Human Ecology
https://doi.org/10.1007/s10745-022-00384-8

Influence of Indigenous Herding Activities on the Spatio-temporal Distribution of Reindeer during the Summer-Autumn Period: Case from Yamal, Russia

Alexandra Terekhina[1] · Violetta Filippova[1] · Alexander Volkovitskiy[1] · Kirill Shklyar[1] · Pavel Orekhov[1] · Natalia Sokolova[1] · Svetlana Abdulmanova[1] · Aleksandr Sokolov[1]

Accepted: 12 December 2022

Abstract
The movement patterns of domestic reindeer depending on indigenous herding practices were studied using GPS collars. Data were collected during the summer-autumn of 2021 from the private Nenets herd in the South of Yamal Peninsula, Russia. We classified the types of herders' influence on reindeer and estimated the densities of GPS fixes on pastures in four time periods in June – November. Based on ethnographic data and personal experience of migrating with Nenets, we hypothesized that a long-lasting stay of reindeer at a nomadic campsite is the significant indicator of human influence on a herd. Our GPS data registered that reindeer stayed at campsites significantly longer in July during the peak of insect harassment. This factor determined the maximum level of human control over the herd as shown by the limited distance of dispersal of reindeer from a campsite. By early August, the active phase of bloodsucking insects concludes as does active control of the herd, allowing a return to freer foraging and increased range of movement.

Keywords Reindeer · Traditional ecological knowledge · GPS collars · Arctic · Yamal peninsula · Russian federation

Introduction

Reindeer (*Rangifer tarandus*) – wild and (semi)-domestic populations – are recognized as one of the ecosystem engineers of the Arctic, that have become the significant "actors" in recent studies on greening and shrubification of the tundra (Olofsson et al., 2009; Forbes et al., 2010; Cahoon et al., 2012; Bernes et al., 2015; Beest et al., 2016; Skarin et al., 2020; Verma et al., 2020; Mekonnen et al., 2021; Vuorinen et al., 2022; etc.). These large herbivores not only have complex effects on ecosystems, but also are a cornerstone of the stability and potential of the traditional economy and livelihood of the indigenous people of the entire circumpolar zone – hunters and reindeer herders. The Yamalo-Nenets Autonomous Okrug (hereinafter referred to as YNAO) of the Russian Federation in North-Western Siberia is a world leading reindeer herding region with the largest population of domestic reindeer (ca. 650 thousand) and one of the few places that maintains the tradition of family nomadic pastoralism (Klokov, 2020; Stammler, 2005; Terekhina & Volkovitskiy, 2020).

In the Russian academic tradition, domestic reindeer are studied mainly as an object of agricultural disciplines (Yuzhakov, 2003). From an ecological point of view, reindeer – vegetation interactions in Yamal are considered mainly within the framework of the "overgrazing" concept. Some researchers claim that the current model of reindeer herding in the YNAO to be an uncontrolled process (opposite to the previous Soviet state reindeer herding of big reindeer herding enterprises), which negatively impacts on tundra vegetation, reducing forage resources and thus leading to the collapse of reindeer herding itself (Kryazhimskiy et al., 2011; Veselkin et al., 2021). The delichenization of the tundra is seen as a direct result of the rapid increase in the number of reindeer in Yamal private non-state households since the post-Soviet 1990s (Ektova & Morozova, 2015; Golovatin et al., 2012). According to some scholars, the most important factor behind these changes is the intention of Nenets households to accumulate the excessive number

✉ Alexandra Terekhina
terekhina.yamal@gmail.com

[1] Arctic Research Station of Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences, Zelenaya Gorka Str., 21, 629400 Labytnangi, Russia

Published online: 31 December 2022

of reindeer as an immanent quality of the Nenets extensive reindeer herding tradition (Bogdanov & Golovatin, 2017). Geobotanical studies in 2017 recorded "the poor condition of winter pastures and the complete absence of forage for winter, late autumn and early spring grazing on the entire Yamal Peninsula" (Geobotanical assessment, 2017: 101). However, such studies are based on Soviet standards for assessing grazing capacity, developed from geobotanical surveys in the 1920s-1930s (Andreev, 1934; Gorodkov, 1926; Igoshina, 1937). These assessments ignore contemporary reindeer herding practices and have no explanation for current reindeer populations on Yamal that have only experienced declines due to extreme weather events and not because of lack of forage.

We believe that new climatic and social conditions require the revision of methods for estimation of grazing capacity and call for a better understanding of the domestic reindeer ecology in Yamal that considers indigenous practices. Further, study of reindeer foraging behavior in this region requires clarifying human (pastoral) influence on animals. The core of the Samoyedic type of reindeer herding of Northern Eurasia used by tundra Nenets, Khanty, and Komi-Izma people, in contrast to other reindeer herding traditions, is consistent control of the herd by humans. Schematic descriptions of pasturing practices in different regions of Russia, including Yamal, have already been made (Baskin, 2009; Golovnev et al., 2014; Istomin & Dwyer, 2021; Karpov, 2006; Stammler, 2005), but most of them present a socio-anthropological view focusing on cultural aspects, or were made decades ago based on researchers' observations, without the benefit of geospatial technologies.

Since in ecological studies herbivory is considered mainly during the growing season, we decided to focus on the spatio-temporal interactions of the Nenets and their reindeer during summer and autumn periods. We used GPS data from a herd selected as a model in the South of Yamal Peninsula. The geospatial technologies have been widely used to analyze the ecology of *Rangifer tarandus* living in wild (caribou) North American, and for semi-domestic Scandinavian contexts (Baltensperger & Joly, 2019; Newmaster et al., 2013; Reimers et al., 2014; Skarin et al., 2008; Valinger et al., 2018 and others). In Russia, GPS collars have only been used experimentally in certain regions of the North to track the movements of wild and domestic reindeer for agricultural and conservation needs (Elsakov et al., 2011; Savchenko et al., 2019; Salman et al., 2020). Thus, this article presents the first analysis of satellite monitoring of domestic reindeer in Western Siberia. The entire research was carried out in partnership with reindeer herders.

The purpose of this article is to quantify the herders' levels of control over reindeer through the analysis of the spatio-temporal distribution of the herd across summer-autumn pastures. We analyzed reindeer movement patterns, classified the types of herders' manipulations with animals, and revealed their "degree of freedom" of reindeer while foraging depending on human influence. The results obtained can become the basis for further study of the preferred habitats of domestic reindeer in the Yamal tundra, foraging behavior, and hence, reindeer effect on vegetation.

Methods

Study Area

Domestic reindeer movements were studied within the area of the Erkuta ecological field station situated downstream of the Yorkutayakha River in the subarctic shrubby tundra (68.12° N, 69.08° E) in the Yamal Peninsula, the Arctic zone of Russia – subzone E (Walker et al., 2005) (Fig. 1). The study area is located in the southern part of the

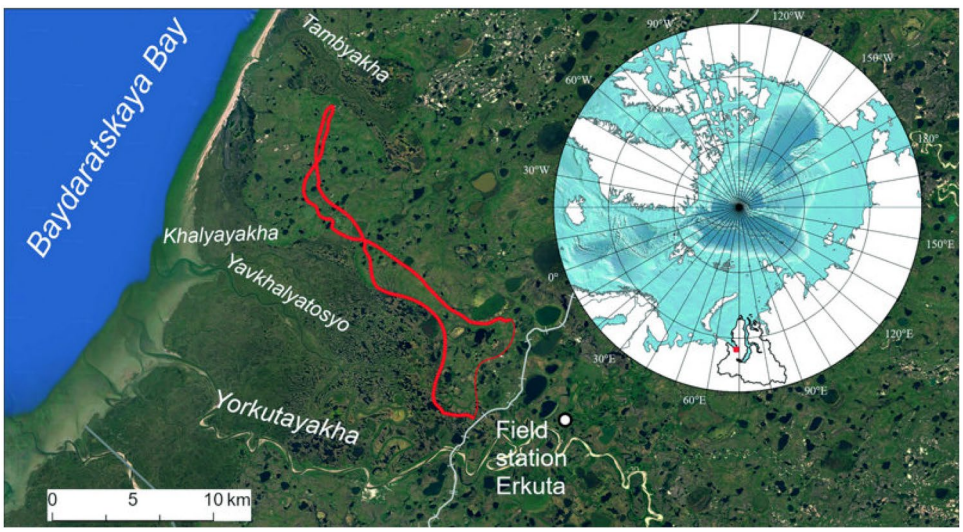

Fig. 1 Study area. In the main map: the nomadic route of the model herd in June – November is marked with a red line; the railroad is marked with a white line. In the insert map: the YNAO area is marked with the black line with the study area shown in the red square. The imagery base map is from Esri and Earthstar Geographics, the insert map is from Natural Earth (available from https://www.naturalearthdata.com/)

Central-Yamal southern landscape region of the province of flat and gentle-ridged southern tundra marine plains. Landscapes of III and IV marine terraces, river and sea floodplains dominate in the landscape structure (Melnikov, 1991).

