Reindeer spatial use before, during and after construction of a wind farm

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Abstract

The Fakken Wind farm (WF) was built in 2010-12 on the Fakken peninsula on the south-east corner of the island of Vannøy. Field and GPS sampling was conducted to test the interaction between reindeer spatial use and the WF with associated infrastructure for the period 2007-2015. “Before data” for both direct observations and GPS-positions confirmed that the site where the WF was built was an important winter grazing area for reindeer. Testing data from before, during and after construction of the WF showed that the overall use on the island and for the WF area did not change during the study period. The reindeer density did not vary significantly among the periods, both for the WF and power line areas. We found no avoidance responses on reindeer spatial use towards the WF during the operation periods for direct observation data. However, we found some significant changes in reindeer area use that may be related to disturbance from human activities for the calving period during construction in WF zone 1 and road zone 1 (GPS-data), and for the power line area during construction in summer and autumn (direct observational data). Our study site represents an area where coexistence of reindeer husbandry and wind energy development is possible, with negligible effects on reindeer spatial use during and after WF development. We recommend that new WFs should be built close to existing infrastructure and limit a potential increase in human accessibility to remote areas where reindeer are less accustomed to human activity.

Keywords: Avoidance, peninsula, power line, *Rangifer tarandus*, Sami reindeer herders, wind farm

1. Introduction

The amount of infrastructure has increased in Arctic regions over the last 50 years (Klein, 2000; Forbes, 2006), especially in Scandinavia (Bartzke et al., 2014). The demand for renewable energy is growing, and construction of wind power, hydro power and solar power plants affects the habitats of many cervid species (e.g., Mahoney and Schaefer, 2002; Bartzke et al., 2014). Because of their extensive land use and social behaviour of forming groups (Skogland, 1984; Reimers et al., 2014), *Rangifer* sp. are vulnerable towards anthropogenic development that reduce movement patterns or pasture utilization (Reimers and Colman, 2006; Panzacchi et al., 2013; Beyer et al., 2016). In Norway, five wind farms (WF) have been built within reindeer ranges along the northern coast, and by 2016, eight more WFs had achieved concession, but were not yet built (https://www.nve.no/konsesjonssaker/, accessed 28 Oct 2016).

Reindeer herdsmen and their management authorities fear detrimental effects from WFs and their associated roads and power lines on movements and spatial use of reindeer (Colman et al., 2012a; 2013; Skarin et al., 2015). Recent studies have found minimal avoidance in situations when human activity is less prevalent in connection with infrastructure (Panzacchi et al., 2013; Colman et al., 2015; Eftestøl et al., 2016). These studies revealed how construction of infrastructure induce a temporary shift in use of areas away from construction activities, but with no avoidance response in the operation period. Increased human presence, transportation and construction activities during the construction period likely frightens the animals, resulting in reduced use of the surrounding areas. Supporting this, Skarin et al. (2015) found reduced movement rates for reindeers' use of migration corridors during construction of a WF, mostly in relation to the access road.

Since WFs cover large areas, need access roads and power lines, they may induce large-scale shifts in spatial use for reindeer. Studies need to sample at an appropriate spatial and temporal scale in order to identify real effects of the disturbance (Bartzke et al., 2014; Colman et al., 2017). Moreover, reindeer congregate into large herds, move through expansive landscapes, and fluctuate their use of pastures within their home range over time (e.g., Bergerud et al., 1984; Hinkes et al., 2005; Reimers et al., 2014). This signals a need for more long-term studies in several areas with different environmental conditions (Colman et al., 2013; Bartzke et al., 2014; Johnson and Russell, 2014) to make sound generalizations about effects of WFs on reindeer spatial use. Most studies on the effects of infrastructure on reindeer have been conducted post-construction with only correlative evidence backing conclusions (Reimers and Colman, 2006; Colman et al., 2017). Colman et al. (2017) and Bartzke et al. (2014) highlight the importance of before and after studies to better understand measured effects and aid in the proper interpretation of observed patterns.

We studied free ranging, semi-domesticated reindeer inhabiting the island Vannøy in Troms, Northern Norway, where a WF containing 18 wind turbines was built between 2010 and 2012. The island maintains year-round pasture for the reindeer, with no long distance seasonal migrations. Previous studies of WF development and reindeer have focused mainly on the summer half of the year (Colman et al., 2012a; 2013) or only the migration period (Skarin et al., 2015), thus data for the winter, late autumn and calving seasons was pertinent. How effects on spatial use may vary between seasons and years were investigated by sampling reindeer use for a period of nine years of direct observation, and two and a half years of GPS-monitoring. Our data spans before, during and after construction of the WF, enabling us to test the reindeers' spatial use within and amongst these periods. The existing road system on the island and its use for access to and from the WF for all vehicles and equipment also allowed us to test possible effects of road traffic to and from the WF. Additionally, we field sampled a four year period along a power line area and tested the effects from construction of this power line during an upgrade in conjuncture with the WF on reindeer spatial use.

From a hypothesis of negative effects of WF, roads and power lines on reindeer spatial use, we tested both regional and local avoidance towards these stimuli, predicting the strongest negative effects during the construction period with a heightened amount of human activity in the area. We also predicted reduced use of the WF area during operational years as a consequence of the turbines themselves and increased human activities in the form of operational and maintenance activities.

