Effects of Wind Power Development on Reindeer: Global Positioning System Monitoring and Herders' Experience★

Authors: Eftestøl, Sindre, Tsegaye, Diress, Flydal, Kjetil, and Colman, Jonathan E.

Source: Rangeland Ecology and Management, 87(1) : 55-68

Published By: Society for Range Management

URL: https://doi.org/10.1016/j.rama.2022.11.011

Rangeland Ecology & Management 87 (2023) 55–68

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: www.elsevier.com/locate/rama

Original Research

Effects of Wind Power Development on Reindeer: Global Positioning System Monitoring and Herders' Experience ☆

Sindre Eftestøl[1,2], Diress Tsegaye[1,2,*], Kjetil Flydal[1], Jonathan E. Colman[1,2]

[1] University of Oslo, Department of Biosciences, Centre for Ecological & Evolutionary Synthesis, Blindern, 0316, Oslo, Norway
[2] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, 1432, Ås, Norway

ARTICLE INFO

Article history:
Received 30 September 2021
Revised 8 September 2022
Accepted 28 November 2022

Key Words:
Avoidance
GPS data
Herders' knowledge
Movement patterns
Reindeer
Wind power

ABSTRACT

Testing and documenting effects of wind farm (WF) infrastructure on wildlife are crucial considering increasing development throughout Scandinavia, especially for reindeer, which require large areas for grazing and are vulnerable to disturbances. We present results from 2011 to 2019 for semidomesticated reindeer tracked with Global Positioning System (GPS) transmitters, along with herders' knowledge about reindeers' habitat use and changes following WF development within the Raggonjarga reindeer district summer range in Finnmark, Norway. We tracked up to 36 females (ranging from 19 to 36 individuals per year), from their arrival in the study area in April to their departure in the end of October. We evaluated habitat use before, during, and after WF development at the home range and landscape scales. We also evaluated reindeer habitat use qualitatively based on semistructured interviews with local herders. The herders' reported negative effects of the WF on reindeer, both on general habitat use and intrarange movements, resulting in less use of grazing areas surrounding the WF and increased workload for the herders. The GPS results partly support the herders' experiences. We found negative effects of the WF at the landscape scale, except during summer, where the effect was positive. Results at the home range scale showed negative effects of the WF in spring and summer, but not autumn. Different results at different scales make identifying causality challenging, especially as yearly variation was also large. Different results for summer and autumn may relate to changes in herding activities and larger movement patterns, respectively. Similar and contrasting results from the two methods suggest a need for both sources of data in combination to understand and improve land management. Including herders' knowledge to understand results from GPS data is thus crucial. We also suggest future studies focus on mechanisms behind behavioral changes to better understand cause-and-effect relationships and how effects can be mitigated.

Introduction

Production of renewable energy is increasing in many parts of the world, along with concerns for potential negative effects on local ecosystems and other user groups. In Scandinavia, the number and size of wind farms (WFs) has been increasing since the 1990s (Enevoldsen and Permien, 2018; Munkejord, 2018; Todd, 2019). Motivated by public demand and governmental green energy certificate subsidies, the amount of wind power increased from a total of 9.9 TWh in 2020 to 11.8 TWh in Norway in 2021 (NVE, 2022) and is estimated to increase from 27.5 TWh in 2020 to 30 TWh in Sweden within 2030 (Swedish Energy Agency, 2020). While wind energy is an important alternative for reducing carbon emissions, WFs are mostly located in remote areas of Scandinavia and may lead to fragmentation and disturbance of wildlife habitats. Thus, documenting and testing the effect of WF infrastructure alone or in synergy with existing infrastructure is crucial considering their increasing density and dispersal throughout Scandinavia.

Terrestrial WFs may lead to the mortality of individuals for numerous species of bats (Arnett et al., 2016) and birds (Zwart et al., 2016) or avoidance of habitats by other animals, such as large predators (Ferrão da Costa et al., 2018) and cervids, including reindeer *Rangifer tarandus* (e.g., Skarin and Åhman, 2014; Skarin et al., 2018). Depending on existing human disturbance and additional disturbances from WFs, the cumulative negative effects on wildlife populations may

☆ This work was supported by Varanger Power Company, the Swedish Environmental protection Agency, the Swedish Energy Agency (VindVal project), and the Norwegian Research Council (project 255635).

* Correspondence: Diress Tsegaye, PO Box 1066, 0316 Oslo, Norway
E-mail address: d.t.alemu@ibv.uio.no (D. Tsegaye).

https://doi.org/10.1016/j.rama.2022.11.011
1550-7424/

reach thresholds where habitat functionality is reduced, especially for species like reindeer that are vulnerable to human disturbances and depend on large grazing areas (Eftestol et al., 2021). In general, when scaling up local adverse effects from WFs on wildlife, it may have severe consequences at the population level (May et al., 2019).

Reindeer pastoralism is an important part of the culture and economy for indigenous Sami people of Scandinavia, Finland, and the Russian Kola-peninsula (Bjørklund, 2013). Semidomesticated reindeer ranges cover more than 50% of land areas in Norway and Sweden, overlapping areas of existing infrastructure and planned WFs. In this context, there is an escalating land use conflict (Pape and Löffler, 2012), often exacerbated by lack of communication among user groups, including WF developers and Sami reindeer pastoralists. According to Norwegian Nature Diversity Act (Ministry of Climate and Environment, 2009), traditional knowledge should be included as part of assessment and decision-making processes, and such involvement has been emphasized in some social science studies (Oskal et al., 2009). However, most biological studies on habitat use of semidomesticated reindeer lack traditional knowledge and information on herding activities (see reviews by Skarin and Åhman, 2014; Flydal et al., 2019). Herders' knowledge can contribute to planning of biological studies (Sandström et al., 2003), such as defining study areas or seasons, while also considering choice of sampling methods (e.g., counting animal pellets, measure of changes in lichen volume, direct observation of animals or tracking animals using GPS, respectively). Herders' knowledge and experience may also help interpret results from biological studies. This calls for closer collaboration between herders and biologists in planning, conducting, and interpreting studies on the effects of WFs on reindeer.

Studies on effects of WFs and associated infrastructure on semidomesticated reindeer habitat selection vary from no effect (Colman et al., 2013; Tsegaye et al., 2017) to some effects on home range, with less use of areas up to a few km from WF infrastructure (Skarin et al., 2015; Skarin and Alam, 2017; Skarin et al., 2018). Interestingly, and compared with results based on GPS data from such studies, reindeer herders often report stronger negative effects from WFs on the basis of their experience during herding activities. Possibly, indirect effects on a large scale or local movement patterns connected to habitat use in areas seemingly unaffected by WFs could be underestimated in previous studies since information from herders (qualitative data) has seldom been considered while interpreting quantitative data (e.g., Colman et al., 2013). Herders (Utsi and Holtan, personal communication, 2016) argue that avoidance of WF areas may lead to overgrazing in other parts of the range, as well as conflicts with neighboring districts if reindeer move outside their population range. Also, herding activities may be more time consuming if reindeer increase movement rates away from otherwise preferred habitats due to the WFs. On the other hand, active herding could also mitigate reindeer avoidance effects. Thus, information on such activities is crucial when interpreting results from GPS data on reindeer habitat use.

We aimed at investigating changes in habitat use of reindeer at both individual home range (here after "home range") and "landscape" scales using resource selection functions (RSFs) and how reindeer herdsmen coped with eventual changes after WF development within the Raggonjarga reindeer district's summer range in Finnmark, Norway. We compared how selection differed between periods (i.e., before, during, and after WF development) and present results based on GPS data along with herders' knowledge about reindeer movement patterns and habitat use when interacting with a WF on their summer range. Herders also contributed to interpreting and discussing results from the GPS data. For example, we include how reindeer use of an area might relate to herding activities, which again might counteract or acerbate negative effects of the WF.

Importantly, GPS data on habitat use of reindeer are objective, while experiences and descriptions from herders are subjective information gathered in a context of area use conflict. If results based on GPS analyses and herders' experiences deviate, we present possible reasons and suggest further research to verify findings before conclusions are made.

Materials and Methods

Study area

The Raggonjarga reindeer district is located in Finnmark County, Norway. The district's spring, summer, and autumn pastures are located on Varanger peninsula, while the winter pastures are located near the border toward Finland (Fig. 1). The reindeer population during winter has varied between 3 974 animals in March 2011 and 3 686 animals in March 2019. Approximately 80% of the population is female, and with a calving rate of approximately 90%, the summer population is usually 6 500–7 000 animals (Landbruksdirektoratet, 2019). Our study area was used by reindeer from April to October and is located within the northwestern part of the district, including the Rákkocearru WF on a plateau in the northwestern end of the Varanger peninsula (see Fig. 1). The development of the WF started on 10 June, 2013 and was completed at the end of September 2014 (Table 2). The WF has 15 wind turbines, each with a tower of 80 m and a rotor diameter of 101 m, and a total height for each turbine of approximately 130 m. In connection with the WF, about 20 km of gravel road (< 5 m wide) was built, along with a short power line of approximately 2 km connecting the WF to the existing grid. The WF is built on a ridge dominated by boulders in the northern section of the summer range. Even if the ridge itself has poor reindeer habitat, the northern part of the range as a whole constitutes important pastures and is the most used section of the entire summer range. Most human infrastructure can be found along the coast or the eastern and southern borders of the study area. A road runs along the entire southern, eastern, and northern borders, with several cabins along this road. There are also a few cabins dispersed individually throughout the range, an area with a few cabins clustered together along the western coastline (without road connection), the village of Berlevåg, and some smaller power lines (22–66 Kv). Approximately 40 km south of the WF in the southwestern corner of the study area, there is a small settlement and an opencast mining quarry (Eftestøl et al., 2019).

For analyses of habitat use we delimited the study area based on geographical and infrastructural barriers and traditional knowledge on herding practice/traditional use of the summer range (Utsi, personal communication, 2019; for details, see Appendix 1). Together with herding activities, a fence to the south, and the road, valley, and river along the eastern border of the study area delimits the study area (see Fig. 1).

Communication with reindeer herders

Rákkonjárga reindeer district consists of eight family groups of reindeer owners that collectively herd their reindeer in this area. We conducted qualitative and mostly semistructured interviews (Huntington, 1998) with herders, along with unstructured dialog. Most of our communication has been done on a regular basis with the leader of the herding district (Table 1), but with additional communication with other herders during field work. The district leader represents all family groups and herders, and they have continuously discussed topics related to our study with the others before and after interviews/dialog with the research group.