The study area is situated in the southern part of the Yamalskiy *raion* (district) of YNAO, the municipality with ca. 225.000 reindeer, herded by more than 5.500 nomads (mostly Nenets) migrating all year round in tundra. Up to 90 percent of the households are private, but one state reindeer herding enterprise still exists after the post-Soviet economic changes. The size of privately-owned herds varies from 50 to 2500 reindeer, reflecting the different economic status of households. Yamal reindeer herders migrate distances of 50–1500 km, using sledges with draught reindeer and sometimes snowmobiles in winter. There are several private herds using the pastures within the study area of the Erkuta ecological field station in different seasons.

Herding Practices

In the spring the Nenets pastoralists of the Yamal Peninsula start to migrate with their herds from one campsite to another every 3–8 days (excluding the calving time, when the stop lasts 2–4 weeks). They reach the main summer grazing area by the end of July where many households also stay for a longer period or slowly migrate between pastures (Nenets – *tango''lava*, Russian – *letovka*, literally – summering). In autumn, households begin to gradually return, and in the end of October – November after the formation of stable ice on rivers – Nenets quickly move to their winter pastures. The term "campsite" in this paper means a temporary nomadic camp area where *chums* (nomadic tents), sledges, a corral and other items are arranged. Campsite also includes a wider surrounding area of several hectares used for daily management of a herd, where reindeer do not forage. Nenets households occupy the same places for campsites every year, located usually on hard and elevated dry tundra uplands. We use the term "staying" as a temporal characteristic of the duration of existence of a nomadic campsite at one place on the migratory route.

The Nenets herding practices consist of regular reindeer-targeted manipulations made by herders (Yuzhakov & Mukhachev, 2001). The following actions (hereinafter set forth in English/Nenets) such as herder's duty/*ma''alkova,* pushing transport animals to corral/*yorkolava*, migration/*yamdanava*, reindeer sledge journey/*ngedalyova*, concentrating a herd near chums because of insects/*padeva* were the most common types of human influence on herd in the studied period (Table 1; Fig. 2). The herders' influence on reindeer has different levels of intensity, humans restricting the freedom of movements and foraging of specific reindeer (e. g., of transport bulls while sledge journeys) and of the entire herd (during *yorkolava*).

In this paper we focused on regular, daily types of human influence found in our data on reindeer GPS fixes such as corraling transport animals at campsites, since migration and long-distance sledge travel are comparably rare events and could be easily identified in the whole data (moreover, we checked each such track with the herders).

Table 1 Common Nenets actions influencing on reindeer herd

Name (Eng/Nen)	Description
Herder's duty/*ma''alkova*	Nenets remain on duty and look after a herd twenty-four hours a day during the summer period (a herder with a reindeer team and a dog). While keeping the required foraging/resting regime, a herder guides his herd, limiting the radius of the reindeer withdrawal from a campsite. Reindeer may be allowed to graze more freely in the second half of August when parasitic insects disappear
Pushing transport animals to corral for harnessing, slaughtering/*yorkolava*	During snowless periods Nenets travel by sledges pulled by reindeer. When draught reindeer are needed, the entire herd is driven to the campsite and moved in a circle, while its transport part is concentrated in a corral in front of chums – a semicircle of sledges and net or ropes. Transport bulls are changed daily during the June-July period (a duty reindeer team usually "works" for 12 h)
Migration/*yamdanava*	The Nenets migrate at 3–7 km distance in snowless periods. All people and their belongings are carried by sledges pulled by reindeer. A single household requires up to 50 draught reindeer to migrate to a new campsite. A herder drives the rest of the unladen reindeer
Reindeer sledge journey/*ngedalyova*	The tundra people journey to visit neighboring campsites, trading posts and infrastructure facilities. They can cover a 10–20 km distance traveling on sledge at once. During a bare-ground season one sledge requires 4–6 draught reindeer
Standing of a herd near chums because of insects/*padeva*	In the warm and windless weather when reindeer are extremely harassed by insects a herd is pushed to a campsite by a herder or may even come on its own. Reindeer circle around to prevent from mosquitoes bites or stand still if warble flies and nose bot flies are active while people stay nearby (*ty'' tyakhana me* – "stay behind reindeer") preventing reindeer from running away

Fig. 2 The most common types of human influence on reindeer in the summer – autumn period: **A** – *ma''alkova*; **B** – *yorkolava*; **C** – *yamdanava*, **D** – *ngedalyova*, **E** – *padeva* (photos by authors)

Model Herd

The reindeer herd of the private Nenets household (ca. 1000 head) involved in the project spends summer – autumn period in the area of the Erkuta research station (Fig. 1). This herd's pastures are limited by natural features (Yavkhalyatosyo River, Khalyayakha River, Tambyakha River, and the eastern shore of the Baydaratskaya Bay) and the Obskaya–Bovanenkovo railroad.

In total, 13 GPS collars were put on the model herd reindeer in June, 2021. The animals for tagging were selected by the agreement with the owners, to present reindeer gender and age group typical for the Yamal private herds: 7 collars for female reindeer (*yakhadey*, full-grown females including 1 *khabtarka* – barren female used as draught reindeer), 2 collars for castrated males used for transportation (*khabt*), 1 collar for a castrated male not used as draught reindeer (*menaruy*), and 3 collars for a non-transport male breeder (*khora*) (Fig. 3).

Equipment Characteristics

Lotek Litetrack Iridium 420 collars fitted with GPS transmitters (Lotek Telemetry Inc.) were selected for the project. The collar weighs 400–450 g depending on the length of the strap making up less than 1% of animal body weight. The schedule of signals, as well as the sample of reindeer, was formed differently than in studies on movement of semi-domestic Saami reindeer in Scandinavia, where mainly females are tagged and equal intervals of signals are set (e. g., Skarin, et al., 2008). The higher proportion of males (transport bulls and breeders) in Nenets herds, in comparison with the Saami herds, and the separation of bulls and females in spring (calving) and autumn (rut), required an assessment of the movements of each of these groups. We assumed that the different schedule of positioning every category of reindeer would become more relevant, allowing to simulate more accurately the movement of the entire herd (or 2 sub-herds: breeding and transport). Animals were divided according to sex and function, with females and males presenting separate subgroups. GPS positioning was scheduled to have 1 signal from each subgroup in a 15-min interval. In the female subgroup, each collar recorded GPS fixes every 1 h and 45 min; in the male group – once every 1 h and 30 min. Our schedule was established to ensure the functioning of the collars in cold conditions for at least 2 years. All GPS fixes we received were with DOP values lower than 7, which means an accuracy from 4 to 14 m (Jung et al., 2018).

Data Analysis

In this study we used the GPS data of reindeer movements from the 27th of June to the 11th of November 2021, when the herd stayed in the immediate vicinity of the Erkuta

Fig. 3 The reindeer GPS tagging procedure: putting the collar on (photos by authors)

ecological research station. We divided this time into several periods based on three reasons: different reindeer movement patterns (GPS data), different seasonal pastures specified in the reindeer herding literature (winter, early spring, late spring, summer, early autumn, late autumn) (Podkorytov, 1995), and the view of the herders (traditional knowledge – see in the section below).