2. Study area and methods

2.1. Study area

The study area encompasses the Fakken peninsula (i.e., WF area) in southeast, and the power line area in southern parts of Vannøy island, Troms county, Norway (Fig. 1). The island is approx. 223 km^2 with year-round reindeer husbandry, and the WF area is approximately 60 km^2. The winter population of reindeer on the island varied between 300 and 400 during the study period 2007-2015 (supplementary, Table S1), see also Reindriftsforvaltningen (2015). The island is characterized by low-lying areas along the coast, while the inland is mountainous. The vegetation in Vanøy changes gradually from grass and *Calluna* heaths in low altitude zones to more oroarctic types in higher altitudes (Virtanen et al., 1999). Average elevation for the entire island is 240 m.a.s.l., while the WF area is on average 89 m.a.s.l. Reindeer pasture is mostly (93.4 %) below 600 m.a.s.l., with limited to no vegetation above this (Rapp and Røthe 2014 'Unpublished results'). Settlements, roads and other infrastructure on the island are mainly located within a 4-500 m band along the western, southern and southern part of the eastern coasts (Fig 1). The only exceptions are two power lines, and an associated dirt road or trail transecting remote parts of the mid-section of the island (Fig. 1). On the north coast and along the northern part of the east coast there are no roads or other infrastructure (Fig. 1). The WF area on Fakken peninsula has existing roads and power lines along the southern and eastern coastline. The WF was constructed in the period from the middle of October 2010 to the end of September 2012, but there was no construction work from December 10, 2011 to the end of February 2012. The power line was constructed from February 2011 until August 2012. Importantly, as part of the compensation scheme from the reindeer management authorities, the reindeer district reported an increase in animals killed in traffic during the construction of the WF (Otto Asbjørn Hansen from the Vannøy reindeer district and Jan Gunnar Brattli from Reindriftsforvaltningen (the reindeer management authorities), 'Personal communication'), but with no confirmed road kills from the WF developer (Ronald Hardersen from Troms Kraft power company, 'Personal communication').

2.2. Data collection

The study combines data from direct observations in the study area and GPS-collared reindeer over the entire island (the reindeers' entire home range). Direct observations began in January 2007, and continued once each month until the end of February 2014, with three additional months from April-June 2015 (see supplementary, Table S1). Direct observations were performed by the same observer throughout the study period, except for March 2008, when they were conducted by two other people who walked together. A predetermined route maximized area covered within the WF area. The observer (s) used binoculars to scan the surroundings from all viewpoints/ridges providing maximal visibility (Downes et al., 1986; Colman et al., 2003) and registered all animals observed on a 1:30 000 topographic map, similar to Colman et al. (2013). Care was taken to avoid disturbing reindeer while in the field, but this did not influence the total area surveyed. When reindeer were located, the animal's position was marked using GPS in combination with compass direction and the map. When reindeer were in groups, the approximate position of the centre of the group was mapped. Female reindeer, especially accompanied by calves, are considered more sensitive towards human activities and infrastructure than males (Reimers and Colman 2006). Observations were divided into three periods in relation to the WF construction (before: August 2007-15 October 2010; during: 15 October 2010-30 September 2012; after: 1 October 2012-30 June 2015) and in five seasons (autumn: 1 August-30 October; winter: 1 November-30 April; calving: 1-31 May; summer: 1 June-31 July) (see supplementary, Table S1, S2). Direct observations were also conducted from 2009 to 2012 (before: January 2009-January 2011; during: February 2011-August 2012; see supplementary Table S2) along an existing power line corridor that was upgraded in conjuncture with the WF (Fig 1).

In addition to direct observations, we used GPS-tagged females with positions recorded every 3 h from 19th September 2009 to 1st February 2012 (see supplementary, Table S2). The reindeer herdsmen were involved in all aspects of capturing and equipping the GPS collars on their reindeer. A total of 14 GPS-marked animals were used, but the number decreased in later periods due to life span of GPS batteries and some mortality unrelated to the GPS-collars (Otto Asbjørn Hansen, 'Personal communication'). We used the GPS Plus collars with double battery packs (2D, with position registering every 3rd hour the batteries last usually last between 2 and 3 years) from Vectronic's Aerospace GmbH (Berlin, Germany). The herd is free ranging over most of the year. To reduce potential influence from the herdsmen during drives and gatherings, we removed data during gatherings (see Skarin et al., 2008; Anttonen et al., 2011; Eftestøl et al., 2016). Because we did not continue the GPS-project after 2012, we have no GPS data for the "after" period. The presence of GPS marked animals varied in relation to seasons in the different parts of the island (see supplementary, Table S2). Out of the total 64594 GPS positions recorded from 14 marked animals throughout the study period, 7415 GPS positions (i.e. 10 %) were in the WF area. The distribution in relation to season within the WF area were 63% (winter), 20% (autumn), 12% (calving) and 5% (summer).

Based on topography and location of the different infrastructure that might interact with reindeer spatial use, we divided the WF area into the following sub-zones (Fig. 1): (1) WF zone 1, areas lying within 500 m of the WF turbines and farther than 250 m from main roads; (2) WF zone 2, areas lying more than 500 m away from WF, and farther than 250 m from main roads; (3) Road zone 1, lower lying areas within 250 m from the main roads on the stretch from the south western end of the study area to the start of WF access road in the south western corner. Road zone 1 represents that part of the existing road within the WF area that was used for transport of material and personnel to and from the WF during construction); and (4) Road zone 2,lower lying areas less than 250 m from the main road on the stretch of WF access road to the end of the study area. Road zone 2 represents the rest of the existing road that was not used for transport of material and personnel during construction. The division was made taking into account proximity to existing infrastructure and human activity, presence of the WF, and vegetation/snow conditions expected to vary in the different elevation zones. In particular, snow and ice conditions along the coast (road zones) are less severe compared to areas further into the WF zones (Otto Asbjørn Hansen, 'Personal communication'), and this in turn may affect pasture dynamics and spatial use by reindeer independent of the WF and roads. We collected information related to habitat quality in the study area in particular and on the island overall (see supplementary, Table S3). For the Arctic in general (Fryxell and Sinclair, 1988) and Vannøy in specific (Virtanen et al., 1999; Colman et al., 2014), there is a strong correlation between elevation and pasture production and quality (Hebblewhite et al., 2008). The power line corridor was treated as one area separately (i.e., power line area).

