over 1000 species of vascular plants [99]. Thus, reindeer can survive without lichen if there are many wet plants under the snow, such as horsetail and evergreen grasses, which contain many vitamins, proteins and microelements. Climate change in Siberia has had environmental effects, including inducing changes in species composition [100–103], the abundance of animals and plants [104–106] and annual biological cycles [2,107]. It has a strong influence on the grazing cover of reindeer pastures, especially in the central parts of the YNAO, where thinner snow cover, milder weather and shorter periods of low temperatures are favourable for reindeer because of the higher availability of forage. For example, the tendency for the increased growth of deciduous shrubs observed in recent decades is apparently closely related to the higher and more intense summer temperatures in Western Siberia [108]. S. Rasmus et al. also noted the positive effects of the advanced development of vegetation and the consequent higher availability of fresh forage plants for milk-producing dams and their calves, as the calves would be fit by the time the calf marking period starts in the summer [3,107]. However, in the more northern parts of Siberia and Fennoscandia, "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" [3]. Walker et al. [109] demonstrated this phenomenon of a faster increase in the aboveground biomass of circumpolar arctic tundra vegetation in more southern Arctic areas: southern tundra subzones exhibited approximately 20–26% biomass increases, whereas northern tundra subzones had increases of 2–7%. However, these processes are much slower in the YNAO. Kovalevskaya N.M. et al. [49] mentioned that the results of their analysis of satellite data suggest that over the past three decades and more, there has been a relatively small (compared to that in other Arctic regions) increase in the productivity of Yamal vegetation and a slight increase in near-surface temperatures. While the degradation of reindeer pastures is increasing (Figure 4) that results in destroying reindeer health (Figure 5) and changing the reindeer diet.

Warming has an unclear effect on Arctic reindeer herding and can also result in higher reindeer losses because of increased risks of entomoses [110] and helminthic diseases [42]. Besides, reindeer are better adapted to hypothermia than to overheating. In hot weather, the physiological activity of metabolic processes in reindeer decreases, and they are not able to accumulate a sufficient supply of nutrients for successful wintering [97]. Therefore, reindeer losses are a likely outcome of climate warming in the Arctic zone of Western Siberia.

Figure 4. Degradation of reindeer pastures in Yamal.

Figure 5. Teeth of a three-year-old deer worn out on the mineral base in the tundra.

The rather weak impact of climate change on the reindeer population in the northern areas of the YNAO (Yamalsky and Tazovsky districts) can be explained by the more significant contribution of non-climatic factors. This region is known as the place with the most intensive industrial development in the Arctic region of Russia. Industrial development is associated with the degradation of reindeer pastures due to the disruptive effect of developing logistic and industrial infrastructure. Anthropogenic activities [2] in recent years and technogenic emissions of combustion products from fuel and energy enterprises into the atmosphere [111–114], as well as metallurgical production and mining, which produce excessive amounts of some macro-and microelements, all of which affect the physiological parameters of reindeer. In the areas near industrial centres, atmospheric pollution affects lichen first, causing its disappearance from the vegetation cover of pastures [51]. Nevertheless, YNAO is the only Arctic region in Russia where the number of domesticated reindeer has constantly increased during the last 50 years even in the conditions of intensive gas and oil extraction, political shifts and during the crisis of the 1990s [115]. It can be a result of the positive impact of industrial development and extending urban areas which provided stable markets for reindeer products. Oil and gas companies gave a stable tax base which was reinvested also in the rural economy including reindeer enterprises [25]. A high degree of nomadism among the Indigenous Peoples and dominance of individual reindeer husbandries (60% of reindeer belong to individual reindeer herders [71]) in YNAO became the preconditions for stronger socio-ecological and economic resilience of reindeer herding livelihood to shifting political context in 1960–2018. While in other Russian Arctic regions, there were dramatic declines in reindeer numbers associated with the years of institutional reforms wherein ownership rights changed; the reorganization of kolkhozes (enterprises with collective ownership) into sovkhozes (enterprises with state ownership). Later from 1991 to 2003, a decrease in the reindeer population was caused by the withdrawal of state subsidies. Finally, up to 2003, the reindeer population in reindeer enterprises decreased to approximately 35% of their previous populations [25] in all Arctic reindeer herding regions (except YNAO) of Russia.