ArcGIS Pro, version 2.9.2 was used for processing and visualizing data. The R software environment, version 3.6.3, was used for statistical analysis (R Core Team, 2022). The Wilcoxon signed-rank test (R Core Team, 2022) was used for testing the hypotheses. Only significant results with p.value less than 0.05 are presented.

Based on our long-term ethnographic experience, we assume that a smaller area of reindeer distribution over pastures means more intensive control of reindeer by a herder (or greater limitation of free movement and foraging). Thus, the presence of reindeer at a campsite indicates the direct human-animal interaction, that is, reindeer do not move freely at this time and definitely do not forage. To confirm this suggestion, we calculated the average and maximum distances that the reindeer moved away from the campsites as well as the total area of the herd distribution in different periods. We also estimated the percentage of GPS fixes at each campsite. The statistical adehabitatHR package (Calenge, 2006) and the kernel density estimation-based method (Silverman, 1986; Wand & Jones, 1995) were used for identification of all campsites areas. To highlight the sites with the highest density of reindeer, GPS fixes were picked out by using the least square cross validation algorithm (LSCV) selected as a smoothing parameter (Seaman & Powell, 1996; Seaman et al., 1999; Worton, 1995). This method allowed us to select the densest clusters of fixes, which in our data were the campsites. We asked the herders to locate all their campsites, but the method of identification based on the GPS data helped to validate their claims, which in some cases were controversial. Our study recognizes a campsite as an area not only occupied with chums, but used for daily work with reindeer where animals are limited in forage. Such an approach makes the results more accurate and will also help in the future studies of this type data, or in the situation when there is no possibility to receive comments from the herders.

To better visualize the distribution of the reindeer during four periods, we used kernel density with the ad-hoc rule-based reference bandwidth method (HREF) with 50% and 95% isopleths. To calculate the areas that were occupied by all the collared reindeer during every campsite stay, we used the minimum 100% convex polygon (MCP 100%) (Calenge, 2006). The average and maximum distances were analyzed by using the Near tool in Arcgis Pro.

We also made a graph, demonstrating the levels of control over the herd by Nenets in different periods of summer—autumn season. We used GPS fixes within the borders of the computed polygons around the campsites to observe the daily time (24 h) of reindeer coming to the campsites, frequency of that and the presence there over periods.

According to Nenets, the order of duty shift in July and beginning of August requires driving a herd to a campsite to change a duty reindeer team at least twice a day (1 per 12 h) (Table 1). Although the increase of insect harassment makes such shuttle movements (pasture – campsite) more frequent. Therefore, we observed the timing and frequency of reindeer moving to campsites. To identify the conditions when reindeer did come to a campsite to protect themselves from insects, we examined the reindeer movements in days with weather most favorable for insects activity: hot days with an average daily temperatures between + 15 and + 30° C and with an average wind speed 0–5 m/s (July 8, 19, 20, 24 and August 4, 5, 6, 2021). Cold and windy days with an average temperature between + 5 and + 10° C and with an average wind speed reaching 10 m/s and higher (July 1, 4, 10, 11, 12, 22 and August 8 2021) were selected in order to make a comparative analysis of reindeer behavior in conditions adverse for insects activity. The preferable/negative for bloodsucking insects weather conditions were identified on the basis of recent field studies in the tundra closest to our study area (Sizikov, 2005). The selected dates correspond to the terms of mass flight of mosquitoes (*Aedes* sp., Culicidae) (first week of July – first week of August), warble flies (*Hypoderma tarandi*, L., Oestridae) and nose bot flies (*Cephenemyia trompe* L., Oestridae) (third week of July – first week of August) in southern Yamal tundra (Fyodorova et al., 2019). We used the meteorological data of HOBO U30-NRC local weather station of the Erkuta research station which records basic weather parameters every 5 min.

Interview with Herders

After the initial processing of the GPS data, we compiled a 19 item questionnaire for our Nenets partners (Supplementary information 1) to clarify the details on the summer-autumn grazing of the model herd. The questionnaire consists of thematic sections: mapping the different periods, locating campsites, and visualizing the reindeer movement patterns. Regarding all the questions, we first asked the herders to draw on an empty map, and only after that we showed them the map with GPS data in order to compare results. This section also included questions about long-distance sledge trips and other single events (e. g. seasonal panty (velvet antlers) sawing). The other part of the questionnaire was related to the details of regular summer – autumn herding practices. A special section included questions about "insect time" and behavior of people and reindeer during the period of insect harassment.

In the course of the study, we relied on long-term ethnographic observations of the anthropologist on our team. Despite the fact that the answers to some questions were known to us, they were asked in order to get explanations from herders taking part in the study. Semi-structured interviews were conducted with the two herders of the model herd. Answers (with the permission of the informants) were recorded. In the Results we excluded the special ethnographic part but gave the answers of Nenets throughout the entire section in accordance with the general logic of presentation. We used the Nenets herders' explanations to contextualize interpretation of the geospatial data in the Results and Discussion sections.

Results

The GPS tracking reveals movement patterns of the tagged reindeer from the end of June to November. According to these patterns, we identified four different periods. Variation in daily movements of the herd relates to herding practices for pastures with different characteristics (bonitet, forage composition, biomass, etc.) and weather conditions impacting insect harassment (Table 2; Fig. 4). Herders concurred with the 4 periods characterization of movement patterns and enriched our understanding of Nenets herding practices during interviews.

Figure 5 shows the area of sites with GPS fixes concentrated at the campsites under the herders' control, as well as the 50% and 95% isopleths of the utilization distribution of reindeer during each period. The locations of campsites were confirmed by the herders. Area of each campsite varies from 0.01 to 0.68 km2, with mean value—0.37 km2 and mean diameter of campsite is about 200 m.

To analyze the features of each period and define the differences among them, we separated all GPS fixes based on various parameters, such as duration of staying, area of distributed GPS fixes at the campsite, mean and max distances of reindeer tracks. Distance that reindeer covered while grazing and the quantity of GPS fixes within the campsite borders relative to overall number demonstrate the level of human control of the animals (Table 3).

On average, the duration of every staying in period I is 5 days, which is mostly matching with the duration of stayings over period III (mean duration – 7 days). In II and IV periods the campsites stayed in one place for a long time (about a month). In support of our assumption about the correspondence between smaller area and herders' intensive control, we found a positive correlation between area

Table 2 Pasturing periods from the end of June to the beginning of November, 2021

No	Date	Area	Activity
I	27.06 – 03.08	Route to the summer pastures	Migration to the Baydaratskaya Bay shore, major insect harassment, continuous 24-h herders duty, two *yorkolavas* per 24 h
II	04.08 – 03.09	Summer pastures	Main summer pastures. First week – total control over the herd because of insect harassment; later – more free grazing
III	04.09 – 23.09	Early autumn pastures	Migration back to the Obskaya-Bovanenkovo railroad, semi-free grazing
IV	24.09 – 11.11	Late autumn pastures	Separation of transport bulls and control over them; free grazing of the rest animals; rutting season. Gathering all reindeer together at the last campsite for moving southwards to winter pastures

of 100% distributed fixes over the stayings and duration there ($r = 0.6$; $p = 0.002$).

In I period an average 21.6% of GPS fixes were located at the campsites; in II period (1 campsite) – 13.8%; the average values of periods III and IV are roughly equal – 6.5% and 6.3%. The proportion of GPS fixes at the campsites correlates negatively with the reindeer dispersing area, MCP 100% ($r = -0.7$; $p = 0.002$) where the area values vary from 10.66 to 152.06 km^2, and proportion values – from 1.3 to 27.6%.