2.3. Data analysis

All statistical analyses were conducted in R version 3.2.22 (R Core Team, 2015). To investigate any potential effects on the entire island, we compared the density of reindeer between the WF area (15 km^2), power line area (20.5 km^2) and the rest of Vannøy island (172.5 km^2), excluding areas above 600 m.a.s.l. defined as inaccessible (see Fig. 2). Densities were calculated for the different periods in winter (only winter numbers were available from the management authorities; see Reindriftsforvaltningen 2015) using the sum monthly direct observations in the study areas and the official number of reindeer occupying the rest of the island.

We checked the power of the test for the direct observation data for the WF area prior to actual analysis and found the monthly sampling sizes were too small (see supplementary, Table S1) to apply t-tests or GLM for the periods of calving, summer and autumn. We did not find animals in the WF area in10 out of 15 months during summer, and on average there were only 4.2 animals in summer compared to 32.7 animals the rest of the year (see supplementary, Table S1). Data for the sampling months (i.e., 19, 12 and 11 months for before, during and after periods) for winter were enough to apply statistical analyses with a good power. We used GLM in winter to evaluate the relationship between observed reindeer (response variable) and the different zones (i.e., WF zones 1 vs 2, and road zones 1 vs 2) in the WF area. The three periods (before, during and after) in the WF area were compared for each zone using a similar model as above. We also compared periods regardless of zones in order to investigate potential effects for the entire WF area. We did multiple comparison tests to compare the three levels of periods using the package ‘predictmeans’ in R (R Core Team, 2015). For the power line area, we used binomial exact test (McDonald, 2014) to compare periods (before vs. during) using total number of individuals observed in each season (i.e., autumn, winter, calving and summer) since the number of sampling months were too few to apply other advanced tests with a good enough power.

For the GPS-data set, an equal number of random data points within the WF area was generated, i.e. assuming that the entire area is available to the animals (similar to landscape level home range (Johnson et al., 1980). The different zones created within the WF area made comparisons between used and available points possible within each zone (Manly et al., 2002).We then made selectivity ratios based on the “actual used” and “random” available points within each zone for each period within each season in the WF area using the use-availability design in R (Manley et al., 2002; R Core Team, 2015). In this data set, we compared the zones within each period, and checked whether the selectivity coefficient for each of the zones within each period was equal, less or more than expected.

Further, we generated an equal number of random data points with actual GPS positions within the entire Vannøy island (i.e., in areas below 600 m.a.s.l.), and divided the entire island into five areas. We then analysed the selectivity ratios between periods for each of the areas in each season (areas A1-A5, see these areas from Fig. 1). “A1” is the WF area (i.e., Fakken peninsula) where the WF was built. “A2” is a power line area adjacent to the WF area on the southern part and includes the area between the south western corner of the WF area and the point where all traffic to/from the island comes/goes (i.e., a power line corridor affected during construction and operational periods by increased traffic). “A3” is located adjacent to the WF area in the northern part, while “A4”and “A5” are further north on the island. We did this to test the reindeers’ year round area use pattern for each part of the island and investigate whether their large scale use patterns and intensity of use were affected by the WF. We also tested the avoidance effect in areas inland (i.e., northwest) from the power line, comparing the period before and during construction, and assuming an area of cumulative disturbance from power line construction and road traffic towards the coast.

3. Results

3.1. Direct observation

The winter population of reindeer on Vannøy varied slightly during the study period, decreasing from 366 individuals in 2007 (before) to 305 in 2011 (during), and then increasing back to 387 individuals in 2015 (after), see also supplementary (Table S1). On average, the WF area had higher densities of reindeer (2.44 ± 0.67, number km^{-2}; Mean ± SD) and power line area had the lowest densities (0.56 ± 0.54) compared to the rest of the island (1.86 ± 0.23) in winter ($P < 0.05$). The WF area was and remained an important winter range (Fig. 2). The reindeer density did not vary significantly among the periods, both for the WF area (before: 2.35 ± 0.70, during: 2.38 ± 0.69, after: 2.67 ± 0.59; $P > 0.05$) and power line area (before: 0.50 ± 0.52 and during: 0.66 ± 0.58; $P > 0.05$). There was a reduction in density for the remainder of the island during the construction period (before: 1.86 ± 0.19, during: 1.60 ± 0.12, after: 2.02 ± 0.16; $P < 0.05$), reflecting a reduction in the overall winter population in 2011 (Fig. 2).

There was no significant effect when comparing reindeer densities for each period for each WF zone in the WF area during winter (Table 1). When comparing road zones within each period, we found a significantly lower density in road zone 1 than in road zone 2 (Table 1). However, since road zone 1 also had a lower density before the construction of the WF, this does not indicate negative effects from the WF. There were also no significant differences between WF zones when comparing each period separately (Table 1), indicating that the WF had no measurable negative effect on space use of reindeer. Similarly, the power line area had no measurable effect on reindeer spatial use in winter and calving seasons (Table 2). For both summer and autumn seasons, we found a significant reduction during the construction period in the power line area (Table 2).