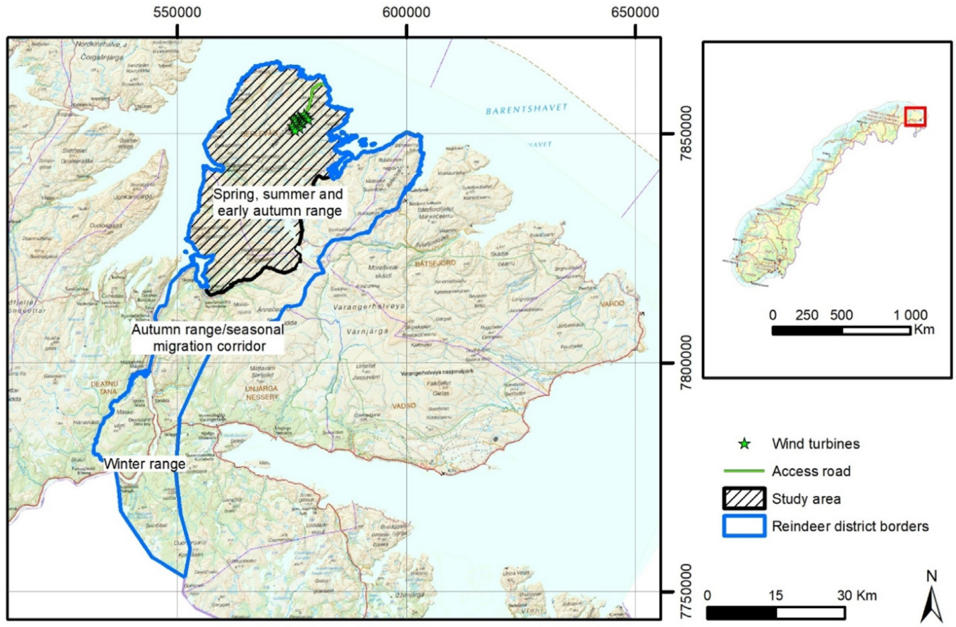

Fig. 1. Map of Rákkocearru reindeer district showing the study area, seasonal reindeer ranges, and migration routes, Varanger peninsula, Finnmark, northern Norway.

Table 1
Approximate number and form of communication contributing to data sources provided by herders before, during, and after wind farm construction. Numbers for email, phone, and "other" are based on combined monthly averages per year, excluding minor or private talks.

Communication	Approximate average per yr	Total (10 yr)	Main information gathered (used in the analysis)
In person during meetings	2-3	20-25	Information involving detailed maps and fieldtrips. Familiarization with local practice and challenges. Understand production, reindeer movement patterns, and habitat use. Gain trust and understand informants' perceptions and experiences.
Email and attachments	2-4	25-30	Validate our information and interpretations of various discussions, figures/visualizations, and GPS results. Clarify uncertainties or misunderstandings.
Phone conversations	7-10	75-100	Planning, confirmation of information, updates, discuss concerns, equipment, and organize fieldwork.
Yearly reports and presentations	1	10	Broader understanding of challenges, perceptions, and feelings within the context of WF development and semidomestic reindeer.
Presentations within the scientific community and administrative management authorities, also sent and discussed with the herders	0-1	2	Feedbacks from oral presentation of results at: (i) Conference on wind energy and wildlife impacts held in Estorli, Portugal in 2017, (ii) reindeer conference in Sweden in 2019, (iii) Norwegian water resources and energy directorate in 2020, and (iv) display of posters at 14th Arctic Ungulate Conference in 2015, Røros, Norway.

Furthermore, email communications from the research group, including drafts of both GPS and "herders experiences" results, were exchanged with the reindeer district secretary, and the secretary and/or the district leader forwarded and/or discussed these drafts with all other active herders. There were no significant disagreements between herders in relation to their experiences of effects from the WF. The focus of our interviews and dialog with herders, in addition to "mapping" the herders' own activities affecting the reindeers' habitat use, was to include their knowledge about reindeer habitat use in general (i.e., movement patterns, reactions to weather, predators and human disturbance), as well as linking GPS data to various environmental conditions. It was also important to document how the herders perceived the WF effects on the reindeers' habitat use and movement patterns. As GPS data became available and analyzed, communication also included information related to trends in those data.

Often during and after meetings and telephone conversations, earlier drafts of habitat use and reindeer herder experience were updated and then sent by email to the herders. This was done to confirm the information, validate, achieve transparency, and allow further discussion of the details in the field. Herders also provided insight into how they counteracted what they experienced to be occurring through actively adapting their herding activities to adjust for negative effects from the WF.

It is important to understand that reindeer owners and the Sami society are in general strong opponents of WF development in their herding area, and agreements between reindeer districts and WF developers are rare. In 2021, a Norwegian Supreme Court decision resulted in the invalidity of licenses for wind power development in Fosen. The court stated construction violates Sami reindeer herders' right to exercise their own culture. This was following an earlier court decision awarding 89 million NOK in compensation for the affected reindeer district (6 family groups) in the Court of Appeal in 2019 (Superme Court of Norway, 2021). We acknowledge that conflicts of interest involving land use, culture, and economic compensation may influence respondents in interview-based studies (Eftestøl et al., 2022; Skarin et al., 2022; Tømmervik et al., 2022). However, based on culture and local experience, Sami reindeer herders have extensive knowledge on local behavior of reindeer within a given study area. Through experience, they know how reindeer react to various disturbances and how they adapt to changes in grazing conditions. It is therefore crucial to include local knowledge. Nevertheless, there are weaknesses when using interview-based data (Beam, 2012; Friberg, 2019). Information that emerges through conversation or interview will be subjective and may give a distorted picture because people tend to notice conditions in their surroundings that confirm the perception they have of a causal relationship. When conveying experiences to others (interviewee to the interviewer), there may be a tendency to emphasize information that strengthens a causal relationship in which one believes, or which supports oneself in a conflict of interest. Often, reindeer herders will also observe/work with the reindeer in situations of increased disturbance (e.g., herding reindeer back to avoided areas). Thus, we consider interview-based information as valuable for understanding which possible causal relationships should be analyzed through objective data, such as GPS. However, interview-based information alone can give a distorted picture of the real situation, especially if the person being interviewed is involved in conflicts of interest with the WF developers.

Thus, a main goal with this study was establishing trust and dialog between herders and ourselves, such that we could both discuss trends observed by either the herders or in the GPS-data without reserve. This led to the form of integrated results presented here, improving the final interpretation of both GPS data and herders' experiences. Please note that not all data from the herders are specifically tested in this paper but could be interesting for further studies. As such, it shows the potential of integrating traditional knowledge in planning and analyses of scientific studies (Kadykalo et al., 2021).

Reindeer data

In total, 232 271 GPS positions were gathered in the study area from up to 36 GPS-collared females (ranging from 19 to 36 individuals per year), over 8 yr (16 September 2011–30 August 2019). Since the herders themselves changed GPS collars between animals when changing batteries or when a GPS-collared animal was selected for slaughter, we did not have full control over when GPS collars changed between individuals. We thus treated each GPS collar as a separate individual between years. GPS Plus collars from Vectronics Aerospace GmbH were programmed to register animal position every 3 h. Rare GPS fixes below 3-h intervals and all data when the animals were within fenced pens, or when herders forgot to turn the GPS collars off after removing them from animals, were removed. We also excluded data 2 d before they were in the fenced pens and data 2 d after reindeer were herded into the study area. This was done to remove time when reindeer were affected by herding activities and gathering (see Fig. 2 and Appendix 1 for details about the yearly traditional use cycle within the study area). In total, approximately 13% of the GPS data was removed on the basis of the previously listed criteria. Thus, the total number of GPS positions included in our analysis was 193 866 (for details see Table 2). The number of GPS-collared individuals used during the study periods are shown in Table 2.

Study design and model covariates

We used three seasons based on herders' information on reindeer habitat use and traditional herding activities: spring, summer, and autumn. More specifically, the spring season began 2 d after reindeer arrived in the study area, starting 15 April and lasting until 24 June, but with slightly variable start dates each year. Summer began 25 June and ended 2 d before each individual was herded into the handling facility at Stjernevatnet, usually in late August (see Fig. 2) and released on the south side of the fence along the main road. Autumn began 2 d after the animals arrived back into the study area before rut (after 1 September), and lasted until 2 d before they again were herded back into the handling facility at Stjernevatnet (before 30 October). Even if herders look after the reindeer, keeping them within seasonal pastures and preventing unwanted migrations throughout the year, the most intensive herding activities are connected to the larger gathering periods. By dividing the seasons like we did, we excluded these gathering periods and only used GPS data when reindeer were mostly free-ranging in the analyses.

We evaluated habitat use of reindeer using before-after design (i.e., before, during, and after WF development) (e.g., Bartzke et al., 2014; Smokorowski and Randall, 2017; Flydal et al., 2019) at two spatial scales (home range and landscape) because individual and landscape-level characteristics influence habitat selection differently (e.g., Johnson, 1980; Johnson et al., 2005; Laforge et al., 2015). Information from the herders was also important when deciding to analyze data at these two scales and three seasons (spring, summer, and autumn). This was because we expected herding to interact with habitat use differently at different scales, with decreasing influence with decreasing scale. We used qualitative interviews and descriptions to understand how herders' experiences related to and were connected with effects found based on GPS data analyses.

To identify reindeer habitat selection (use vs. availability), we compared observed GPS positions with random points. At the landscape scale (Johnson, 1980), we generated random points within the entire study area. The entire study area was defined as available area for each individual every year and season at this scale. Within the home range scale (Johnson, 1980), random points were generated within each individual yearly seasonal 99% BBMM (Brownian bridge movement model) home range (Horne et al., 2007). On both scales, we used a 1:8 ratio, meaning we generated 8 times as many random points as observed GPS points on the basis of Northrup et al.'s (2013) approach.