We paid special attention to period I, when reindeer spent more time at the campsites. The reindeer movement pattern demonstrates a rather distinct configuration which we called "snowflakes" (Fig. 4). The herd is frequently driven back to the campsite for changing draught reindeer for a duty herder and because of insect harassment. Comparing the maximum distance the herd left the campsite, depending on various weather conditions affecting insect activity, we found out that reindeer moved at a distance of 2.7 km on average (max 3.8 km) on hot and windless days

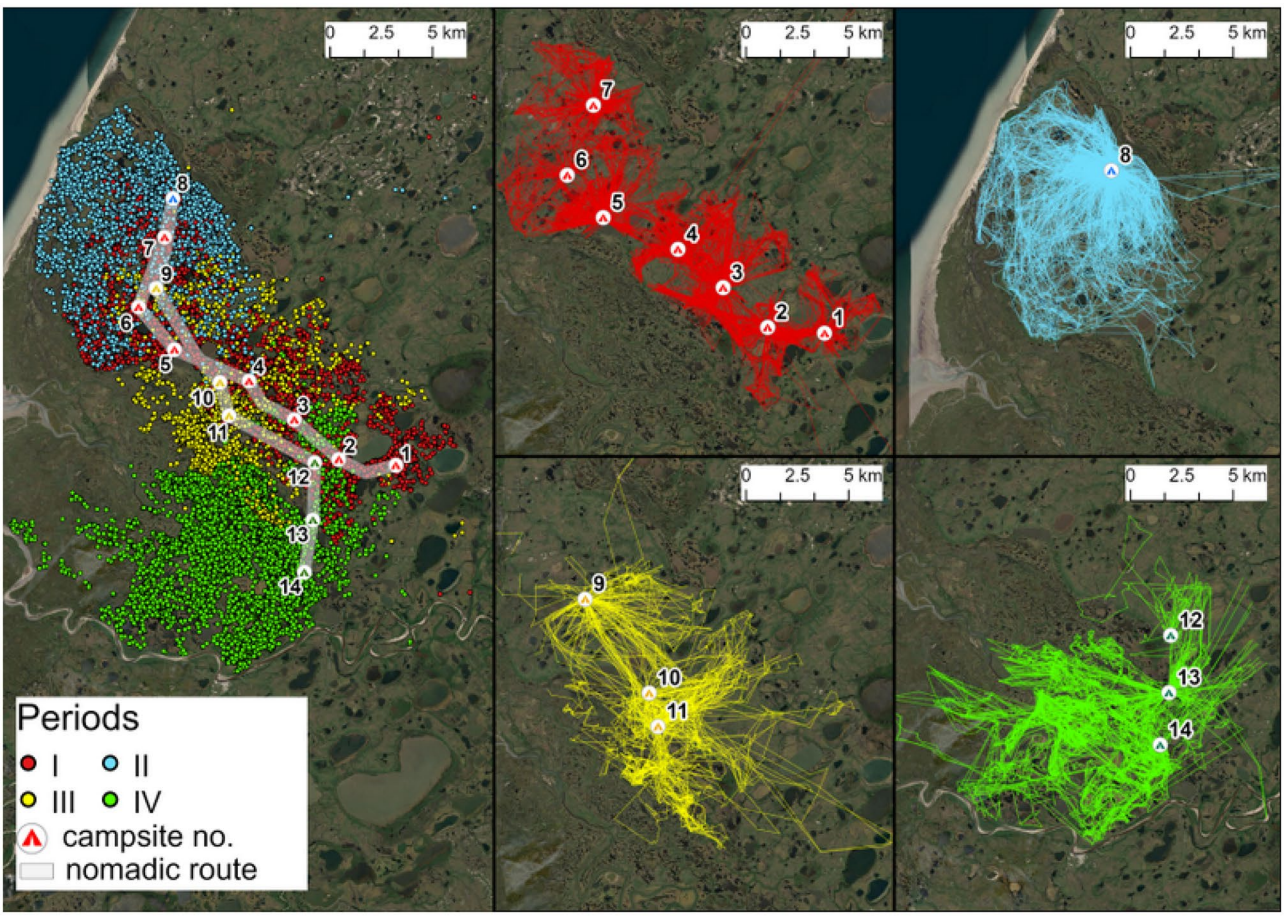

Fig. 4 Distribution of the reindeer GPS fixes (left) and GPS tracks (right, 4 periods) with the campsites from June 27 to November 11, 2021 divided into four periods. The imagery base map is from Esri and Earthstar Geographics

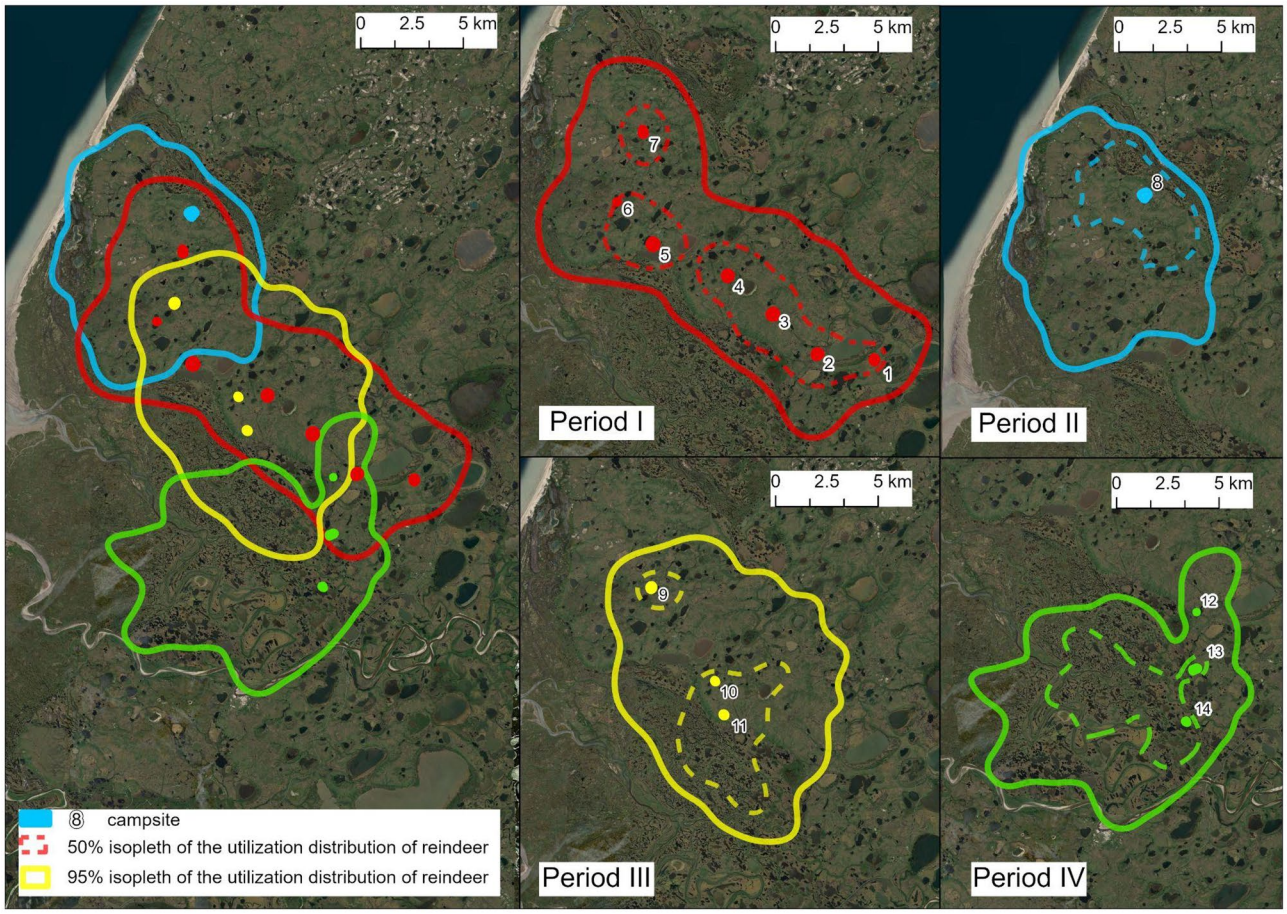

Fig. 5 Estimation GPS fixes density at the campsites and within the 50 and 95% isopleths for 4 periods using the kernel density method. The imagery base map is from Esri and Earthstar Geographics

($n = 7$) and at 4.3 km on average (max 5.7 km) on cold and windy days ($n = 7$) (Fig. 6). The maximum distance the reindeer went off the campsite on cold and hot days is different at $p = 0.007$. The herd also stayed for a longer time at the campsite ($p = 0.024$) of 8 h on average (max 11 h) on hot days, and 4 h on average (max 6 h) on cold days.