Nowadays, one of the key factors impacting the reindeer population in the northern areas of the YNAO (Yamalsky and Tazovsky districts) is the increase in velvet antlers production. Mainly nomadic reindeer husbandries of Tazovskaya, Messoyakhinskaya, Antipayutinskaya, Tanamskaya tundras are integrated into the commodity production of meat and velvet antlers. This is due to the relatively good logistics, the presence of reindeer slaughtering houses and the possibility to sell them velvet antlers. In this group, over the past four years, the sale of velvet antlers has gradually become the main source of income for reindeer herders, and the delivery of meat is an auxiliary one. Subsistence reindeer herding, working mainly to provide the family with food and clothing, is widespread in the northern part of the Gydansky Peninsula, on the coast of the Yuratskaya Bay and other parts of the region, logistically remote from settlements, slaughter facilities and large deposits. This is explained by the high cost of gasoline and the cost of exporting reindeer products and delivering goods to the tundra. The further from the logistics centres, the less profitable commodity production becomes due to the high costs [27]. However, the risk of climate change should also not be ignored in the northern areas of the YNAO, as its influence in the neighbouring territories of the Nenets Autonomous Okrug [82] is rather evident based on changes in the vegetation cover of the tundra and reduced availability of lichen for reindeer under the ice and snow.

In general, climate change can have catastrophic effects on forage for reindeer herding in different Arctic areas. Rees et al. [116] argued that climate change impacts are likely to harm the livelihoods of those who practice reindeer husbandry in Norway and Sweden but have a neutral impact in Finland. The main factors that dictate these impacts are the changes in vegetation distribution caused by the changing climate, especially winter temperature and winds. Nevertheless, Rees et al. [116] suggested that the effect of these changes is expected to be relatively small and well within the range of previous experiences of reindeer herders dealing with climate variability. However, in Western Siberia, climate changes (autumn, winter and summer warming) may become a serious challenge for the preservation of nomadic reindeer herding [117].

A forecast model for the number of reindeer correlated to the average annual air temperatures was developed. We analysed the dynamics of average annual temperatures and the number of reindeer using the ARIMA variable method. It was found that the number of reindeer livestock undergoes seasonal fluctuations every 5 and 10 years and exhibits an overall upward trend. The analysis of the number of domesticated reindeer in the YNAO using autocorrelation and partial autocorrelation with the ARIMA model revealed the presence of a decreasing trend and lag in steps 1 and 7 and the presence of seasonality of 10. Based on the data obtained, a forecast for the number of reindeer in five years was developed. According to this forecast, under the optimistic scenario with the continued increasing rates for average annual temperatures, the number of reindeer livestock will increase; under the pessimistic scenario, it will stabilize at the 2016 values (Figure 6).

The ARIMA forecasting model showed that, with the continued increasing rates of average annual temperatures, the growth of the reindeer population in the YNAO will continue until 2025. After 2023, the dynamics of reindeer population growth will slow down or become negative. This model describes only long-term trends. Weather and climatic extremes (the formation of an ice crust over large areas, freezing rain, heat waves) can have catastrophic effects on the reindeer population because, in many areas, reindeer pasture resources are insufficient, which reduces the adaptive capabilities of the reindeer and the survival of offspring. Given the cyclical nature of these processes, the most dangerous period was predicted to be the spring of 2023–2024. However, Klokov K.B. et al. [118] were not as optimistic regarding climate change increasing reindeer livestock populations. With each increase in the average monthly air temperature of 2°C, the boundaries of the thermoneutral zone can move north by about 100 km, which will lead to worse conditions for keeping reindeer, especially in warm years. As a result, the southern part of the Yamal Peninsula may become a zone of “risky reindeer herding”, and the zone of comfortable grazing will be reduced.