Using ArcGIS 10.7.1, we generated distance variables associated with the WF. Distance variables included minimum distance to wind turbines and access roads. To control for landscape features and pasture conditions, we extracted elevation for each data point from topographic data provided by Norge Digitalt (pixel size 25×25 m) and 25 vegetation types provided by NORUT (Landsat TM/ETM+, pixel size 30×30 m, available at https://norut.no/) for each data point. We then classified the 25 vegetation/habitat types into 8 main groups (details are given in Table S1, available online at …) based on plant structure and landscape features (Gaare and Skogland, 1975). To capture the complexity of the landscape at a biologically meaningful scale for reindeer, we extracted vector ruggedness measures (VRM) from DEM (digital elevation model) within a 3×3 moving window centered on each cell following Sappington et al. (2007). VRM integrated variation in slope and aspect (Sappington et al., 2007; Poole et al., 2016), a dimensionless ruggedness value that ranges between 0 (flat) and 1 (most rugged). Typical values for natural terrain range between 0 and 0.5, with rugged landscape defined to be greater than 0.02. We also extracted NDVI (Normalized Difference Vegetation Index) for the study period using MODIS HDF data. We used the NDVI from the Moderate Resolution Imaging Spectroradiometer (MODIS) receiver using the novel "R" package MODIStsp (Busetto and Ranghetti, 2016). We used NDVI time-integrated as a covariate because it is a measure of primary productivity (Pettorelli et al., 2005; Hebblewhite et al., 2008; Bischof et al., 2012). For each reindeer GPS position, we constructed a yearly NDVI time series based on the 16-d satellite images available (pixel size 250×250 m). The time series NDVI was smoothed and interpolated per day for each year across the growing seasons (Ruimy et al., 1994; Bischof et al., 2012).

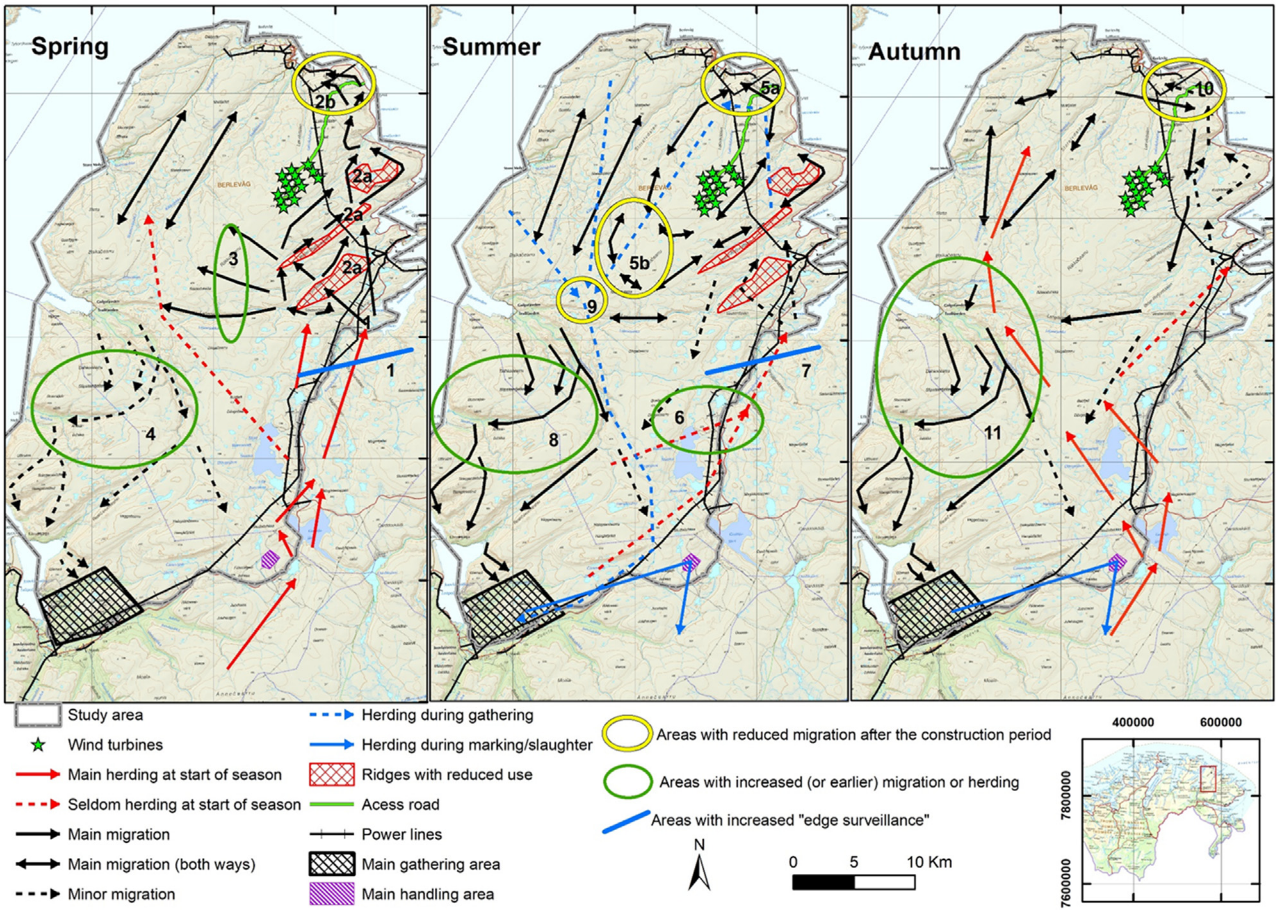

Fig. 2. Traditional reindeer herding/migration/movement patterns and the effects from the wind farms on these based on reindeer herder's experiences (numbers in map relate to numbers in the result section 3.1).

Table 2
Study periods over the 9 study yr for reindeer in the Varanger peninsula main study area, Finnmark, northern Norway.

WF development phase	Yr	Date	No. of GPS-collared reindeer	No. of GPS positions	Dates excluded from analyses[1]
Before	2011	02/10-31/10	32	2 777	
	2012	24/04-31/10	35	33 144	01/09-29/09
	2013	29/04-09/06	35	10 679	
During	2013	10/06-24/10	35	16 477	01/09-27/09
	2014	16/04-30/09	24	14 015	01/09-24/09
After	2014	01/10-31/10	20	2 609	
	2015	16/04-22/10	33	32 029	01/09-25/09
	2016	16/04-23/10	36	29 355	22/08-30/08
	2017	07/05-24/10	29	20 506	01/09-25/09
	2018	23/04-19/10	23	18 311	01/09-22/09
	2019	25/04-25/08	19	13 964	

[1] Excluded was from periods of heavy herding, when the herd was fenced, or located outside the study area.

We excluded pairs of covariates (one of them) from the models with a Pearson's correlation coefficient of $|r| > 0.6$. As a result, distance from access road to WF was excluded from all the models because it was highly correlated with distance to WF turbines ($r > 0.95$). We chose distance to WF because feedback from herders indicated that the turbines caused the effects, not the roads. NDVI was also excluded from the summer model at both scales because it was highly correlated with elevation ($r > -0.65$). We preferred to keep elevation assuming that elevation best explains insect harassment during summer.

Data analysis

We evaluated reindeer habitat use using resource selection functions (RSFs; Manly et al., 2002) before, during, and after WF development by fitting logistic regression with generalized linear mixed model in R (Bates et al., 2014) for each of the three seasons (spring, summer, and autumn) separately. We analyzed each season separately for a better understanding of how reindeer respond to the same anthropogenic stimuli at different times of the year with varying ecological attributes. We did the analysis at two levels according to Johnson's (1980) home range and landscape scales for each season.

The response variable was binomial (used/available). The main explanatory variables included period (three levels: "before," "during," and "after") interacted with distance from the WF. We ran models with all possible combinations of covariates known or suspected to influence reindeers' habitat selection. These covariates include elevation, VRM, NDVI, and habitat type (eight levels: "forest," "heath," "marsh," "rocks and exposed ridges," other ridges,"

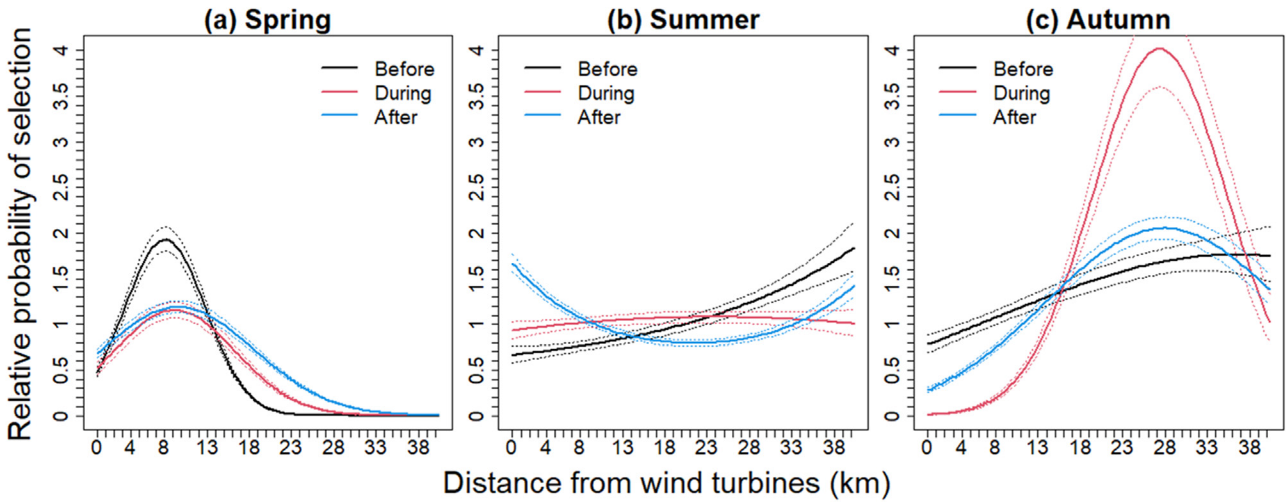

Fig. 3. Relative probability of resource selection (±95% confidence interval) of reindeer at the landscape scale in relation to distance from the wind turbines and development periods (before, during, and after construction) from the RSF models during spring, summer, and autumn seasons, Varanger peninsula, Finnmark, northern Norway.

"snow patch," "unclassified," and "others"). The habitat type "others" was not included in the models due to negligible or no use by the reindeer. We included individual reindeer as a random factor in each of the models to account for variations among individuals (Zuur et al., 2009). When we detected nonlinarites for distance to WF, elevation and VRM, we added a square term. We used a scale () function in R for the distance from WF, elevation, and VRM variables in order to facilitate model convergence (Schielzeth, 2010).

For each season, we selected the best parsimonious model in our set of candidate models (see Tables S2 and S3) on the basis of the lowest Akaike's Information Criterion corrected for small sample sizes (AICc scores) (Burnham and Anderson, 2002). All variables were checked for collinearity using variance inflation factors (VIF; Zuur et al., 2009), for each selected model, with VIF $\geq$ 3.0 as a threshold for removing a variable. To illustrate the results from the RSF models, we estimated the relative probability of selection to show effects of the WF before, during, and after construction as follows:

$$w(x) = \exp\left(\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots \beta_n x_n\right),$$

where $w(x)$ is relative probability of selection at location x, and β_1 through β_n is the estimated relative selection strength for explanatory variables x_1 through x_n from the logistic regression model (McDonald, 2013). All analyses were done in R version 4.1.0 (R Core Team, 2021).