Herders say "it is the mosquitoes and *pilyu (*Nenets – warble flies and nose bot flies) that drive reindeer to the chum" but we clarified some herding nuances in the interviews. As compared with mosquitoes, reindeer cannot tolerate warble flies and nose bot flies which become active on warm sunny days and more resistant to wind (Mörschel, 1999). When escaping from insects, the animals try to ascend any wind-blown hill (Hagemoen & Reimers, 2002; Skarin et al., 2004, 2010) – areas usually used for campsites. Nenets explain that the herd may concentrate on any hill but the duty herder should try to gather reindeer downwind of the campsite, so that the animals make their way windward to the chum. If they are guided in the right direction, the animals run to the campsite searching for protection against insects and thus occupy the area where they already stayed before. At this time people at the campsite, including children, take their place behind the herd to stop single reindeer running away and taking with them all the herd trying to run windward. On the days with high insect activity, a herder may move the herd to the campsite every two hours and on cold and windy days only twice a day, about once every 12 h for changing the draught reindeer. Time spent by reindeer on the campsites without forage differs significantly depending on insect harassment – up to 11 h a day with active insects and half of that on windy days.

We interpret the daily modes of herders – reindeer interactions on a graph comparing the number of GPS fixes at the campsites in different periods (Fig. 7). We excluded a few days of period II which do not represent typical movement patterns: first week of the period (last days of the insect harassment) and last 5 days (the herd was regularly pushed to the campsite while preparing the migration from the summer pastures). We also excluded the data of the last two-day long campsite of period IV, since reindeer were also concentrated for further late autumn migration.

Table 3 Characteristics of reindeer movement over stayings: period classification, sequencing and duration of stayings, area of MCP with 100% of locations over a staying, mean and max distance reindeer moved away from a campsite and proportion of GPS fixes at a campsite relative to all fixes in a staying

Period	Campsite No	Duration of staying, day	Area, MCP 100%, km^2	Mean distance reindeer moved away from a campsite, km	Max distance reindeer moved away from a campsite, km	Proportion of GPS fixes at a campsite, %
I	1	4	17.87	1.3	3.6	23.6
	2	6	27.98	1.4	4.8	19.5
	3	8	45.15	1.9	5.7	25.3
	4	5	20.60	1.2	4.3	27.6
	5	7	24.55	1.3	4.6	26.6
	6	3	18.09	1.7	3.7	8.9
	7	5	27.87	1.4	4.1	19.7
II	8	31	106.13	3.1	9.9	13.8
III	9	7	100.13	1.5	4.4	9.6
	10	5	98.05	3.8	10.0	4.3
	11	8	57.96	2.2	6.3	5.5
IV	12	9	121.23	5.6	10.0	1.3
	13	37	152.06	5.2	14.8	1.6
	14	3	10.66	1.3	3.4	16

Two well-defined peaks in period I correspond to the times of *yorkolava*, confirmed by Nenets herders. The herd usually was driven to the campsite at 10–11:00 before the morning *yorkolava*, and reindeer and herder rested. At 12–14:00 the *habts* were driven into the corral to change draught animals. The time of day for *yorkolava* varied depending on weather and insects' activity. In the evening, the herd was also pushed to the campsite for the *yorkolava* at 20–21:00. We assume that the third peak in period I is related specifically to insect activity. II, III and IV periods do not show such manifest peaks of GPS fixes near campsite since there was no need for 24-day presence of a herder with reindeer after the decrease of insects and *yorkolava* was carried out far less often. According to the herders, it was "chaotic" time for *yorkolava*, i.e. at different hours of daylight (the midnight sun ends in mid-August).

Discussion

Yamal reindeer herding involves continuous interactions between humans and reindeer as is demonstrated by satellite telemetry data. Though the Nenets migration routes and their lifestyle are largely responses to reindeer ecology, and the herders often say "human follows the reindeer", the multiple non-ecological factors such as administrative territory division, infrastructure layout, neighbor relationship and many others can fundamentally affect the pasturing strategy and tactics (Beach, 1990; Dwyer & Istomin, 2008; Dyson-Hudson, 1972). After analyzing the movements of tagged reindeer and evaluating the density of GPS fixes and herd distribution at different time intervals from the end of June to the beginning of November, we found strong signals of herders' manipulations of reindeer in the GPS data, consistent with Nenets' informants interview responses, the maps they annotated, and their observations of the mapped GPS fixes.

Based on the spatio-temporal distribution of GPS fixes during different interactions of herders with herd, we suggest classifying the reindeer movements depending on the intensity of the effect of human influence which defines three "degrees of freedom" for foraging behavior. 1 – the most intensive impact when reindeer are not foraging (*yorkolava*, *yamdanava*, *ngedalyova*); 2 – influence, which moderate, guide and constrain movement of herd (*ma''alkova*); 3 – free grazing (reindeer are left out of direct human control for 1–3 days). Situation when reindeer stay densely or "circle" at the campsite because insect harassment (*padeva*) refers to the first degree of freedom.

Analyzing our data, we suggest looking at human – reindeer interaction in terms of landscape ecology (Risser et al., 1984; Turner & Gardner, 2015). With the domestic reindeer foraging behavior considered as a combination of forage searching, eating and processing solutions (Augustine & Derner, 2013; Belovsky, 1991), we brought the above degrees of decision-making freedom into correlation with the ecological hierarchies, used for studying herbivores foraging behavior (Senft et al., 1987; Skarin & Åhman, 2014; Vistnes & Nellemann, 2008) (Table 4).

The reindeer movement patterns that we call "snowflakes" are a response to weather conditions and have