3.2. GPS-data

Reindeer space use was significantly higher than expected in the WF area during the construction period in all seasons, except in summer (Figs. 3; 4). Similar to the direct observation data, few GPS positions were recorded during summer in the WF area (see supplementary, Table S2). For all seasons (Fig. 3), road zone 1 and WF 1 were used less than expected before the construction of the WF, except for calving when it was used as expected (road zone 1) or more (WF 1). Whereas road zone 2 and WF 2 were used more than expected before the construction of the WF in all seasons, except for calving when it was used as expected (road zone 2) or less than expected (WF 2). Despite less use than expected for both road zone 1 and WF 1 during the construction period for all seasons, we only found an effect for the construction period (i.e., less use during than before) for road zone 1 and WF 1 for the calving season (Fig. 3).

Looking at the different areas within the entire Vannøy island (Fig. 4), we found some variations in space use amongst the areas. There was more use during construction as compared to before construction for the WF area (i.e., for "A1") in autumn and winter seasons; whereas more than expected in calving and less than expected in summer for both periods. The power line area (i.e., "A2") was in general used less than expected for both periods in all seasons, except as expected before, and more than expected during, in winter (Fig. 4). The three areas (i.e., "A3"-"A5") in the rest of the island showed a lot of variation in spatial use. In all seasons, "A4" was used more than expected, while "A5" was used less than expected for both periods (Fig. 4). "A3", which is adjacent to the WF area, was used more than expected during the construction period in all seasons (Fig. 4). In all seasons, we found no avoidance effect of the power line for both periods in the power line area (Fig. 5). For the power line area, the probability of use was relatively higher before than during in all seasons except in autumn, with more use during than before close to the power line (Fig. 5).

4. Discussion

Based on the direct observations, we found that reindeer spatial use did not change in connection with the construction and operations of the Fakken WF on a local (within 15 km^2) scale during winter. GPS-data from periods before and during construction confirmed no negative effects of the WF for winter, as well as summer and autumn. For the calving season, there was about 50% reduced use during construction in the WF zone 1, i.e. areas lying within 500 m of the WF turbines), and about 70% reduced use in road zone 1 (i.e. the road zone along the transport road). Thus, in addition to the direct losses of habitat due to the actual roads and turbine sites, we have an indication of negative effects of WF construction work, especially along the access road during calving, similar to Skarin et al. (2015). However, more use during construction for other seasons makes it difficult to conclude whether the area use during calving was due to natural or random variation or real avoidance effects (Colman et al., 2017). Overall, no support was found for the general hypothesis of avoidance effects towards the WF and associated infrastructure for reindeer on Vannøy during operations. However, a possible increase in road kills due to increased traffic during construction, suggests severe negative effects of construction activity in a situation without avoidance effects.

For the power line area, direct observations showed significant reduction in area use during construction in autumn and summer, most likely a true effect, confirming the results of negative effects from power line construction activities found in Eftestøl et al. (2016). However, similar to the WF area, the results were different between seasons, making it difficult to conclude. Furthermore, the GPS analyses also showed no avoidance effects from the power line area during construction, and the possibilities of negative effects from construction activity and transport on the adjacent road thus appear even less evident. Importantly though, the direct observations may show a local negative effect that the GPS data was not able to capture due to the low number of GPS positions in the power line area. This indicates that more in-depth research is necessary before we will be able to make robust conclusions on the effect of construction work.

On a regional scale, the GPS-data showed that the WF area is a highly preferred grazing area for reindeer, except during the summer period. Since the area where the WF was constructed showed an increase in use during autumn and winter, no clear trend during calving, and less use during summer, it is likely that we recorded shifts in reindeers' space use during construction caused by other factors than WF construction work. Reindeer that used areas along the coast, county road and power line were likely to be at least partially habituated towards human activities in these areas (Stankowich, 2008; Stankowich and Reimers, 2015), and hence, be less sensitive towards construction activities and the existence of the WF compared to areas further away from this infrastructure. The only active, natural predator for reindeer on the island is golden eagle *Aquila chrysaetos*, possibly accelerating habituation towards humans (Nybakk et al., 1999; Hansen and Aanes, 2015). Besides the rare possibility of being chased by domestic dogs, threats from wild predators on the ground are non-existent (http://www.rovbase.no/erstatning, accessed 28

October 2016). In relation to effects from the WF and associated infrastructure, it was primarily in WF zone 1 and road zone 1 that we expected reduced use as a result of the WF and activities related to its construction and operation. However, except for the calving period during construction in WF zone 1 and road zone 1 (GPS-data), and for the power line area during construction in summer and autumn (direct observational data), we found few significant changes in reindeer space use that may be related to disturbance from human activities.

Arguably, this contradicts some earlier findings (e.g., Skarin and Åhman, 2014). However, many earlier studies have sampled only for a short time period, or without proper control areas, as discussed in Reimers and Colman (2006) and Colman et al. (2017), so that less use of an area may have been falsely related to human infrastructure in the landscape. In other words, even if studies covering a regional landscape scale are necessary in order to sample long distance avoidance effects (e.g., Skarin and Åhman, 2014), such studies also requires long time series of data before making conclusions (Colman et al., 2017). As examples, recent GPS-studies report negative effects during construction, but no avoidance from power lines during operation (e.g., Colman et al., 2015; Eftestøl et al., 2016), while some prior studies based on direct observations reported avoidance within 4 km from power lines during operation (see review in Skarin and Åhman, 2014). Using 9 years of direct observation and 3 years of GPS data, we are confident in presenting a balanced sample for reindeer spatial use in the WF area, covering a long enough time span to separate real effects from natural fluctuations. In our study, GPS-data from the entire home range clearly showed how the peninsula with the WF was preferred by the reindeer before construction, a finding which confirmed information provided by the local reindeer herdsmen (Otto Asbjørn Hansen, 'Personal communication').