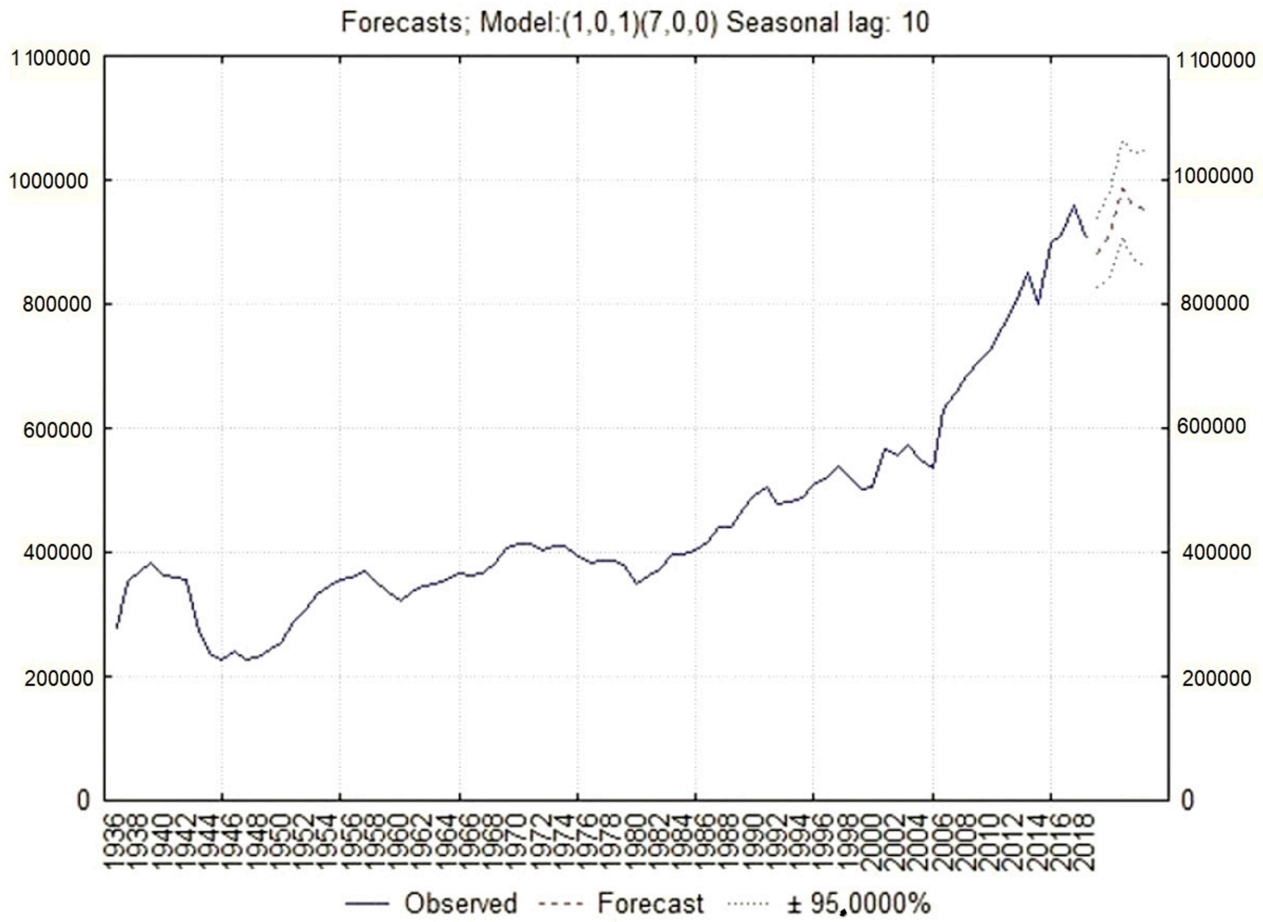

Figure 6. Forecast model for the reindeer population in the Yamal-Nenets Autonomous Okrug (YNAO), 1936–2023.