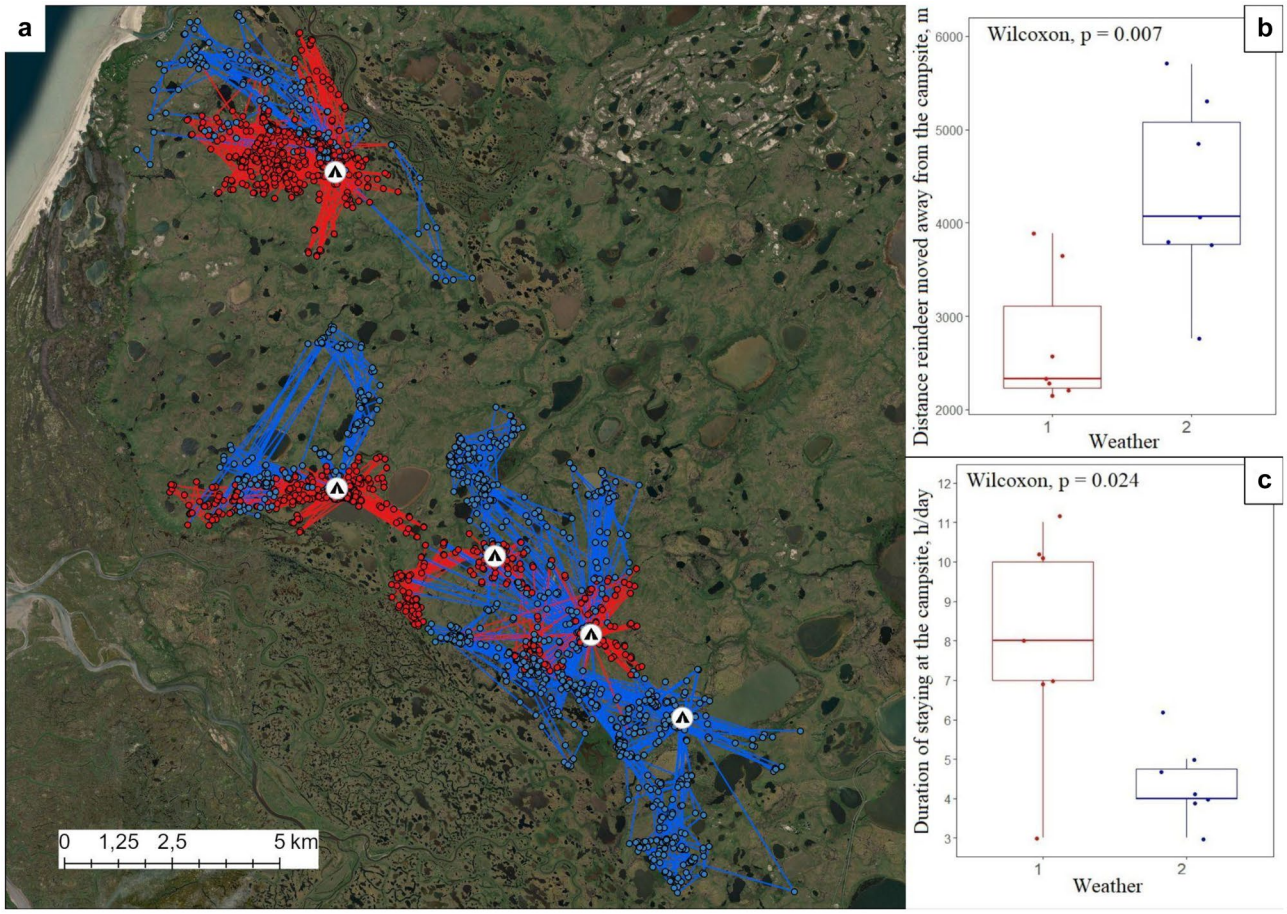

Fig. 6 Reindeer movements in different weather conditions: a) movement tracks (red lines and dots – hot and windless days (1), blue – cold and windy days (2); b) the graph of distribution of the GPS fixes away from campsite (distance); c) duration of reindeer presence at campsite (time). Dots on the graphs – mean values from all collars on a particular day, bold line – median, polygon – first and third quartiles, vertical lines – min and max values. The imagery base map is from Esri and Earthstar Geographics

various lengths of radial elements or "petals"; such reindeer tracks were characterized by Golovnev et al. (2014). Herders' influence on the herd affects reindeer distribution over space and time the animals stayed at the campsite: the more often GPS fixes are located near chums, the less area was occupied by the herd on each staying (Fig. 5, Table 3). Accordingly, the highest level of the herd control and therefore the trampling of the campsite area occurs from the end of June to the beginning of August – in the time of peak insect activity and 24-h duty of herders. As a result, on average 21.6% of GPS fixes were at a campsite within a 200 m diameter and reindeer covered about 1.5 km on average to graze. Graph on Fig. 7 shows the number of GPS fixes at the campsites over I period which is significantly higher than in the other three periods and it is consistent with our ethnographic observations and interviews with Nenets herders.

Insect harassment became mild at the summer campsite near to the Baydaratskaya Bay, and totally disappeared by the end of period II. Consequently, the proportion of GPS fixes in the campsite decreased to 13%, and a mean animal distribution radius extended up to 3 km making up a maximum distance of 10 km. This distance corresponds to the herding regimes of the III and IV periods with free grazing (Table 2). It should be noted that the model herd has no neighboring households in this part of the Yamal tundra. Presence of neighboring herds/households can restrict migrations because of the risk of mixing with other herds. On the contrary, natural "boundaries" (rivers and the Baydaratskaya Bay) within the studied area give the herders an opportunity to leave the herd without direct control for 1–3 days. Such free grazing significantly reduces the negative effect of trampling the pastures.

The extrapolation of our study results to all the private herds in Yamal meets with difficulties since migratory and pasturing patterns vary across the Yamal tundra. However, the Nenets practices of control over the herd will be similar in response to some combinations of factors (weather,

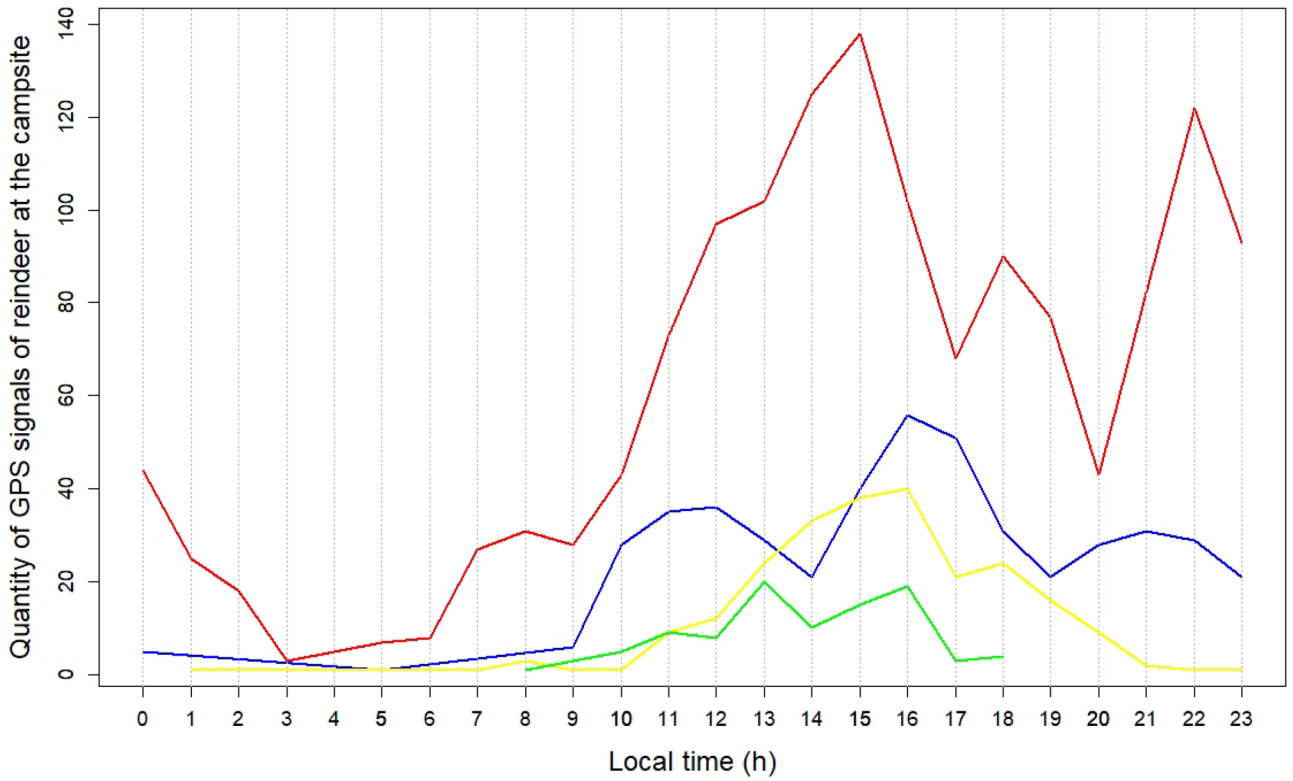

Fig. 7 Daily quantity of reindeer collar GPS fixes within campsites: red line – I period, blue line – II period, yellow line – III period, green line – IV period

insect harassment, pasture conditions, etc.). The identified proportion of herd's signals in the campsites and radius of reindeer distribution over pastureson warm and cold days will be relevant for any Nenets households. The analyzed data could be the base for studying the preferred habitats of reindeer or broadly – reindeer foraging behavior in a new climate, ecological, and social conditions. The warming of the tundra and the increase in summer heat days associated with global climate change even in short-term perspective can significantly affect the freedom of foraging behavior of the Yamal domestic reindeer and reveal the new herding practices.

Table 4 Scale of spatial organization of reindeer herding in Yamal

Scale of ecological hierarchy	Reindeer movement pattern	Human activity impact	Freedom of reindeer foraging behavior
Regional system	Migration between seasonal pastures	Driving the herd along the nomadic rout	Long-distance movements between pastures are entirely determined by the herders. Selection of foraging areas within the nomadic rout borders
Landscape system	Free movement between plant communities	Taking the herd for free grazing	Foraging decision-making between different plant communities (degree 3)
Large patch or plant community	Moving within a limited area	Summer daily herder's duty	Selection of micro-patches or particular plants within the plant community (degree 2)

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10745-022-00384-8.