Results

Reindeer herders' experiences

The herders experienced negative effects of the WF on reindeers' habitat use and intrarange movements (Fig. 2). They reported stronger negative effects on reindeer in areas where turbines are visible and in weather conditions of high visibility (to be addressed in a future study, as are some other results from the herders). A general pattern of habitat use before development, where reindeer migrated northwards on the peninsula along the eastern side, grazed in the northern part of the study area, and then migrated back along the western side (see Appendix 1) changed after WF development. Instead, the herders report a distant avoidance effect of the WF, where reindeer after development tended to move southwards throughout summer, necessitating increased herding activity to keep them grazing within northern sections of the summer range.

Herders' general opinions were that less use of grazing areas surrounding the WF has led to more use and increased grazing pressure in the southern part of the range. Figure 2 illustrates the herders' experiences and understanding of the interactions between reindeer and the WF, with main points outlined as follows (numbers below correspond with Fig. 2):

(1) Increased herding activity in Kongsfjorddalen to prevent animals from migrating south again in the spring.
(2) Reduced use of ridges that are in sight of the wind turbines (2a), as well as reduced movements on the north side of the WF, from east to west (2b)
(3) Increased movements on the south side of the WF, from east to west
(4) Earlier migration southwards from the calving areas. Can already happen at the end of the spring season
(5) Reduced circular movements around the Rákkočearru plateau, both ways, on both the north side (5a) and the south side (5b)
(6) Increased herding north again because the animals come south earlier than before (both at the end of the spring season and early summer)
(7) Increased "edge surveillance" in Kongsfjorddalen to prevent animals from moving south after they have been herded from the south to Kongfjorden (see point 6)
(8) Increased migration south earlier than before
(9) Reduced gathering and herding southward at the end of the summer (in September at the end of the calf marking period)
(10) Reduced movement on the north side of the WF, from west to east
(11) Earlier migration south again after the rut

GPS data: landscape scale

At the landscape scale, the most parsimonious models included distance to wind turbines interacting with period, and the covariates habitat type, elevation, VRM, and NDVI in each season, except elevation in spring and NDVI in summer (Table S2, available online at …). Generally, reindeer showed little use of areas surrounding the WF for all seasons and periods. The only exception was in summer for the postdevelopment period, when the reindeer increased their use of areas closer to the WF compared with farther away (Table 3, Fig. 3).

Table 3
Estimates of reindeer resource sections (RSFs) at the landscape scale in relation to distance from turbines before, during, and after construction in spring, summer, and autumn seasons from 2011 to 2019 in the Varanger peninsula, Finnmark, northern Norway.

Effects	Spring			Summer			Autumn		
	Estimate	SE	95% CI	Estimate	SE	95% CI	Estimate	SE	95% CI
Intercept	1.429	0.046	(1.340, 1.519)	1.323	0.041	(1.242, 1.404)	1.509	0.064	(1.384, 1.633)
Heath	−1.480	0.031	(−1.541, −1.420)	−0.615	0.030	(−0.674, −0.556)	−0.969	0.050	(−1.067, −0.870)
Marsh	−1.455	0.050	(−1.554, −1.356)	−0.365	0.054	(−0.472, −0.258)	−1.395	0.105	(−1.600, −1.190)
Rocks and exposed ridges	−2.498	0.032	(−2.561, −2.436)	−1.935	0.035	(−2.003, −1.867)	−1.583	0.056	(−1.692, −1.474)
Other ridges	−1.384	0.032	(−1.446, −1.323)	−0.601	0.031	(−0.662, −0.539)	−1.036	0.052	(−1.138, −0.933)
Snow patch	−2.132	0.030	(−2.19,0 −2.074)	−1.254	0.031	(−1.314, −1.193)	−1.484	0.051	(−1.584, −1.383)
Unclassified	−2.111	0.035	(−2.179, −2.043)	−1.607	0.037	(−1.679, −1.535)	−1.831	0.062	(−1.953, −1.709)
During	0.276	0.037	(0.204, 0.349)	0.136	0.037	(0.064, 0.208)	0.093	0.061	(−0.026, 0.212)
After	0.470	0.046	(0.380, 0.560)	−0.063	0.032	(−0.127, −0002)	0.057	0.044	(−0.029, 0.143)
Distance from WF	−2.987	0.049	(−3.083, −2.891)	0.189	0.018	(0.154, 0.223)	0.243	0.021	(0.202, 0.284)
Distance from WF[1]	−1.924	0.039	(−2.001, −1.847)	0.024	0.015	(−0.005, 0.053)	−0.060	0.018	(−0.096, −0.024)
Elevation				−0.410	0.009	(−0.428, −0.392)	−0.268	0.016	(−0.299, −0.237)
Elevation[1]				−0.531	0.007	(−0.544, −0.517)	−0.691	0.012	(−0.714, −0.668)
VRM	9.234	0.418	(8.415, 10.052)	2.301	0.241	(1.828, 2.774)	1.535	0.395	(0.761, 2.310)
VRM[1]	−30.491	2.522	(−35.435, −25.547)						
NDVI	0.846	0.028	(0.792, 0.900)				1.747	0.064	(1.621, 1.873)
During × Distance from WF	1.859	0.057	(1.747, 1.970)	−0.156	0.022	(−0.200, −0.112)	1.504	0.061	(1.385, 1.623)
During × Distance from WF[1]	1.068	0.050	(0.970, 1.165)	−0.045	0.019	(−0.082, −0.007)	−0.722	0.041	(−0.803, −0.641)
After × Distance from WF	2.313	0.050	(2.215, 2.410)	−0.336	0.019	(−0.375, −0.298)	0.339	0.025	(0.289, 0.388)
After × Distance from WF[1]	1.375	0.040	(1.296, 1.454)	0.109	0.017	(0.077, 0.142)	−0.189	0.022	(−0.233, −0.145)

[1] Represents a squared term. WF indicates wind turbines; VRM, vector ruggedness measure; NDVI, Normalized Difference Vegetation Index. “Forest” was used as a reference for the habitat type categorical variable, and “before” was used as a reference for period. For details on the habitat types, see Table S1, available online at ...

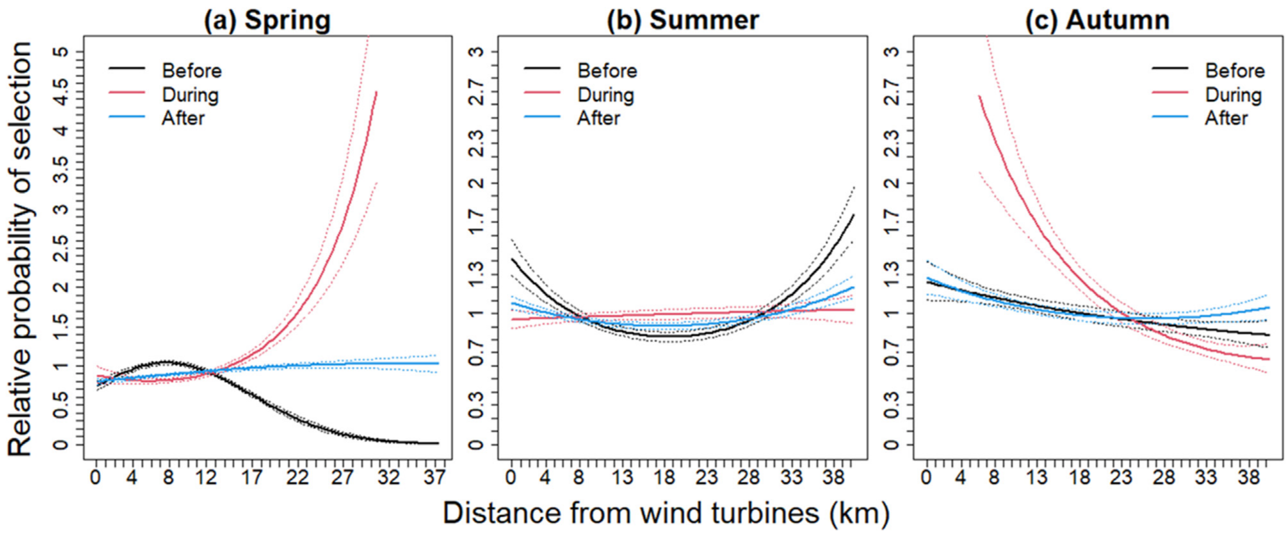

Fig. 4. Relative probability of resource selection (±95% CI) of reindeer at the home range scale (i.e. individual home range within seasonal range) in relation to distance from the wind turbines and development periods (before, during, and after construction) from the resource selection function models during spring, summer, and autumn seasons, Varanger peninsula, Finnmark, northern Norway.

In spring, the highest relative probability of use in the before period was approximately 7.8 km away from the WF compared with approximately 10 km for the during and after periods, an increase of 2.2 km in distance. In general, the use was more intense between approximately 2−13 km away from the WF in the before period compared with during and after periods. The intensity of use within this range was approximately 32−35% lower during and after development compared with before, consequently leading to more use of areas farther away from the WF during and after compared with before (see Table 3, Fig. 3a).

In summer, habitat use increased with increasing distance in the before period. The trend was opposite in the after period, while there was no clear trend during. Compared with before, the use was approximately 23% and 40% higher up to 18 km and 12 km for during and after development, respectively (see Table 3, Fig 3b).

In autumn, all periods show a strong negative effect of the WF. When compared with before development, during showed a 72% decrease in use up to 15 km and after a 38% reduction up to 12 km (see Table 3, Fig. 3c).

For other covariates, selection varied between seasons (see Table 3, Fig. S1, available online at …). Reindeer selected low to medium rugged areas in spring and rugged topography during summer and autumn. They selected lower to medium elevation in summer and autumn (Table S2, available online at …). Areas with increasing NDVI were selected in spring and autumn, while NDVI was not included in the summer model (see Table S2). Reindeer preference to the different habitat types varied considerably between seasons (see Table 3; Fig. S3, available online at …).

GPS data: home range scale

Similar to the landscape scale, the most parsimonious seasonal models included distance to wind turbines interacting with period at the home range scale. The covariates habitat type, elevation, and VRM were included in each season, while NDVI was included only in autumn (see Table S3, available online at …). Generally, reindeer habitat use varied in areas surrounding the WF among seasons and periods.