The dynamics of the reindeer livestock population will likely have an impact on the food security of Arctic Indigenous Peoples because of the increased availability of reindeer products. We assessed the correlation between the reindeer population and consumption of the most important [65] reindeer products (reindeer meat, liver and blood). A total of 1280 Indigenous inhabitants of the Arctic zone of Western Siberia participated in the study (Table 2). The age class distributions of the participants are presented in Table 3. The average age of all participants was 45.7 ± 14.3 years; 396 (30.9%) of the participants were men, and 884 (69.1%) were women. From year to year, there were no differences between the proportions of males/females and various age classes sampled, as the sample remained constant throughout the study.

Table 2. Data on the respondents recruited for the survey, Yamal-Nenets Autonomous Okrug, 2012–2018.

Year	Total Indigenous Population Included in the Study (n = 1280)	Age, Years (45.7 ± 14.3)
2012	151	41.0 ± 12.5
2013	277	42.0 ± 12.7
2014	144	43.0 ± 13.6
2015	150	45.1 ± 13.7
2016	236	45.0 ± 14.0
2017	136	46.5 ± 13.2
2018	186	47.0 ± 12.8

Total	1280	–

Table 3. Forecast data for the reindeer population in the YNAO, 1936–2023.

Year	Forecast	Lower—950,000%	Upper—950,000%	Std. Err.
2018	909,626	702,724.2	1,116,528	102,958.1
2019	906,607	683,151.4	1,130,062	111,195.3
2020	1,076,528	837,681.8	1,315,374	118,854.0
2021	1,082,704	829,418.1	1,335,991	126,039.7
2022	1,088,395	821,464.7	1,355,326	132,829.3
2023	1,087,580	807,684.6	1,367,475	139,280.7

The results of the correlation analysis were inconsistent: an increase in the reindeer livestock population was associated with the decreased consumption of reindeer products (Table 4; Figures 7–9). This does not represent a logical outcome of increases in the number of reindeer in herds. However, this phenomenon is frequently discussed in socioeconomic studies and considered to be a clear outcome of transition processes involving traditional lifestyles [27] and the traditional Indigenous economy—for example, the transfer from a subsistence economy in Western Siberia to commodity production. During the last 10 years, rising trends in the export of traditional reindeer products have decreased local Indigenous Peoples' access to venison and had a negative impact on their health [71]. The export potential of the non-edible parts of reindeer (i.e., velvet antlers, reindeer skins, camuses) should be promoted to support the food security of the Indigenous Peoples, while government policies should focus on improving the access of the Indigenous communities to the edible and medicinal portions of the carcass.

Table 4. Spearman rank-order correlations for the reindeer population and consumption of reindeer products.

Reindeer Products	Spear—R	*p*-Level
Reindeer meat	−0.8	0.01
Reindeer liver	−0.8	0.01
Reindeer blood	−0.8	0.00214

Traditional nutrition is an important part of the Indigenous traditional culture and serves as a remedy to cold stress and increases their adaptation to the severe Arctic climatic conditions. Therefore, as expected, "the Spearman rank-order correlation revealed a strong negative association between the prevalence of arterial hypertension and the consumption of reindeer products" (Table 5; Figures 10–12).

Table 5. Spearman rank-order correlations for the consumption of reindeer products and risk of arterial hypertension.

Reindeer Products	Spear—R	*p*-Level
Reindeer meat	−0.8	0.01
Reindeer liver	−0.8	0.01
Reindeer blood	−0.77	0.01

The results of our previous study showed that there was a dramatic decrease of almost 50% in the consumption of reindeer products by the Indigenous and non-Indigenous Peoples in the YNAO, and only one-third of the studied population still ate venison once or twice daily [65]. This shift threatens their health because a diet rich in venison significantly increases antiatherogenic blood lipid fractions, contributes to the maintenance of normal body weight, and improves microcirculation, tissue fluid exchange and antioxidant protection against free radicals; these effects may explain the high prophylactic activity of venison [62] and its strong positive effects on adapting to cold stress [66] and geomagnetic activity in the Arctic [67]. Venison has been shown to effectively reduce hypertension [59] and the risk of chronic nonobstructive bronchitis [56]. These characteristics make reindeer products an important part of the local population's diet. Maintaining a traditional diet is also an important part of the Indigenous culture that strongly contributes to promoting the Indigenous Peoples' health (Figure 13). Saving these nutritious practices has a positive effect on keeping reindeer herding culturally and environmentally embedded [119].