Concern has been raised regarding long-term negative effects of several WF establishments throughout domestic reindeer ranges of Scandinavia (Pape and Löffler, 2012; Bartzke et al., 2014). Based on a general hypothesis of large scale avoidance responses of reindeer away from areas of human activity (Colman et al., 2012b) and infrastructure (Nellemann et al., 2001; Vistnes and Nellemann, 2001; Vistnes et al., 2004; Skarin and Åhman, 2014; Skarin et al., 2015), and possible cumulative effects of many projects combined, it has been predicted that Sami reindeer pastoralists will lose their traditional grazing lands in areas of wind power development. On Vannøy, however, we found no strong effects of the present scale of WF establishment and associated infrastructure on reindeer area use during the present operational stage. From this, it seems that coexistence of reindeer husbandry and wind energy development within the same areas is possible at this level. However, as a case study, the island of Vannøy differs somewhat from most other reindeer ranges of Scandinavia, thus our results need consideration of how local conditions on the island relate to space use for this particular reindeer herd. Since Vannøy is a year round reindeer herding area locked within the definite borders of an island, we have a situation where the animals do not migrate seasonally between inland winter ranges, and coastal summer ranges, as most other reindeer districts in the northern part of Norway (Colman et al., 2013). Furthermore, the total potential grazing area of this district is relatively small (~208 km^2) compared to most other districts in Troms and Finnmark (average > 1000 km^2), suggesting that large distance avoidance responses within the available pastures may not be an option for the reindeer in this herd. As suggested by Skarin and Åhman (2014), if the disturbance level is high, avoidance responses up to 12 km away from areas of anthropogenic disturbances might be found in *Rangife*r. However, such response distances were not necessarily possible on the island of our study. Even if the island is approximately 5-15 km wide from east to west and 30 km long north to south, areas with human activity affect most of the coast where there are roads and houses, making the areas without human activity less extensive. Although very large-scale response distances might be limited on Vannøy, it is still probable that a reindeer population within such a range would perform the same type of anti-predator behavioural strategies (e.g., Frid and Dill, 2002; Beyer et al., 2013) as in cases where the home range is larger. Thus, some avoidance from the WF on this island, especially during construction in the calving season was expected if the reindeer were disturbed by the WF and associated activities/infrastructure, as was the case. The lack of negative effects in the operational period during winter is likely because the animals are highly motivated to graze in the WF site, as this area provides excellent winter pasture (e.g., Frid and Dill, 2002).

Colman et al. (2013) reported that WF development in semi-domesticated reindeer summer range might have minor effects on habitat use if built in poor habitats, and argued that disturbance effects of human infrastructure likely are context-dependent, and management should thus be careful in planning of WFs to minimize adverse effects. Other studies on WFs document negative effects on reindeer space use during the construction phase of the WF and access road (Skarin et al., 2015) or along the access road during the construction period (Colman et al., 2013). Undoubtedly, human activity frightens reindeer (e.g., high traffic roads and tourist developments) and roads by themselves may allow animals to move faster than otherwise because they can present a path of least resistance. However, it is less obvious how technical developments without associated human activity (e.g., power lines, pipelines, wind farms, hydro power stations) would frighten reindeer on a larger scale and lead to avoidance (Bejder et al., 2009; Colman et al., 2015; Colman et al., 2017; Eftestøl et al., 2016). Wind turbines produce noise and visual disturbance, while the level of human activity within WFs is generally lower than e.g., along public roads or tourist developments. Possibly, reindeer would avoid WFs as a combined effect of human presence and visual/noise disturbance from wind turbines. If so, the avoidance effect is probably less severe when human activity within the WF is relatively low, since it is more likely for reindeer to habituate to permanent technical installations than human activity (Anttonen et al., 2011; Helle et al., 2012; Panzacchi et al., 2013; Johnson and Russell, 2014). It can therefore be inferred that the increase in human activity associated with the WF has been relatively low, mainly composed of technical staff utilizing vehicles, and seldom appearing in the terrain except close to wind turbines and the operation centre. Stronger negative effects of WFs could be expected in areas where e.g., the road network opens up for relatively more recreational activity from nearby tourist destinations or larger settlements (Colman et al., 2013), or in previously remote areas where reindeer usually do not encounter such stimuli (Skarin et al., 2015).

This is the first time the entire home range and multiple years' worth of before, during and after data have been tested in relation to a WF and reindeer area use. It is also the first time winter ranges and calving seasons have been included in a study of WF and reindeer space use. In general, we observed shifts in space use both at the local scale on the WF area, and at the regional scale of the entire island throughout our study period. We suspect that the effect during the construction period would have been more negative if there was active construction work throughout this period (i.e. there was no construction work between 10 December 2010 to the end of February 2011). Furthermore, even if this study concludes with no avoidance effects during operational years, i.e. the animals did not use WF zone 1 less than expected, we do not know if there were other effects such as increased restless behaviour within WF 1 minimizing grazing efficiency, for example when encountering WF-personnel along the roads. Future studies should therefore not only focus on avoidance of larger areas, but also on fright and flight behaviour and grazing dynamics. A long temporal scale is necessary in order to avoid erroneous conclusions about avoidance responses in reindeer, when in fact less use of an area might be caused by natural fluctuations (Bergerud et al., 1984; Bartzke et al., 2014).