In spring, the highest relative probability of use in the before period was at approximately 7.6 km. For during, there was no clear trend between 0 and 10 km, but with clearly higher habitat use of areas farther away. In the after period, habitat use also increased with increasing distance from the WF. When compared with before and within the distance interval of 3−11 km, habitat use decreased 12−18% during and after, while it was equal or higher at distances closer or further away than this (Table 4, Fig. 4a).

In summer, there was more intense use up to approximately 6 km away from the WF before compared with during and after development. In average, the selection decreased 22% during and 16% after development within this zone compared with before. There was also approximately 10% less use during development compared with after up to 1.5 km (see Table 4, Fig. 4b).

In autumn, there was more use close to the WF in all periods, but there were no animals closer than 6 km from WF during. Compared with during, there was 28% less use close to the WF up to approximately 20 km before and after. There was no change in the selection between before and after (see Table 4, Fig. 4c).

Reindeer selected less rugged areas and lower to medium elevation in all seasons (see Table 4, Fig. S2). NDVI had no effect in autumn (see Table 4; Fig S2) but was not included in the spring and summer models (see Table S3). Reindeer selection to the different habitat types also varied considerably between seasons (see Table 4; Fig. S4).

GPS data: comparison of scales and yearly home range maps

When comparing the scales and seasons, results for spring were negative on both scales. For summer and autumn, the results were different between scales. In summer, there was a positive effect at the landscape scale and negative effect at the home range scale. The opposite was found for autumn, with a negative effect at the landscape scale and no difference at the home range scale.

The BBMM maps (see Figs. 5–7) show large yearly and seasonal variation. The best example explaining such variability is for autumn in the yr 2011 and 2012, showing intensive use in the northern section of the study area in 2012 and no use in this section in 2011. Both years are before WF development, indicating that large-scale habitat use changes happened without the development of the WF or any clear differences in other potential disturbances between years.

Table 4
Estimates of reindeer resource sections (RSFs) at the home range scale (i.e., individual home range within seasonal range) in relation to distance from wind turbines before, during, and after construction in spring, summer, and autumn seasons from 2011 to 2019 in the Varanger peninsula, Finnmark, northern Norway.

Effects	Spring			Summer			Autumn		
	Estimate	SE	95% CI	Estimate	SE	95% CI	Estimate	SE	95% CI
Intercept	0.879	0.024	(0.832, 0.926)	0.453	0.034	(0.387, 0.520)	0.654	0.040	(0.576, 0.732)
Heath	−0.579	0.022	(−0.622, −0.536)	−0.221	0.027	(−0.274, −0.167)	−0.276	0.038	(−0.351, −0.201)
Marsh	−0.555	0.040	(−0.633, −0.477)	−0.140	0.050	(−0.237, −0.043)	−1.042	0.085	(−1.208, −0.875)
Rocks and exposed ridges	−0.907	0.026	(−0.958, −0.857)	−1.217	0.033	(−1.281, −1.153)	−0.642	0.045	(−0.73, −0.554)
Other ridges	−0.500	0.023	(−0.545, −0.456)	−0.180	0.029	(−0.237, −0.124)	−0.275	0.040	(−0.353, −0.196)
Snow patch	−0.843	0.022	(−0.886, −0.799)	−0.568	0.028	(−0.624, −0.512)	−0.570	0.040	(−0.648, −0.492)
Unclassified	−1.180	0.026	(−1.231, −1.128)	−0.749	0.036	(−0.820, −0.679)	−0.813	0.054	(−0.919, −0.707)
During	−0.134	0.021	(−0.176, −0.092)	0.169	0.026	(0.119, 0.220	0.189	0.034	(0.122, 0.256)
After	−0.071	0.014	(−0.098, −0.044)	0.084	0.023	(0.040, 0.128)	0.022	0.020	(−0.017, 0.062)
Distance from WF	−0.194	0.012	(−0.218, −0.171)	−0.096	0.018	(−0.132, −0.06)	−0.101	0.016	(−0.132, −0.069)
Distance from WF[1]	−0.179	0.013	(−0.203, −0.154)	0.163	0.015	(0.135, 0.192)			
Elevation	−0.150	0.006	(−0.161, −0.139)	−0.250	0.007	(−0.264, −0.235)	−0.075	0.012	(−0.100, −0.051)
Elevation[1]	−0.062	0.004	(−0.071, −0.054)	−0.085	0.005	(−0.094, −0.076)	−0.165	0.007	(−0.180, −0.151)
VRM	−3.666	0.232	(−4.121, −3.211)	−6.387	0.336	(−7.046, −5.728)			
VRM[1]							−5.821	0.482	(−6.767, −4.876)
NDVI							−0.102	0.074	(−0.107, 0.007)
During × Distance from WF	0.349	0.021	(0.308, 0.391)	0.117	0.023	(0.072, 0.162)	−0.288	0.035	(−0.356, −0.221)
During × Distance from WF[1]	0.266	0.018	(0.230, 0.302)	−0.165	0.019	(−0.202, −0.128)			
After × Distance from WF	0.253	0.014	(0.226, 0.280)				0.057	0.019	(0.020, 0.094)
After × Distance from WF[1]	0.171	0.013	(0.146, 0.197)						

[1] Represents a squared term. WF indicates wind turbines; VRM, vector ruggedness measure; NDVI, Normalized Difference Vegetation Index. "Forest" was used as a reference for the habitat type categorical variable, and "before" was used as a reference for period. For details on the habitat types, see Table S1, available online at ….

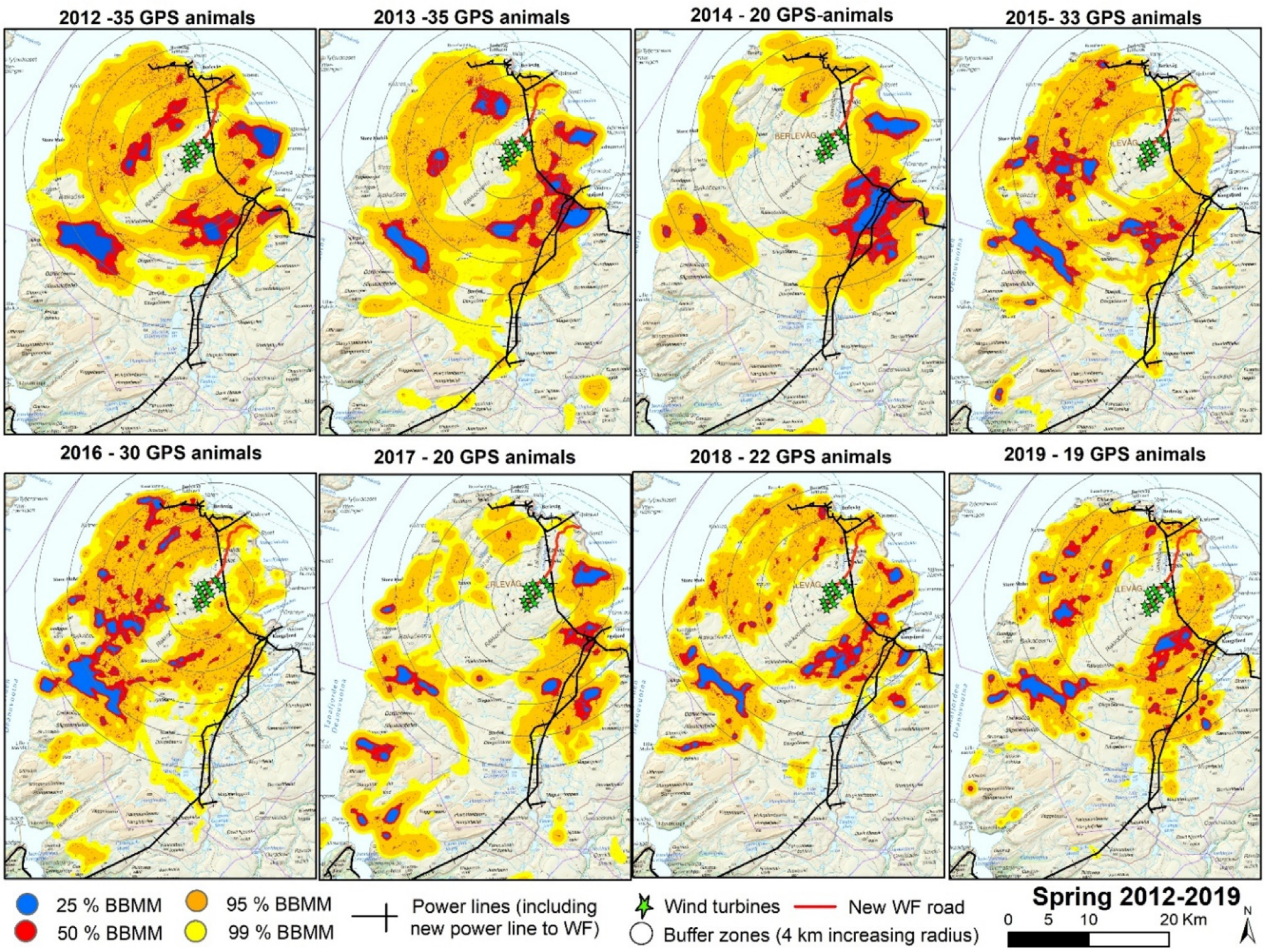

Fig. 5. Brownian bridge movement model (BBMM) maps showing the population home ranges of reindeer during spring in Varanger peninsula, Finnmark, northern Norway. The 25% and 50% BBMM shows the most used areas.

Discussion

Herders' experiences and GPS-data

Results from interviews and GPS-data analyses showed some coinciding trends. In general, herders experienced decreased utilization of pastures in areas near the WF and avoidance responses leading to increased grazing pressure in distant areas. They suggested this was caused by a combination of avoidance and changes in intrarange movement patterns and informed us that increased herding of reindeer after development was done to counteract these negative effects and optimize the utilization of pastures throughout the range, especially during early spring (before calving) and summer.

The GPS data showed both positive and negative effect of the WF across different seasons and scales. Both the home range and landscape scale results confirmed that reindeer avoided areas during and after WF development in spring, supporting previous studies (Skarin and Alam, 2017; Skarin et al., 2018). For summer, there was seemingly an attraction toward the WF at the landscape scale both during and after WF development, but an avoidance at the home range scale. In autumn, reindeer avoided the WF after development at the landscape scale, but not at the home range scale, and with opposing results during development with avoidance at the landscape scale and attraction at the home range scale. However, it is important to emphasize that there were no animals closer than 6 km from the development area in this period. This makes conclusions about effects on the home range scale difficult since it is hard to argue that animals are attracted to a WF at distances more than 6 km, while at the same time, not using areas closer than 6 km.