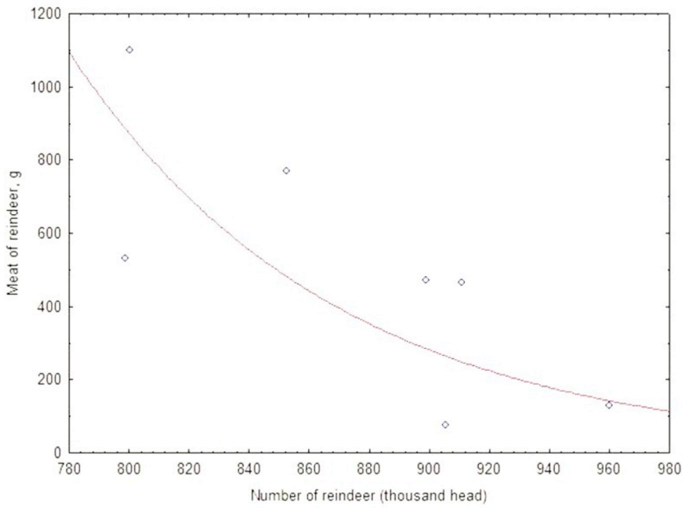

Figure 7. Correlation between the reindeer livestock population and consumption of reindeer meat.

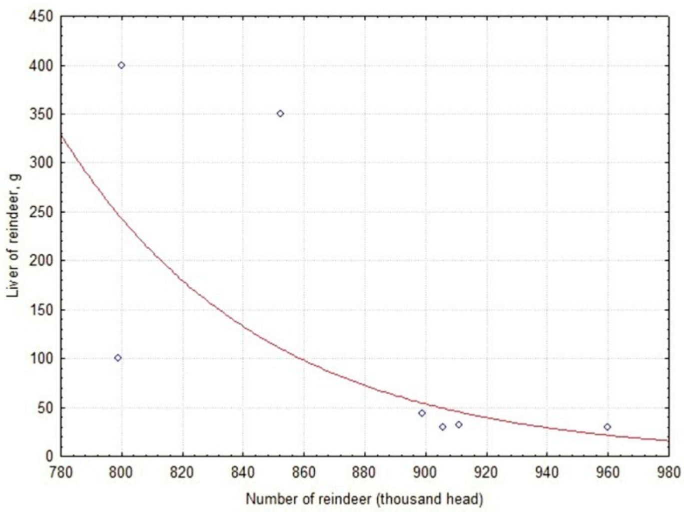

Figure 8. Correlation between the reindeer livestock population and consumption of reindeer liver.

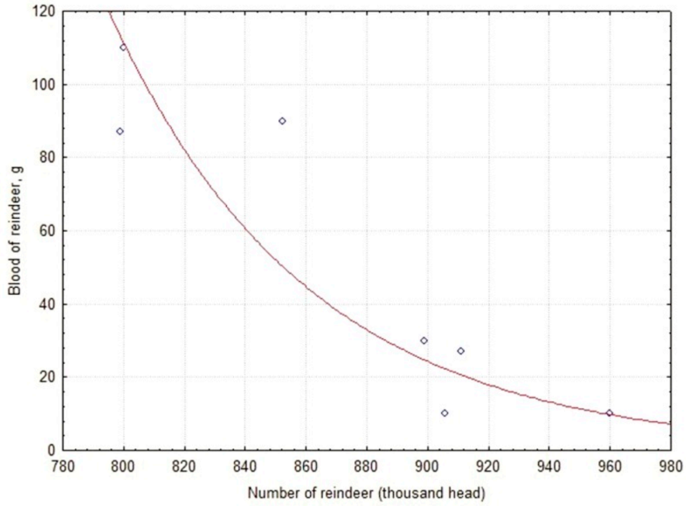

Figure 9. Correlation between the reindeer livestock population and consumption of reindeer blood.