5. Conclusion

We conclude that our study site represents an area where coexistence of reindeer husbandry and wind energy development is possible, with minor negative effects on reindeer spatial use, despite some direct losses of habitat due to road and turbine sites. Clearly, local conditions affect reindeer use, and possible effects of human development like WFs can only be fully understood with a holistic interpretation, including quality and distribution of pastures, natural and artificial movement barriers in the landscape, home range borders, predator presence, reindeer herding activities, and different types of existing disturbances within the reindeer habitat. However, this raises a high level of complexity, and it seems that the best way forward is to present a series of studies representing different environmental contexts. From this study, a WF had no measurable effect on reindeer spatial use at a local or regional scale during its operational period. However, and similar to other studies, possible negative effects on reindeer spatial use in relation to both the upgraded power line and the WF were in connection with the construction period. These responses were likely related to heightened levels of human activity coupled with an anti-predator response in reindeer. Our results cannot be used to infer effects of a WP built in remote areas where reindeer are less accustomed to human activity. We suggest that new WFs should be built close to existing infrastructure, and we underscore the importance of a long temporal scale using before-after-control-impact design to provide precise information for future wind farm developments in *Rangifer* habitats.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication. Funding was provided by the Norwegian Science Council, The Norwegian Water Resource and Energy Directorate, The Norwegian Reindeer Herding Management, Statkraft, Troms Kraft, Nordkraft Vind, Hydro, Statoil, Fred Olsen Renewable, Agder Energi, Statnett, Statskog and the Reindeer Husbandry Research Fund. These sources of funding were in no way involved in any aspects of the research, study design, data collection and analysis, interpretation of results, or manuscript evaluation and eventual publication.

Ethical statement

All applicable international, national and/or institutional guidelines for the care and use of animals in scientific research were followed. The reindeer herdsmen were involved in all aspects of capturing and equipping the GPS collars on their reindeer according to rules and regulations set by the Norwegian board of animal welfare.

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Figure caption

Fig. 1 Map of the study area showing the different zones and related infrastructure on Vannøy island, Norway. A1 refers to WF area, A2 refers to power line area, while A3-A5 are sub-areas (i.e. control areas) in the Vanøy island.

Fig. 2 Reindeer density (number km^{-2}) in winter within wind farm area (i.e., Fakken peninsula: 15 km^2), power line area (20.5 km^2) and the rest of Vannøy island (172.5 km^2). The accessible area for reindeer was below 600 m elevation. NB: The density for the rest of the island is based on the official number (Source: Reindriftsforvaltningen 2015, in Norwegian) and the sum of monthly direct observation for the two study areas

Fig. 3 Selectivity ratios used and available areas in relation to study periods for each season in different zones within the WF area, GPS-data. If selective ratio is higher than 1, the area is preferred by reindeer more than expected, less than expected if less than 1, and as expected if standard error touches 1.

Fig. 4 Selectivity ratios used and available areas in relation to study periods for each season in different areas of the entire island, GPS-data. A1 represents the WF area; A2 represents the power line area; and A3- A5 are control areas in the rest of the island. If selective ratio is higher than 1, the area is preferred by reindeer more than expected, less than expected if less than 1, and as expected if standard error touches 1.

Fig. 5 Avoidance effects of a power line in the power line area. Disturbed area along the road (i.e., below the power line) was excluded from the prediction. Probability overlapping 0.5 (dotted line) represents use proportional to availability, larger than 0.5 represents more use, and smaller than 0.5 represents less use.

Table 1

Comparison of density of reindeer during winter, each month between periods for each zone and between zones in each period in the wind farm (WF) area (i.e., Fakken peninsula) analysed using general linear model.

Comparison between zones		Period (Mean ±SD, number km^{-2})			Between periods	
		Before	During	After	*F-value*	*P-value*
Zone	All zones	2.37±0.70	2.38±0.69	2.66±0.60	0.729	0.489
Road zones	Road 1	1.00±1.93	0.74±1.40	0.96±1.71	0.090	0.914
	Road 2	4.15±2.55	2.58±2.76	3.76±1.93	1.523	0.231
	F-value	*18.349*	*4.61*	*12.86*		
	P-value	*< 0.001*	*0.043*	*0.002*		
WF zones	WF 1	2.32±1.94	2.26±1.71	3.20±2.05	0.913	0.410
	WF 2	2.07±1.54	2.99±1.79	2.43±1.06	1.356	0.270
	F-value	*0.185*	*1.050*	*1.209*		
	P-value	*0.670*	*0.317*	*0.285*		

Table 2

Comparison of number of reindeer observed between periods for the power line area analysed using binomial exact test (number of individuals weighted by the number of months).

Season	Period	Number of months	Observed number of animals	Weighted number of animals	Test	
					95% CI	P-value
Autumn	Before	5	143	114	(0.81,0.91)	< 0.001
	During	4	21	21		
Winter	Before	12	132	99	(0.38,0.52)	0.157
	During	9	121	121		
Calving	Before	2	28	28	(0.27,0.50)	0.060
	During	2	45	45		
Summer	Before	4	113	113	(0.51, 0.65)	0.026
	During	4	81	81		