Interpreting results from both forms of data

Studying effects of human disturbance on habitat use of semidomesticated reindeer is complicated, since different factors are scale dependent and interact. For example, large-scale reindeer herding activities may differ between years, either because of the infrastructure in question or other reasons like predator distribution, pasture conditions, or changes in other human activities. Since RSF models on habitat use are based on the assumption of free-ranging animals, results from studies on semidomesticated reindeer may be biased by herding activities. In essence, this is why information on herding activities needs to be included when interpreting results from RSF studies based on reindeer GPS data. Thus, regional effects of infrastructure on reindeer seasonal area use may be shown through landscape habitat analyses by including herders' experiences (e.g., Skarin et al., 2018). However, large-scale temporal changes in habitat use at the landscape scale are still difficult to interpret because natural fluctuations in habitat use are a key part of reindeer grazing ecology. Furthermore, several factors affecting habitat use, such as overgrazing, predation, human activity, and insect harassment in combination with wind and predominant wind directions (cold air from the arctic sea or warmer

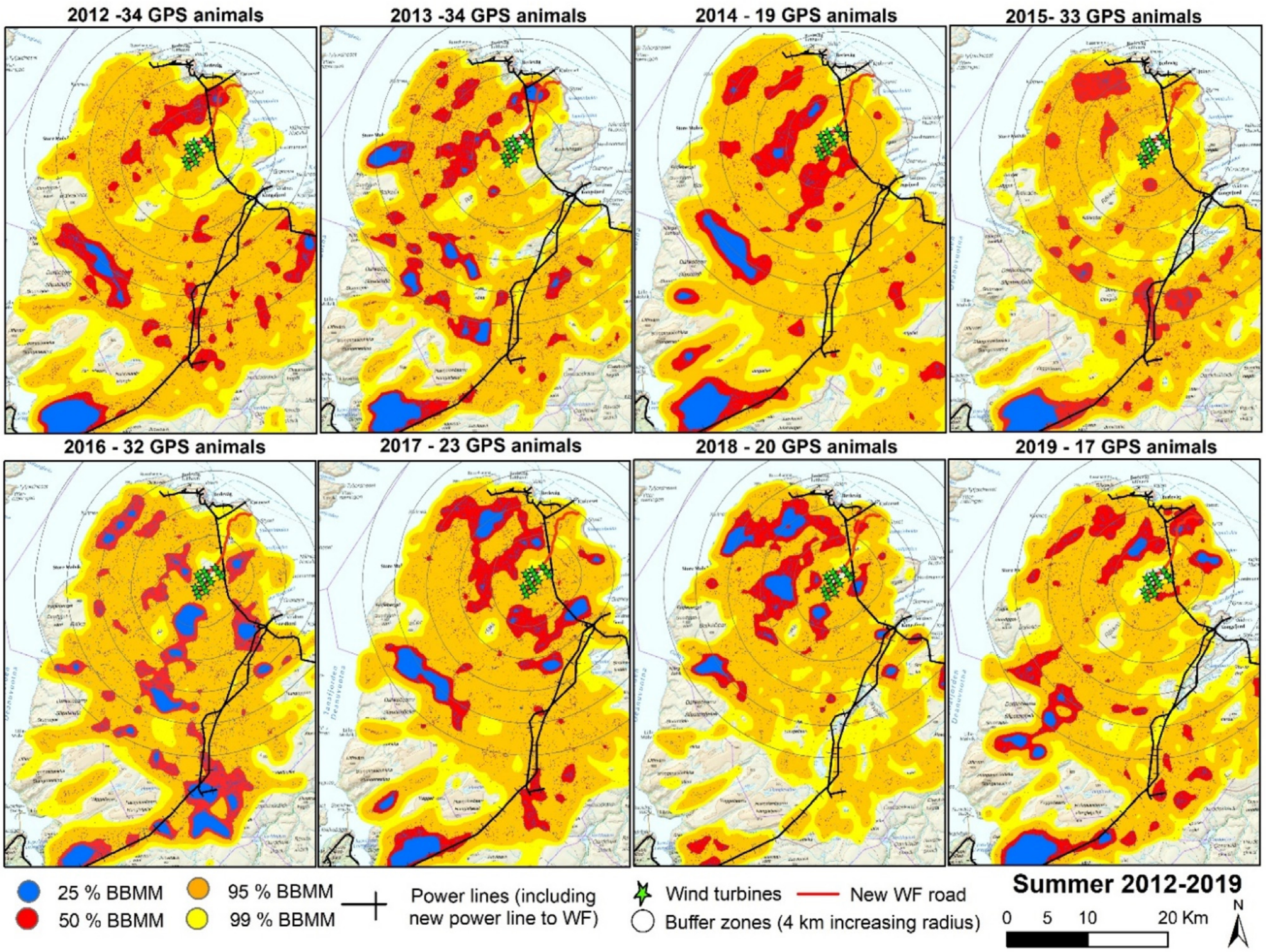

Fig. 6. Brownian bridge movement model (BBMM) maps showing the population home ranges of reindeer during summer in Varanger peninsula, Finnmark, northern Norway. The 25% and 50% BBMM shows the most used areas.

winds from the south) may be unknown (i.e., not possible to control for in the analyses) (Flydal et al., 2019). Part of a reindeer herd may simply choose to graze in areas farther away from a WF in 1 yr, independent of potentially negative stimuli, emphasizing the importance of studying reindeer habitat use for periods of several years and on several scales.

We found similar avoidance trends for both home range and landscape scales in spring, with the most intense use pushed from 7.8 km to 10 km away from WF, supporting herders' experience. However, with little use of habitats closer to turbines in any period, the disturbance stimuli only appear at larger distances, making it difficult to conclude about cause and effect. The fact that some of the habitat covariates had similar or sometimes stronger effect than distance from WF complicates the cause-and-effect relationship further. However, in the barren and open landscapes, reindeers' perception of turbine rotation on the horizon, as well as increased vulnerability during calving, could explain such an effect. Herders confirmed that reindeer often reacted when a rotating turbine appears on the horizon. The results could also be due to changes in movement patterns that reduced movement from east to west on the north side of the WF in the start of the season (as the herders also experienced) and therefore reduced access to the northernmost part of the range. Results for summer and autumn are difficult to interpret because home range and landscape scale results differ. If scale dependent, such relationships could be explained by the fact that semidomesticated reindeer area use is partly selected by herders (Skjenneberg and Slagsvold, 1979; Bjørklund, 1990; Forbes, 2006). When including information from herders, it is possible that increased herding of animals back north during and after development is the reason for the apparent WF attraction effect on the landscape scale in summer. Therefore, in our view, positive effects on landscape scale during summer does not necessarily contradict the herder's experiences with negative effects throughout the summer season. It may indicate that herding activities during late spring and early summer counteracted the negative effects on this scale. This is supported by the negative effects on the home range scale, where herding activities probably interact less with the animals' area use. Furthermore, looking into differences between years of large-scale directional movements typical during herding for GPS-marked animals, the herders' claims of increased herding activity from south to north during early summer seem to be supported by the GPS data (see Table S4 and Fig. S5, available online at …). In autumn, the apparent WF avoidance at the landscape scale could also be partly explained by changes in movement patterns, with a decreased use of the longer northeastern route, which includes larger areas close to the WF, back toward the winter range in the south. Although such reasoning may seem speculative, the herders experience with less use of the areas east of the WF in this season is supported by yearly seasonal BBMM maps for autumn. Furthermore, the lack of negative effects on the home-range scale indicates limited avoidance effects per se in autumn, lending support that the landscape effects may be caused by either changes in movements patterns or other unknown factors. With respect to unknown factors or natural

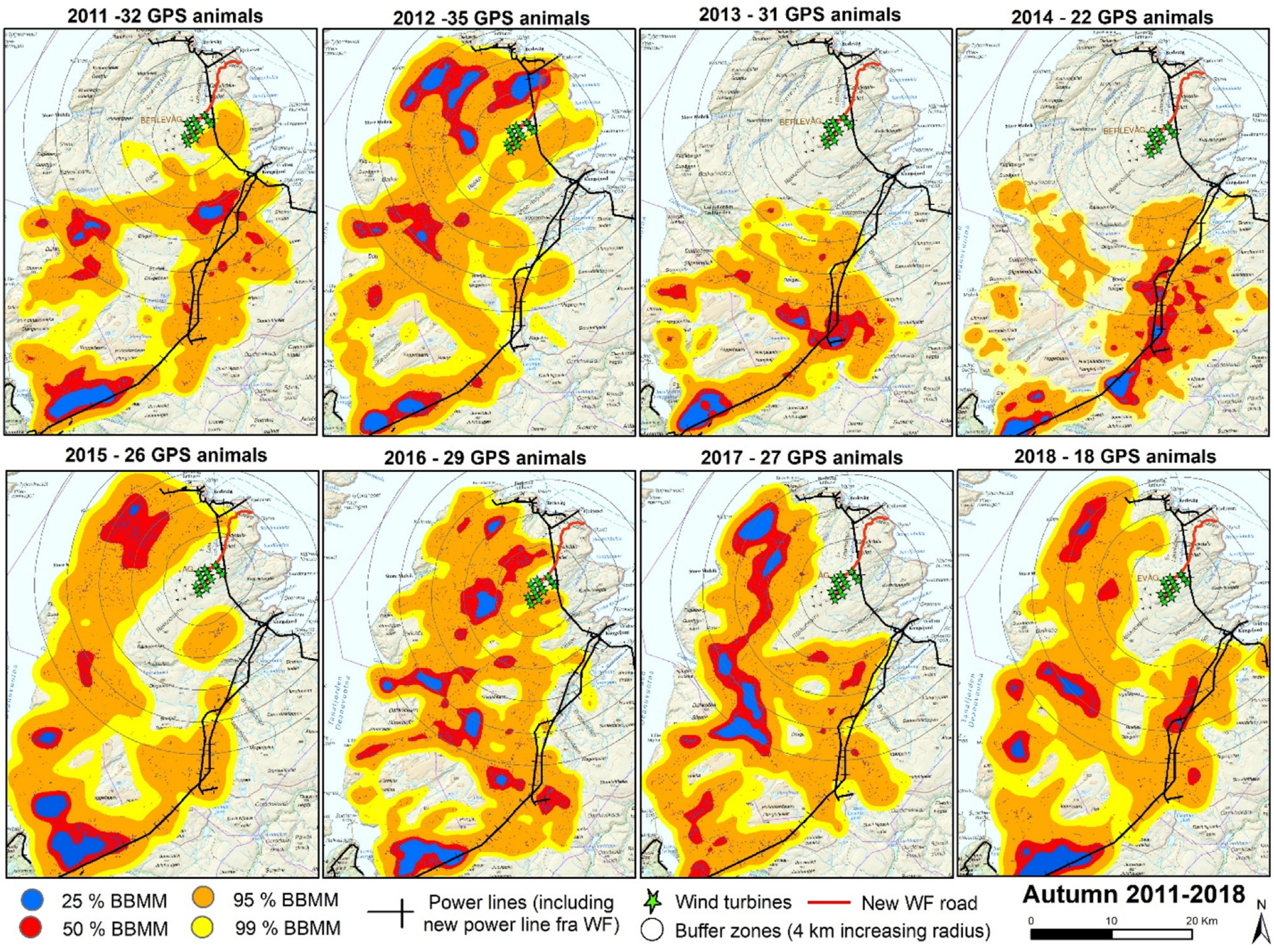

Fig. 7. Brownian bridge movement model (BBMM) maps showing the population home ranges of reindeer during autumn in Varanger peninsula, Finnmark, northern Norway. The 25% and 50% BBMM shows the most used areas.