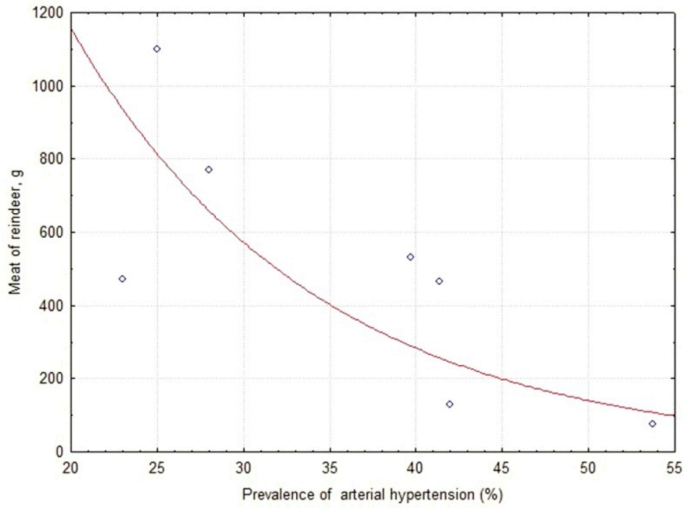

Figure 10. Correlation between the consumption of reindeer meat and the prevalence of arterial hypertension.

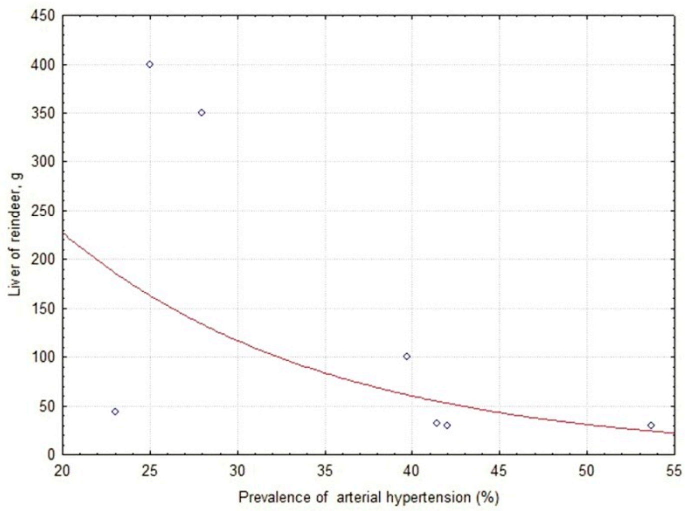

Figure 11. Correlation between the consumption of reindeer liver and prevalence of arterial hypertension.

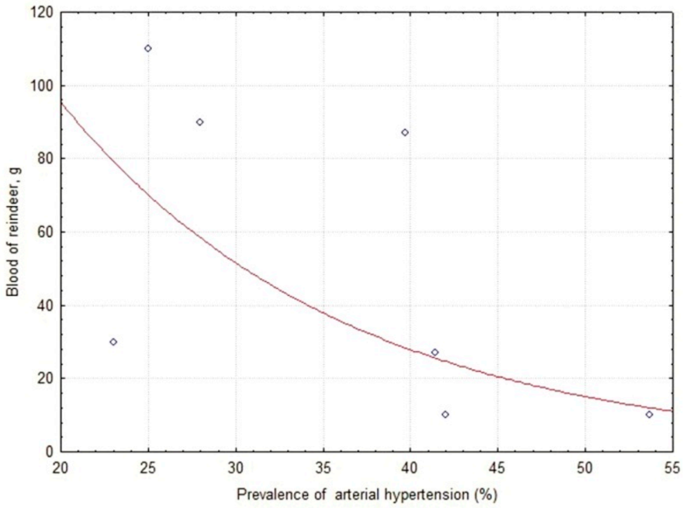

Figure 12. Correlation between the consumption of reindeer blood and the prevalence of arterial hypertension.