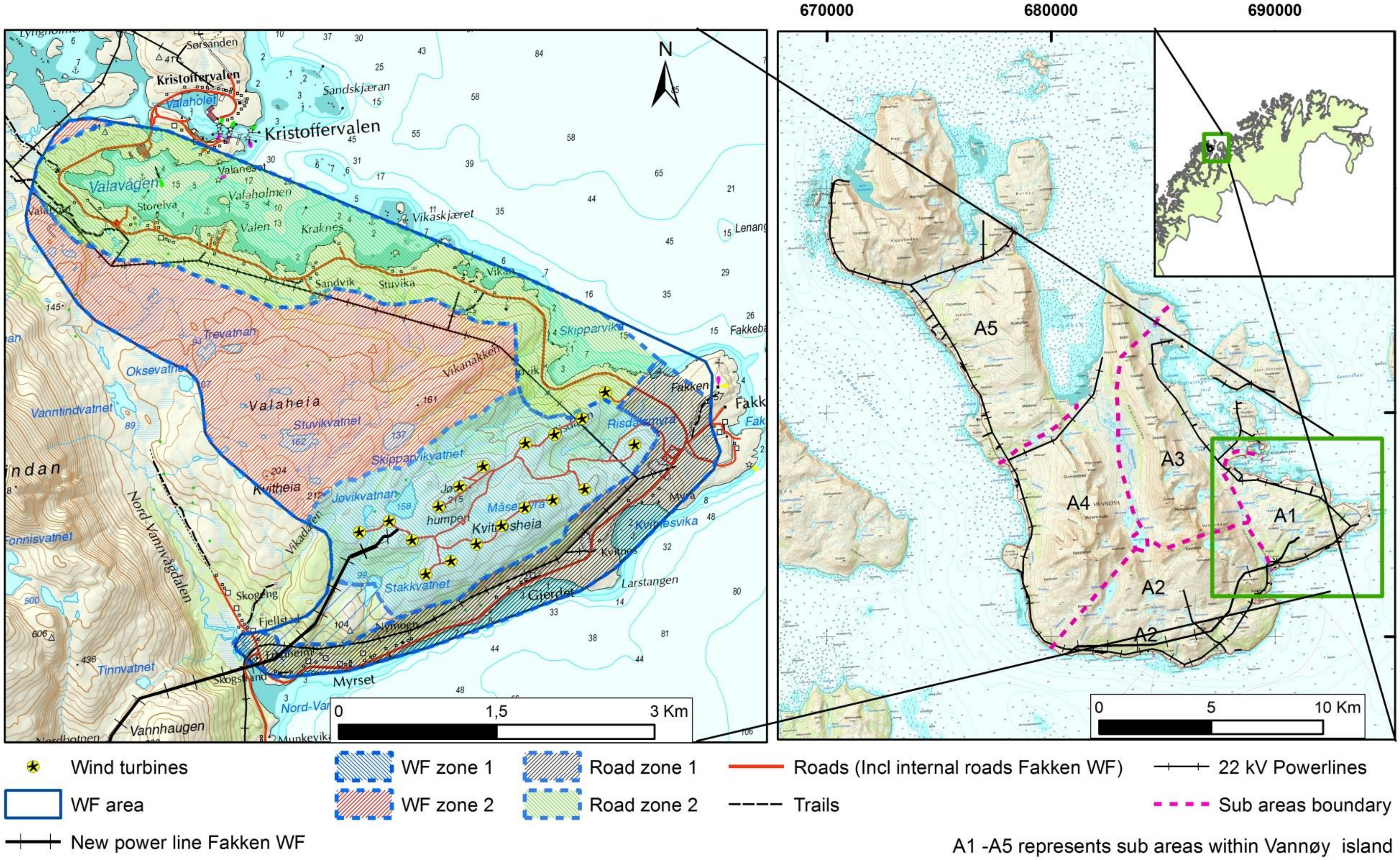
670000
680000
690000
7800000
7790000
7780000
N
Kristoffervalen
Valaheia
Kvitheia
Kvitfjellsheia
Skipparvika
Fakken
Myrset
Vannhaugen
0
1,5
3 Km
A1
A2
A3
A4
A5
0
5
10 Km
Wind turbines
WF area
New power line Fakken WF
WF zone 1
WF zone 2
Road zone 1
Road zone 2
Roads (Incl internal roads Fakken WF)
Trails
22 kV Powerlines
Sub areas boundary
A1 -A5 represents sub areas within Vannøy island

Fig. 1

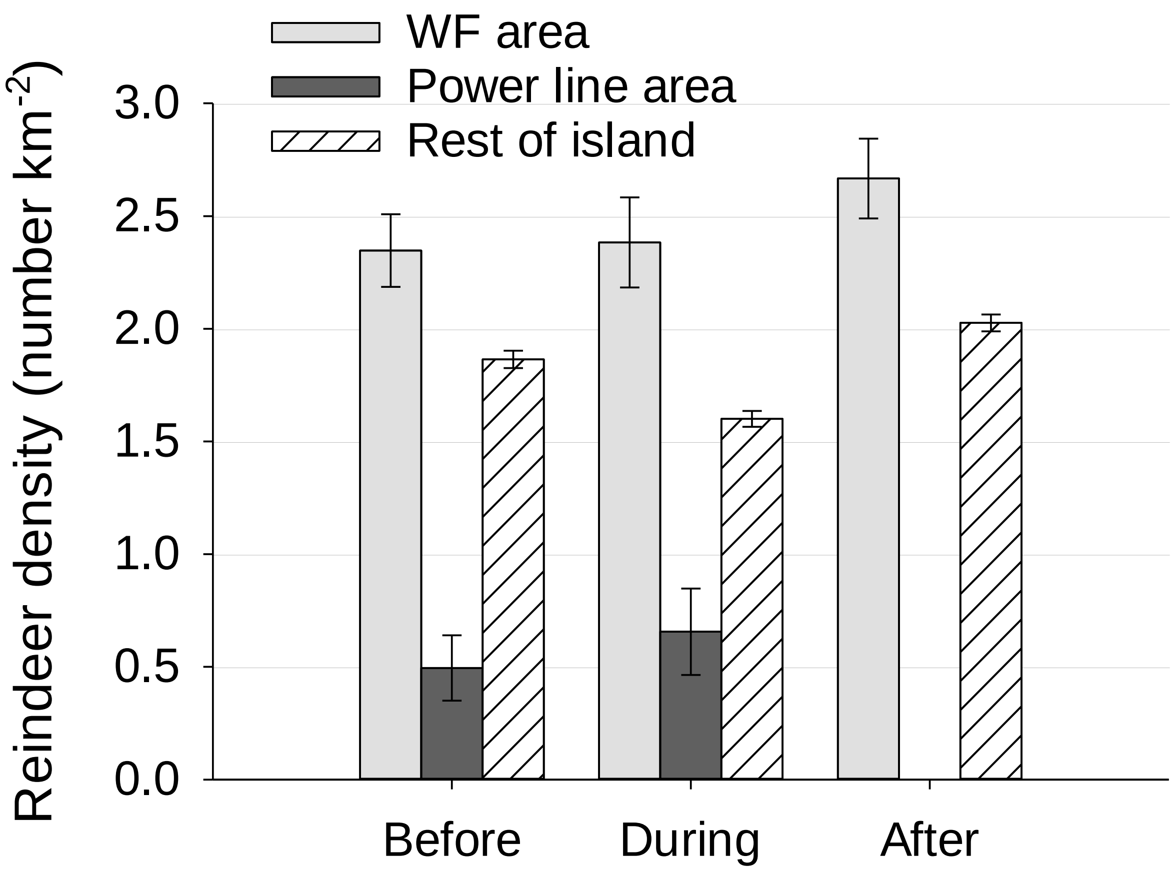
WF area
Power line area
Rest of island
Reindeer density (number km^{-2})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Before
During
After