Acknowledgements We are deeply grateful to the YNAO Government and our partners, the Nenets family of Efim Serotetto. We thank Karl Mertens for language improving and helpful comments.

Funding This paper was prepared with the support of the Russian Science Foundation (project No. 22–24-00642).

Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval All applicable international, national and/or institutional guidelines for the social and animal studies were followed. The local participants voluntarily provided their information and gave their consent to conduct the studies.

Conflict of Interest The authors declare they have no competing interests.

References

Andreev, V. N. (1934). Forage base of Yamal reindeer herding. *Soviet Reindeer Herding, 1*, 99–164. In Russian.

Augustine, D. J., & Derner, J. D. (2013). Assessing herbivore foraging behavior with GPS collars in a semiarid grassland. *Sensors, 13*(3), 3711–3723. https://doi.org/10.3390/s130303711

Baltensperger, A. P., & Joly, K. (2019). Using Seasonal Landscape Models to predict space use and migratory patterns of an arctic ungulate. *Movement Ecology, 7*(18). https://doi.org/10.1186/s40462-019-0162-8

Baskin, L. M. (2009). *Reindeer: Management of behavior and populations. Reindeer herding. Hunting*. In Russian. Tovarishchestvo nauchnykh izdatelstv KMK.

Beach, H. (1990). Comparative systems of reindeer herding. In J. G. Galaty & D. L. Johnson (Eds.), *The World of Pastoralism: Herding Systems in Comparative Perspective* (pp. 255–298). Belhaven Press.

Beest, M. T., Sitters, J., Ménard, C. B., & Olofsson, J. (2016). Reindeer grazing increases summer albedo by reducing shrub abundance in Arctic tundra. *Environmental Research Letters, 11*, 125013. https://doi.org/10.1088/1748-9326/aa5128

Belovsky, G. E. (1991). Insights for caribou/reindeer management using optimal foraging theory. *Rangifer, 11*(4), 7–23. https://doi.org/10.7557/2.11.4.987

Bernes, C., Bråthen, K. A., Forbes, B. C., et al. (2015). What are the impacts of reindeer/caribou (*Rangifer tarandus* L.) on arctic and alpine vegetation? A systematic review. *Environmental Evidance, 4*, 4. https://doi.org/10.1186/s13750-014-0030-3

Bogdanov, V. D., & Golovatin, M. G. (2017). Anthrax in Yamal: An ecological view of traditional reindeer husbandry. *Ecology, 2*, 77–82. https://doi.org/10.7868/S0367059717020056. In Russian.

Cahoon, S. M. P., Sullivan, P. F., Post, E., & Welker, J. M. (2012). Large herbivores limit CO2 uptake and suppress carbon cycle responses to warming in West Greenland. *Global Change Biology, 18*, 469–479. https://doi.org/10.1111/j.1365-2486.2011.02528.x

Calenge, C. (2006). The package "adehabitat" for the R software: A tool for the analysis of space and habitat use by animals. *Ecological Modeling, 197*(3), 516–519. https://doi.org/10.1016/j.ecolmodel.2006.03.017

Dwyer, M. J., & Istomin, K. V. (2008). Theories of nomadic movement: A new theoretical approach for understanding the movement decisions of nenets and komi reindeer herders. *Human Ecology, 36*, 521–533. https://doi.org/10.1007/s10745-008-9169-2

Dyson-Hudson, N. (1972). The study of nomads. *Journal of Asian and African Studies, 7*, 2–29. https://doi.org/10.1177/002190967200700103

Ektova, S. N., & Morozova, L. M. (2015). Rate of recovery of lichen-dominated tundra vegetation after overgrazing at the Yamal Peninsula. *Czech Polar Reports, 5*(1), 27–32. https://doi.org/10.5817/CPR2015-1-3

Elsakov, V. V., Schanov, V. M., & Belyaev, N. V. (2011). Satellite research methods in reindeer pastures monitoring and mapping. *Current Problems in Remote Sensing of the Earth from Space, 8*(2), 201–207. In Russian.

Forbes, B. C., Macias-Fauria, M., & Zetterberg, M. P. (2010). Russian Arctic warming and "greening" are closely tracked by tundra shrub willows. *Global Change Biology, 16*, 1542–1554. https://doi.org/10.1111/j.1365-2486.2009.02047.x

Fyodorova, O. A., Siben, A. N., & Khlyzova, T. A. (2019). Distribution and flight dates of bloodsucking dipterans and warble flies and nose bot flies on the territory of the Yamalo-Nenets Autonomous District. *Veterinaria Kubani, 1*, 21–24. https://doi.org/10.33861/2071-8020-2019-1-21-24. In Russian.

Geobotanical assessment of reindeer pastures in Yamalskiy and Tazovskiy districts of Yamalo-Nenets Autonomous Okrug. (2017) Report, ed. by Ermokhina, K. A. Salekhard.

Golovatin, M. G., Morozova, L. M., & Ektova, S. N. (2012). Effect of reindeer overgrazing on vegetation and animals of tundra ecosystems of the Yamal peninsula. *Czech Polar Reports, 2*(2), 80–91. https://doi.org/10.5817/CPR2012-2-8

Golovnev, A. V., Lezova, S. V., Abramov, I. V., Belorussova, S. Y., & Babenkova, N. A. (2014). *Ethnoexpertise in Yamal: Nenets nomadism and gas fields*. In Russian. AMB Press, Ekaterinburg

Gorodkov, B. N. (1926). Reindeer pastures in the North of the ural region. *Ural, 2*, 43–66.

Hagemoen, R. I. M., & Reimers, E. (2002). Reindeer summer activity pattern in relation to weather and insect harassment. *Journal of Animal Ecology, 71*(5), 883–892. https://doi.org/10.1046/j.1365-2656.2002.00654.x

Igoshina, K. N. (1937). The pasture fodder and forage seasons in the ural reindeer herding. *Soviet Reindeer Herding, 10*, 125–191. In Russian.

Istomin, K. V., & Dwyer, M. J. (2021). *Reindeer herders' thinking: A comparative research of relations between economy, cognition and way of life*. Verlag der Kulturstiftung Sibirien SEC Publications.

Jung, T. S., Hegel, T. M., Bentzen, T. W., Egli, K., Jessup, L., Kienzler, M., Kuba, K., Kukka, P. M., Russell, K., Suitor, M. P., & Tatsumi, K. (2018). Accuracy and performance of low-feature GPS collars deployed on bison Bison bison and caribou Rangifer tarandus. *Wildlife Biology, 1*, 1–11. https://doi.org/10.2981/wlb.00404

Karpov, N. S. (2006). *Dynamics of reindeer pasture vegetation in the tundra zone of North-Eastern Yakutiya*: PhD thesis. Institute of Biological Problems of the Cryolithozone Siberian Branch of the Russian Academy of Sciences

Klokov, K. B. (2020). Diversity of regional trends in traditional reindeer husbandry in the Russian Arctic. *IOP Conference Series: Earth and Environmental Science, 539*, 012180. https://doi.org/10.1088/1755-1315/539/1/012180

Kryazhimskiy, F. V., Maklakov, K. V., Morozova, L. M., & Ektova, S. N. (2011). Systematic analysis of biogeocenosis of the Yamal

Peninsula: Simulation of the impact of large-herd reindeer breeding on vegetation. *Ecology, 5*, 323–333. In Russian.

Mekonnen, Z. A., Riley, W. J., Berner, L. T., et al. (2021). *Environmental Research Letters*, *16*, 053001. https://doi.org/10.1088/1748-9326/abf28b

Melnikov, E. S. (1991). *Explanatory note to the map of natural complexes in the north of Western Siberia for the purpose of geocryological forecasting and planning of environmental protection measures for mass construction (scale 1:1000000)*. In Russian. VSEGINGEO, Moscow.