variation, it is important to empathize the large yearly variation in area use during autumn. The best example explaining such variability is for autumn in the yr 2011 and 2012, showing intensive use in the northern section of the study area in 2012 and no use in this section in 2011. Both years are before WF development, indicating that large-scale habitat use changes happened without the development of the WF or any known differences in other potential disturbances between years.

Herders also reported that the visual stimuli of the turbines themselves were weaker in autumn because of shorter days and, in general, more days with ocean fog that reduces visibility. The perceptual world or *umwelt* for reindeer is different from humans (Van Dyck, 2012). Since herders interact with reindeer and observe them "continuously," the herders' experiences and traditional knowledge are important to include to be able to understand "the reindeers' perspective" (Skarin and Åhman, 2014). This suggests that quantitative GPS-data analyses alone may be insufficient for documenting large-scaled effects from infrastructure on reindeer. Most importantly, barrier effects along migration routes and increased directional movement rates away from the disturbance, also after the animals leave the "zone of influence," could lead to effects on habitat use at the landscape scale.

Effects on herders and from herders

Information from herders indicate that traditional herding activities have changed in response to changes in reindeer habitat use and movement patterns relative to the WF. To counteract negative effects, the herders increased daily herding activities with the reindeer for longer periods throughout summer. Even if the geographical range of semidomesticated reindeer populations in Norway is partly defined by active herding (Tveraa et al., 2007), an increase in this workload is not necessarily sustainable over time (Furberg et al., 2011).

In our case, the herders probably moderated negative effects from the WF on habitat selection of semidomesticated reindeer, and this is likely occurring in other areas and for other forms of infrastructure and disturbances. This could be a reason for stronger negative effects recorded for wild reindeer and caribou toward most infrastructure other than WFs (Panzacchi et al., 2013; Plante et al., 2018), as well as behavior responses being modified through domestication (Reimers et al., 2012). However, the opposite effect may happen as well, for example, if the herders move the entire herd away from an area to avoid conflict, it may lead to reduced use of areas near infrastructure. Whatever reason for reindeer habitat use, new infrastructure and land use conflicts affect Sami reindeer pastoralism (Johnsen, 2016), with herding activities in response to human disturbances being part of the picture. This emphasizes the importance of including herders' experiences when interpreting results from habitat analyses on semidomesticated reindeer.

Uncertainties, further research, and conclusions

Migratory behavior, large population ranges, and herding practice involving cyclic difference in the use of certain grazing areas complicate studying the effects of infrastructure on habitat selection of semidomesticated reindeer. Flydal et al. (2019) discussed the importance of before-after study designs, including long time series of sampling. Our study shows how large yearly and seasonal variation in habitat selection can appear, independent of the WF and other factors controlled for in the analyses. Only 1 (summer) or 2 yr (spring and autumn) of data from before construction of the WF may in general lead to unbalanced results. For example, during spring, a wave of greener vegetation gradually extends into higher altitudes of mountain landscapes, affecting reindeer habitat selection (Skogland, 1984; Fryxell and Avgar, 2012; Iversen et al., 2014; Rivrud et al., 2018). In our study, the onset and progress of the spring green-up varied between years and were related to differences in habitat use. However, even if NDVI is included in the models, increasing our understanding of spring greening on selection patterns, we could not control for effects of yearly variation in onset of spring at the landscape scale. Such variation relates to availability of green pasture throughout the landscape, affecting when the animals arrive in the seasonal pasture, as well as landscape connectivity and movements between areas within the seasonal pasture. The implications of this are highly relevant when testing habitat use relative to a single stationary object (e.g., a WF) within a larger landscape. Our results differ from some studies on WFs (e.g., Colman et al., 2013; Tsegaye et al., 2017), but in support of others (e.g., Skarin and Alam, 2017). In short, we lack a clear understanding of why reindeer seemingly behave differently in different study sites, as well as among years within the same study sites. To understand this better, future studies should also investigate the mechanisms behind the behavioral changes documented, including both positive and negative changes. In that light, we are currently working on an extension of this study through 2024. Lessons learned from herders' traditional knowledge are being implemented in planning of the study design, and we will focus more on specific mechanisms of WF effects on reindeer behavior. These include visual effects of turbines and how this may change between years depending on dominant weather type, along with habitat connectivity and temporal variation in herding activity, pasture availability, and insect harassment. These aspects will be crucial in further analyses of both existing and future GPS data from the Raggonjarga Reindeer District, as well as other reindeer districts with existing or new WFs throughout Scandinavia.

Implications

Although some contradicting results were found, it should be underlined that the avoidance distances we documented partly confirmed herders' experiences, suggesting decreased grazing pressure as far as 10 km from this WF. Such distant effects have seldom been documented in previous studies on infrastructure and Rangifer based on GPS-data analyses (e.g., Johnson and Russell, 2014; Plante et al., 2018). Plante et al. (2018) reported a cumulative habitat loss of 30% of seasonal ranges but suggested further research to confirm whether this could translate into population decline of the investigated caribou herds. However, our analyses and information from herders also suggest that there are large differences in effects between seasons and in relation to actual causes to potential effects (changes in migration pattern vs. avoidance). An important conclusion is also that possible negative effects may in some cases be mitigated by increased herding activities. This depends on resources within the affected reindeer district, weather conditions during the period with negative effects, and access to the areas.

Through cooperation and communication with local herders, we were able to integrate local knowledge with GPS results for reindeer habitat use. These two sources combined gave us a more holistic understanding of the reindeers' habitat use toward the WF, supporting the need for both sources of data used in combination. To better understand and improve land management for multiple user groups, more cooperative, multiscale, multiyear, and before-during-after studies are necessary. However, since land use conflicts could affect peoples' experiences and views, GPS monitoring of reindeer is of major importance as a means of gaining objective knowledge.

Declaration of Competing Interest

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

Acknowledgments

We would like to thank reindeer herders, Frode Utsi, Magne Andersen, Stig Rune Smuk, and Kate Utsi, from the Raggonjarga reindeer district for very meaningful cooperation, lending us their reindeer, providing important background information, and assisting with GPS tagging. We also like to thank the district secretary Brynly Ballari.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2022.11.011.

References

Arnett, E.B., Baerwald, E.F., Mathews, F., Rodrigues, L., Rodríguez-Durán, A., Rydell, J., Villegas-Patraca, R., Voigt, C.C., 2016. Impacts of wind energy development on bats: a global perspective. Bats in the anthropocene: conservation of bats in a changing world. Springer Open, Berlin, Germany, pp. 295–325.

Bartzke, G.S., May, R., Bevanger, K., Stokke, S., Røskaft, E., 2014. The effects of power lines on ungulates and implications for power line routing and rights-of-way management. International Journal of Biodiversity Conservation 6, 647–662.

Bates, D., Mächler, M., Bolker, B. M., and Walker, S. 2014 Fitting linear mixed-effects models using lme4. Available at: http://arxiv.org/pdf/1406.5823.pdf. Accessed 7 May, 2019.

Beam, G., 2012. The problem with survey research. Routledge and CRS Press, England, UK.

Bischof, R., Loe, L.E., Meisingset, E.L., Zimmermann, B., Van Moorter, B., Mysterud, A., 2012. A migratory northern ungulate in the pursuit of spring: jumping or surfing the green wave? American Naturalist 180, 407–424.

Bjørklund, I., 1990. Sámi reindeer pastoralism as an indigenous resource management system in northern Norway: a contribution to the common property debate. Development and Change 21, 75–86.

Bjørklund, I., 2013. Domestication, reindeer husbandry and the development of Sámi pastoralism. Acta Borealia 30, 174–189.

Burnham, K.P., Anderson, D.R, 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, Berlin, Germany. pp. 488.

Busetto, L., Ranghetti, L., 2016. MODIStsp: an R package for automatic preprocessing of MODIS Land Products time series. Computers & Geosciences 97, 40–48.

Colman, J.E., Eftestøl, S., Tsegaye, D., Flydal, K., Mysterud, A., 2013. Summer distribution of semi-domesticated reindeer relative to a new wind-power plant. European Journal of Wildlife Research 59, 359–370.

Eftestøl, S., Flydal, K., Tsegaye, D., Colman, J.E., 2019. Mining activity disturbs habitat use of reindeer in Finnmark, Northern Norway. Polar Biology 42, 1849–1858.

Eftestol, S., Tsegaye, D., Flydal, K., Colman, J.E., 2021. Cumulative effects of infrastructure and human disturbance: a case study with reindeer. Landscape Ecology 36, 2673–2689.

Eftestøl, S., Tsegaye, D., Flydal, K., Colman, J.E., 2022. Gradual improvement in knowledge on effects of wind power plants on reindeer (in Norwegian). Tidsskriftet Utmark 45, 41–50.

Enevoldsen, P., Permien, F.H., 2018. Mapping the wind energy potential of Sweden: a sociotechnical wind atlas. Journal of Renewable Energy 11.

Ferrão da Costa, G., Paula, J., Petrucci-Fonseca, F., and Álvares, F. 2018. The indirect impacts of wind farms on terrestrial mammals: insights from the disturbance and exclusion effects on wolves *(Canis lupus). In:* Mascarenhas, M., Marques, A., Ramalho, R., Santos, D., Bernardino, J., and Fonseca, C. [eds.]. Biodiversity and wind farms in Portugal. Cham, Switzerland: Springer. p. 111-134.