Figure 13. Traditional Yamal Nenets ritual of drinking fresh blood of a slaughtered reindeer in the tundra.

Dissemination of knowledge on the importance of reindeer products for the Indigenous Peoples health as well as strengthening social policy to support reindeer herding husbandries in YNAO could encourage reindeer herders to keep on following nomadic lifestyle and, correspondingly, a traditional diet with a prevalence of reindeer meat and other-by reindeer products.

The main strength of our study was using unique empirical quantitative research data collected from the reindeer herders during expeditions that took place over seven years (2012–2018) and data from the longitudinal monitoring of reindeer livestock in the period 1936–2018 provided by researchers and local authorities. Most similar studies examined fragmented populations and time frames, with unclear results. However, our study had several limitations. The methodological quantitative approach was focused on using a limited number of variables for representing climate and diet changes since we were intended to analyse the impact of climatic factors on the food security of the Indigenous Peoples. While non-climatic drivers were also considered to explain the weak correlation of the factors. The studied population was recruited while undergoing a medical examination at health care institutions—municipal hospitals and feldsher-midwife medical stations in remote settlements. Participation was voluntary and did not include all representatives of the reindeer herding communities of the studied territories, which may limit the generalizability of the findings. It would also be of value to examine food security in reindeer herding and fishing communities and the impact of traditional reindeer and fishing products and plants on the health and wellbeing of the local communities.

4. Conclusions

Studying climate change and its impacts on reindeer herding while considering the input of anthropogenic and technogenic factors can provide new insights into the temporal and spatial warming variabilities in the Arctic zone of Western Siberia. In our study, the different data sets on the dynamics of annual air temperatures and reindeer livestock populations in three districts of the YNAO enabled us to not only study the ongoing climate changes in general but also examine their specific impacts on the Indigenous Peoples' food security. We conclude that as the average annual temperature increases, the size of the reindeer herds will grow, which is probably associated with the increase in the forage base for the reindeer because of the increased productivity of vascular plants in the warming climate. In the YNAO, an increase in the average annual temperature was correlated with an increase in the reindeer population and, in the long term, did not depend on the socio-economic model of the organization of reindeer husbandry, despite the fact that from 1936 to 2019, there were significant political and economic changes. This trend for the impact of climate change was more evident in the central districts of the YNAO.

Climate change is occurring and will continue to occur, faster in higher latitudes than in other regions. Climate change's consequences for livelihoods dependent on reindeer herding should be analysed in the context of the impacts of associated challenges and opportunities, such as exploration of the Arctic's bioresources and involvement of the Indigenous Peoples in bioproduction. Adaptation to climate change could be used as an opportunity to improve the living conditions and food security of the Indigenous Peoples and to sustain their livelihoods in the context of all related issues. Thus, climate change becomes an opportunity for supporting Arctic life and livelihoods. Any policies or regulatory measures should be developed, implemented, monitored and enforced with the full and fair participation of the Indigenous Peoples.

Climate change is already occurring and is unlikely to be curtailed soon, meaning that the effects must be addressed. The impacts of climate change on the Indigenous Peoples can be reduced by working collaboratively to ensure that indigenous interests are respected and that indigenous needs are met without precluding the involvement of others in the region and without being overwhelmed by climate change's detrimental impacts.

The results presented in this work will hopefully encourage dialogue among local practitioners, researchers and policymakers. Our study focused on reindeer husbandry, but the approach is applicable to other traditional Indigenous nature-based livelihoods (e.g., fishing, hunting, and gathering) facing the need to adapt because of the changing climate.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Arctic Scientific Research Centre of YNAO (protocol No. 01/1-13, 16 January 2012).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The study did not report any data.

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Conflicts of Interest: The authors declare no conflict of interest.

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