Mörschel, F. M. (1999). Use of climatic data to model the presence of oestrid flies in caribou herds. *Journal of Wildlife Management, 63*, 588–593. https://doi.org/10.2307/3802647

Newmaster, S. G., Thompson, I. D., Steeves, R. A. D., Rodgers, A. R., Fazekas, A. J., Malores, J. R., McMullin, R. T., & Fryxell, J. M. (2013). Examination of two new technologies to assess the diet of woodland caribou: Video recorders attached to collars and DNA barcoding. *Canadian Journal of Forest Research, 43*(10), 897–900. https://doi.org/10.1139/cjfr-2013-0108

Olofsson, J., Oksanen, L., Callaghan, T., Hulme, P. E., Oksanen, T., & Suominen, O. (2009). Herbivores inhibit climate-driven shrub expansion on the tundra. *Global Change Biology, 15*, 2681–2693. https://doi.org/10.1111/j.1365-2486.2009.01935.x

Podkorytov, F. M. (1995). *Yamal Reindeer Herding*. In Russian. L.: Tipografiia LAES.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. Retrieved August 2022 from http://www.R-project.org

Reimers, E., Tsegaye, D., Colman, J. E., & Eftestøl, S. (2014). Activity patterns in reindeer with domestic vs. wild ancestry. *Applied Animal Behaviour Science, 150*, 74–84. https://doi.org/10.1016/j.applanim.2013.10.010

Risser, P. G., Karr, J. R., & Forman, R. T. T. (1984). *Landscape Ecology: Directions and Approaches.* Illinois Natural History Survey. Special Publication No 2. Champaign, Illinois.

Salman, A. L., Savchenko, A. P., Grebel, G., Okhlopkov, I. M., Savchenko, P. A., Dubintsov, S. A., Soukhovolsky, V. G., & Muravyov, A. N. (2020). Information and space technologies in the development of hunting and domestic reindeer husbandry. *IOP Conference Series: Materials Science and Engineering, 456*, 012059. https://doi.org/10.1088/1757-899X/456/1/012059

Savchenko, A. P., Salman, A. L., Savchenko, P. A., Savchenko, I. A., Dubintsov, S. A., & Muravyov, A. N. (2019). Use experience of collars with radio beacons of Argos satellite system produced by ES-PAS Ltd. for the study of reindeer Taimyr-Evenk population. *Journal of Physics: Conference Series, 1399*(3), 033047. https://doi.org/10.1088/1742-6596/1399/3/033047

Seaman, D. E., Millspaugh, J. J., Kernohan, B. J., Brundige, G. C., Raedeke, K. J., & Gitzen, R. A. (1999). Effects of sample size on kernel home range estimates. *Journal of Wildlife Management, 63*(2), 739–747. https://doi.org/10.2307/3802664

Seaman, D. E., & Powell, R. A. (1996). An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology, 77*(7), 2075–2085. https://doi.org/10.2307/2265701

Senft, R. B., Coughenour, L. M., Bailey, D. W., Rittenhouse, O. E., Sals, O. E., & Swift, D. M. (1987). Large herbivore foraging and ecological hierarchies. *BioScience, 37*(11), 789–799. https://doi.org/10.2307/1310545

Silverman, B. W. (1986). *Density Estimation for Statistics and Data Analysis*. Chapman & Hall. https://doi.org/10.1002/bimj.4710300745

Sizikov, S. Yu. (2005). *Protection of reindeer from bloodsucking two-winged insects and imago gadflies in Yamalo-Nenets Autonomous okrug*: doct. thesis. In Russian. Research Institute of Veterinary Entomology and Arachnology, SB RAS. Tyumen.

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

Skarin, A., Danell, Ö., Bergström, R., & Moen, J. (2004). Insect avoidance may override human disturbances in reindeer habitat selection. *Rangifer, 24*(2), 95–103. https://doi.org/10.7557/2.24.2.306

Skarin, A., Danell, Ö., Bergström, R., & Moen, J. (2008). Summer habitat preferences of GPS-collared reindeer *Rangifer tarandus tarandus*. *Wildlife Biology, 14*(1), 1–15. https://doi.org/10.2981/0909-6396(2008)14[1:SHPOGR]2.0.CO;2

Skarin, A., Danell, Ö., Bergström, R., & Moen, J. (2010). Reindeer movement patterns in alpine summer ranges. *Polar Biology, 33*, 1263–1275. https://doi.org/10.1007/s00300-010-0815-y

Skarin, A., Verdonen, M., Kumpula, T., Macias-Fauria, M., Alam, M., Kerby, J., & Forbes, B. C. (2020). Reindeer use of low Arctic tundra correlates with landscape structure. *Environmental research letters, 15*(11), [115012]. https://doi.org/10.1088/1748-9326/abbf15

Stammler, F. (2005). *Reindeer nomads meet the market. Culture, property and globalisation at the "End of the land"*. Lit Verlag, Berlin.

Terekhina, A. N., & Volkovitskiy, A. I. (2020). Patterns of resource use by nomads of Yamal: ethnography of macro-regions. In *Arctic and Siberian energy: resource using in the context of socio-economic changes*, edited by Davidov, V. N. (pp. 87–113). In Russian. Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera), RAS, Saint-Petersburg.

Turner, M. G., & Gardner, R. H. (2015). Landscape metrics. In *Landscape ecology in theory and practice*, edited by Turner, M. G. & Gardner, R. H. (pp. 97–142). Springer, New York. https://doi.org/10.1007/978-1-4939-2794-4_1

Valinger, E., Berg, S., & Lind, T. (2018). Reindeer husbandry in a mountain Sami village in boreal Sweden: The social and economic effect of introducing GPS collars and adaptive forest management. *Agroforestry Systems, 92*, 933–943. https://doi.org/10.1007/s10457-018-0249-z

Verma, M., Schulte to Bühne, H., Lopes, M., Ehrich, D., Sokovnina, S., Hofhuis, S. P., & Pettorelli, N. (2020). Can reindeer husbandry management slow down the shrubification of the Arctic? *Journal of Environmental Management, 267*, 110636. https://doi.org/10.1016/j.jenvman.2020.110636

Veselkin, D. V., Morozova, L. M., & Gorbunova, A. M. (2021). Decrease of NDVI values in the southern tundra of Yamal in 2001–2018 correlates with the size of domesticated reindeer population. *Modern Problems of Remote Sensing from Space, 18*(2), 143–155. https://doi.org/10.21046/2070-7401-2021-18-2-143-155. In Russian.

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

Vuorinen, K. E. M., Austrheim, G., Tremblay, J., Myers-Smith, I. H., Hortman, H. I., Frank, P., Barrio, I. C., Dalerum, F., Björkman, M. P., Björk, R. G., Ehrich, D., Sokolov, A., Sokolova, N., Ropars, P., Boudreau, S., Normand, S., Prendin, A. L., Schmidt, N. M., Pacheco-Solana, A., et al. (2022). Growth rings show limited evidence for ungulates' potential to suppress shrubs across the Arctic. *Environmental Research Letters, 22*, 034013. https://doi.org/10.1088/1748-9326/ac5207

Walker, D. A., Raynolds, M. K., Daniels, F. J. A., Einarsson, E., Elvebakk, A., Gould, W. A., Katenin, A. E., Kholod, S. S., Markon, C. J., Melnikov, E. S., Moskalenko, N. G., Talbot, S. S., Yurtsev, B. A., the other members of the CAVM Team. (2005). The Circumpolar Arctic vegetation map. *Journal of Vegetation Science, 16*(3), 267–282. https://doi.org/10.1111/j.1654-1103.2005.tb02365.x

Wand, M. P., & Jones, M. C. (1995). *Kernel Smoothing*. Chapman & Hall, London. https://doi.org/10.1007/978-1-4899-4493-1

Worton, B. J. (1995). Using Monte Carlo simulation to evaluate kernel-based home range estimators. *Journal of Wildlife Management, 59*(4), 794–800. https://doi.org/10.2307/3801959

Yuzhakov, A. A., & Mukhachev, A. D. (2001). *Ethnic reindeer herding in Western Siberia: Nenets type*. In Russian. SB RAAS Press, Novosibirsk

Yuzhakov, A. A. (2003). *Nenets native breed of reindeer*: doct. thesis. In Russian. Salekhard.