Flydal, K., Tsegaye, D., Eftestøl, S., Reimers, E., Colman, J.E., 2019. Rangifer within areas of human influence: understanding effects in relation to spatiotemporal scales. Polar Biology 42, 1–16.

Forbes, B.C., et al., 2006. The challenges of modernity for reindeer management in Northernmost Europe. Reindeer management in northernmost Europe. Ecological studies (analysis and synthesis) [eds.]. Springer, Berlin, Heidelberg, Germany. pp. 11–25.
Friberg, J.H., 2019. Dubious informants, credible research? Norwegian Journal of Sociology. 3, 119–136.
Fryxell, J., Avgar, T, 2012. Catching the wave. Nature 490, 182–183.
Furberg, M., Evengard, B., Nilsson, M., 2011. Facing the limit of resilience: perceptions of climate change among reindeer herding Sami in Sweden. Global Health Action 4. doi:10.3402/gha.v3404i3400.8417.
Gaare, E., Skogland, T, 1975. Wild reindeer food habits and range use at Hardangervidda. In: Wielgolaski, F.E., Kallio, P., Kauri, H., Ostbye, E., Rosswall, T. (Eds.), Fennoscandian tundra ecosystems: ccological studies (analysis and synthesis). Springer, Berlin, Heidelberg, Germany, pp. 195–205.
Hebblewhite, M., Merrill, E., McDermid, G.J., 2008. A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. Ecological Monograph 78, 141–166.
Horne, J.S., Garton, E.O., Krone, S.M., Lewis, J.S., 2007. Analyzing animal movements using Brownian bridges. Ecology 88, 2354–2363.
Huntington, H.P., 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic 51, 237–242.
Iversen, M., Fauchald, P., Langeland, K., Ims, R.A., Yoccoz, N.G., Bråthen, K.A., 2014. Phenology and cover of plant growth forms predict herbivore habitat selection in a high latitude ecosystem. Plos One 9, e100780.
Johnsen, K.I., 2016. Land-use conflicts between reindeer husbandry and mineral extraction in Finnmark, Norway: contested rationalities and the politics of belonging. Polar Geography 39, 58–79.
Johnson, C.J., Boyce, M.S., Case, R.L., Cluff, H.D., Gau, R.J., Gunn, A., Mulders, R., 2005. Cumulative effects of human developments on arctic wildlife. Wildlife Monograph 160, 1–36.
Johnson, C.J., Russell, D.E., 2014. Long-term distribution responses of a migratory caribou herd to human disturbance. Biology Conservation 177, 52–63.
Johnson, D.H., 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61, 65–71.
Kadykalo, A.N., Cooke, S.J., Young, N, 2021. The role of western-based scientific, indigenous and local knowledge in wildlife management and conservation. People and Nature 3, 610–626.
Laforge, M.P., Vander Wal, E., Brook, R.K., Bayne, E.M., McLoughlin, P.D., 2015. Process-focussed, multi-grain resource selection functions. Ecology Modeling 305, 10–21.
Landbruksdirektoratet. 2019. Resource accounts for the reindeer herding industry For the reindeer herding year 1. April 2018–31 March 2019. Rapport nr. 34/2019 (in Norwegian).
Manly, B.F., McDonald, L., Thomas, D., McDonald, T.L., Erickson, W.P., 2002. Resource selection by animals: statistical design and analysis for field studies. Kluwer Academic Publishers, Boston, MA, USA. pp. 221.
May, R., Masden, E.A., Bennet, F., Perron, M., 2019. Considerations for upscaling individual effects of wind energy development towards population-level impacts on wildlife. Journal of Environmental Management 230, 84–93.
McDonald, T.L., 2013. The point process use-availability or presence-only likelihood and comments on analysis. Journal of Animal Ecology 82, 1174–1182.
Ministry of Climate and Environment. 2009. Nature Diversity Act 19 relating to the management of biological, geological and landscape diversity. Available at: https://www.regjeringen.no/en/dokumenter/nature-diversity-act/id570549/ Accessed 29 August, 2021.
Munkejord, M. 2018. Analysis: Nordic wind power growth takes off. Available at: https://www.montelnews.com/en/Accessed 25 June, 2020.
Northrup, J.M., Hooten, M.B., Anderson, C.R., Wittemyer, G., 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. Ecology 94, 1456–1463.
NVE. 2022. Vindkraft i Norge. Available at: https://www.vindportalen.no/Vindportalen-informasjonssiden-om-vindkraft/Vindkraft/Vindkraft-i-Norge Accessed 20 March, 2022.
Oskal, A., Turi, J. M., Mathiesen, S. D., and Burgess, P. 2009. EALÁT: reindeer herders' voice: reindeer herding, traditional knowledge and adaptation to climate change and loss of grazing land. Available at: https://oaarchive.arctic-council.org/handle/11374/47 Accessed 30 August, 2021.
Panzacchi, M., Van Moorter, B., Jordhøy, P., Strand, O., 2013. Learning from the past to predict the future: using archaeological findings and GPS data to quantify reindeer sensitivity to anthropogenic disturbance in Norway. Landscape Ecology 28, 847–859.
Pape, R., Löffler, J., 2012. Climate change, land use conflicts, predation and ecological degradation as challenges for reindeer husbandry in Northern Europe: what do we really know after half a century of research? Ambio 41, 421–434.
Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J., Stenseth, N.C., 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20, 503–510.
Plante, S., Dussault, C., Richard, J.H., Cote, S.D., 2018. Human disturbance effects and cumulative habitat loss in endangered migratory caribou. Biology Conservation 224, 129–143.
Poole, K.G., Serrouya, R., Teske, I.E., Podrasky, K., 2016. Rocky Mountain bighorn sheep *(Ovis canadensis canadensis)* winter habitat selection and seasonal movements in an area of active coal mining. Canadian Journal of Zoology 94, 733–745.
R Core Team. 2021. R: a language and environment for statistical computing. Available at: https://www.R-project.org/Accessed 25 May, 2021.
Reimers, E., Røed, K.H., Colman, J.E., 2012. Persistence of vigilance and flight response behaviour in wild reindeer with varying domestic ancestry. Journal of Evolution Biology 25, 1543–1554.
Rivrud, I.M., Sivertsen, T.R., Mysterud, A., Åhman, B., Støen, O., Skarin, A., 2018. Reindeer green-wave surfing constrained by predators. Ecosphere 9, e02210.
Ruimy, A., Saugier, B., Dedieu, G., 1994. Methodology for the estimation of terrestrial net primary production from remotely sensed data. Journal of Geophysical Research 99, 5263–5283.
Sandström, P., Pahlén, T.G., Edenius, L., Tømmervik, H., Hagner, O., Hemberg, L., Olsson, H., Baer, K., Stenlund, T., Brandt, L.G., Egberth, M, 2003. Conflict resolution by participatory management: remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. Ambio 32, 557–567.
Sappington, J., Longshore, K.M., Thompson, D.B., 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave desert. The Journal of Wildlife Management 71, 1419–1426.
Schielzeth, H., 2010. Simple means to improve the interpretability of regression coefficients: interpretation of regression coefficients. Methods in Ecology and Evolution 1, 103–113.
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.
Skarin, A., Alam, M, 2017. Reindeer habitat use in relation to two small wind farms, during preconstruction, construction, and operation. Ecology and Evolution 7, 3870–3882.
Skarin, A., Nellemann, C., Ronnegard, L., Sandstrom, P., Lundqvist, H., 2015. Wind farm construction impacts reindeer migration and movement corridors. Landscape Ecology 30, 1527–1540.
Skarin, A., Niebuhr, B., Sandström, P., Tømmervik, H., 2022. The ecological evidence in the Fosen case analysis of reindeer use of winter pastures and consequences of wind power development (in Norwegian). Tidsskriftet UTMARK 45, 19–27.
Skarin, A., Sandström, P., Alam, M, 2018. Out of sight of wind turbines—reindeer response to wind farms in operation. Ecology and Evolution 00, 1–14.
Skjenneberg, A.S., Slagsvold, L., 1979. Reindeer husbandry and its ecological principles (translated from Norwegian).
Skogland, T., 1984. Wild reindeer foraging-niche organization. Ecography 7, 345–379.
Smokorowski, K.E., Randall, R.G., 2017. Cautions on using the before-after-control-impact design in environmental effects monitoring programs. Facets 2, 212–232.
Superme Court of Norway. 2021. Licences for wind power development on Fosen ruled invalid as the construction violates Sami reindeer herders' right to enjoy their own culture. Available at: https://www.domstol.no/en/supremecourt/rulings/2021/supreme-court-civil-cases/hr-2021-1975-s/ Accessed 08 August, 2022.
Swedish Energy Agency. 2020. New statistics on installed wind power, annual Wind Power Statistics in 2020 (in Swedish). Available at: https://www.energimyndigheten.se Accessed 28 August, 2021.
Todd, F. 2019. Renewable energy capacity in Sweden to double to 30GW by 2030. Available at: https://www.nsenergybusiness.com/news/renewable-capacity-sweden-2030/Accessed 15 February, 2020.
Tømmervik, H., Skarin, A., Niebuhr, B.B., Sandström, P., 2022. Calculation of lost and negatively influenced winter pastures due to establishment of wind power parks and connected electrical power lines in Fosen reindeer herding district (in Norwegian). Tidsskriftet UTMARK 45, 28–40.
Tsegaye, D., Colman, J.E., Eftestol, S., Flydal, K., Rothe, G., Rapp, K., 2017. Reindeer spatial use before, during and after construction of a wind farm. Applied Animal Behavioral Science 195, 103–111.
Tveraa, T., Fauchald, P., Yoccoz, N.G., Ims, R.A., Aanes, R., Hogda, K.A., 2007. What regulate and limit reindeer populations in Norway? Oikos 116, 706–715.
Van Dyck, H., 2012. Changing organisms in rapidly changing anthropogenic landscapes: the significance of the Umwelt's concept and functional habitat for animal conservation. Evolution Applications 5, 144–153.
Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and extensions in ecology with R. Springer, New York, NY, USA. pp. 596.
Zwart, M.C., McKenzie, A.J., Minderman, J., Whittingham, M.J., 2016. Conflicts between birds and on-shore wind farms. In: Angelici, F. (Ed.), Problematic wildlife. Springer, Cham, Switzerland, pp. 489–504.