Fig. 2

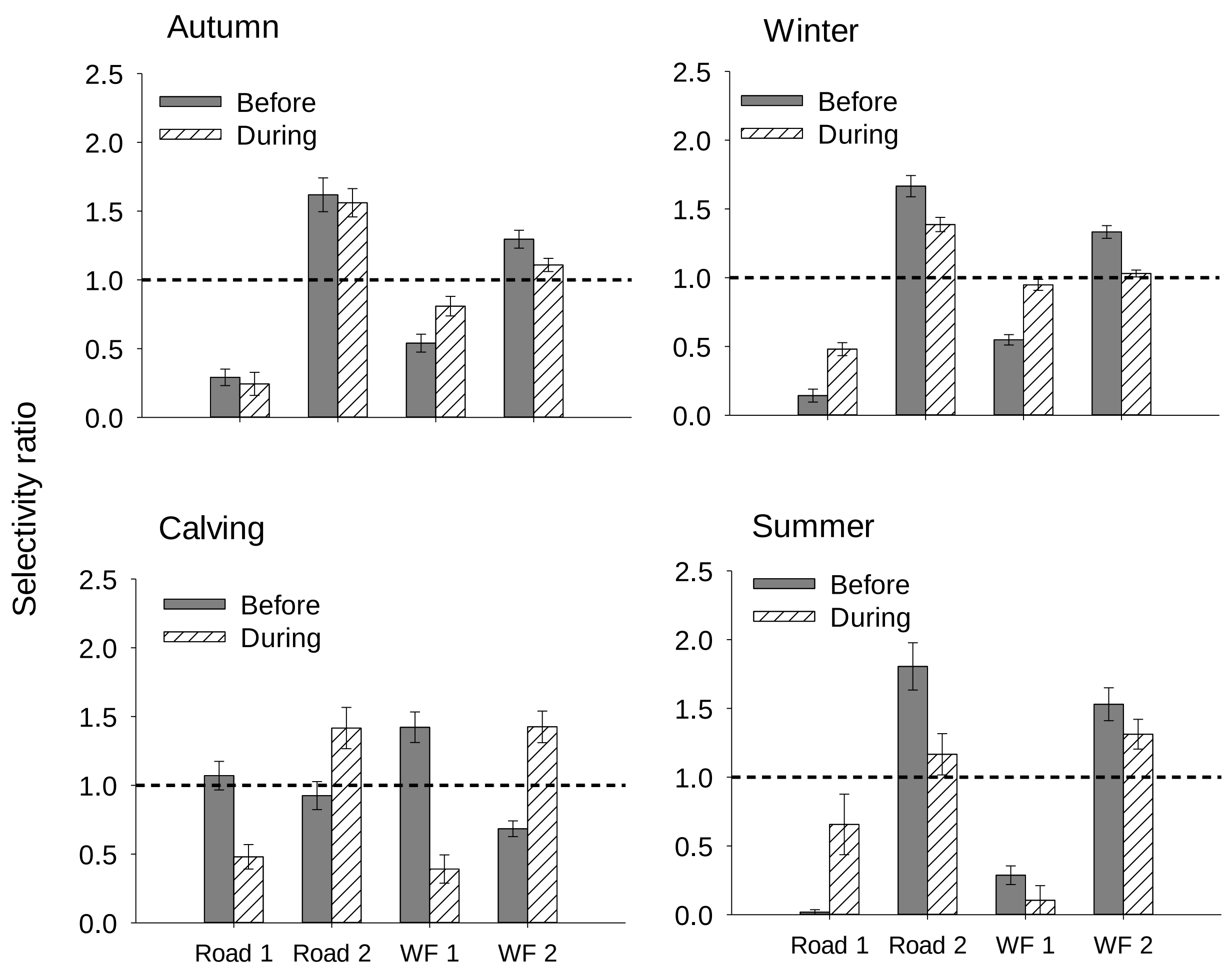
Autumn
Winter
Calving
Summer
Before
During
Selectivity ratio
2.5
2.0
1.5
1.0
0.5
0.0
Road 1
Road 2
WF 1
WF 2

Fig. 3

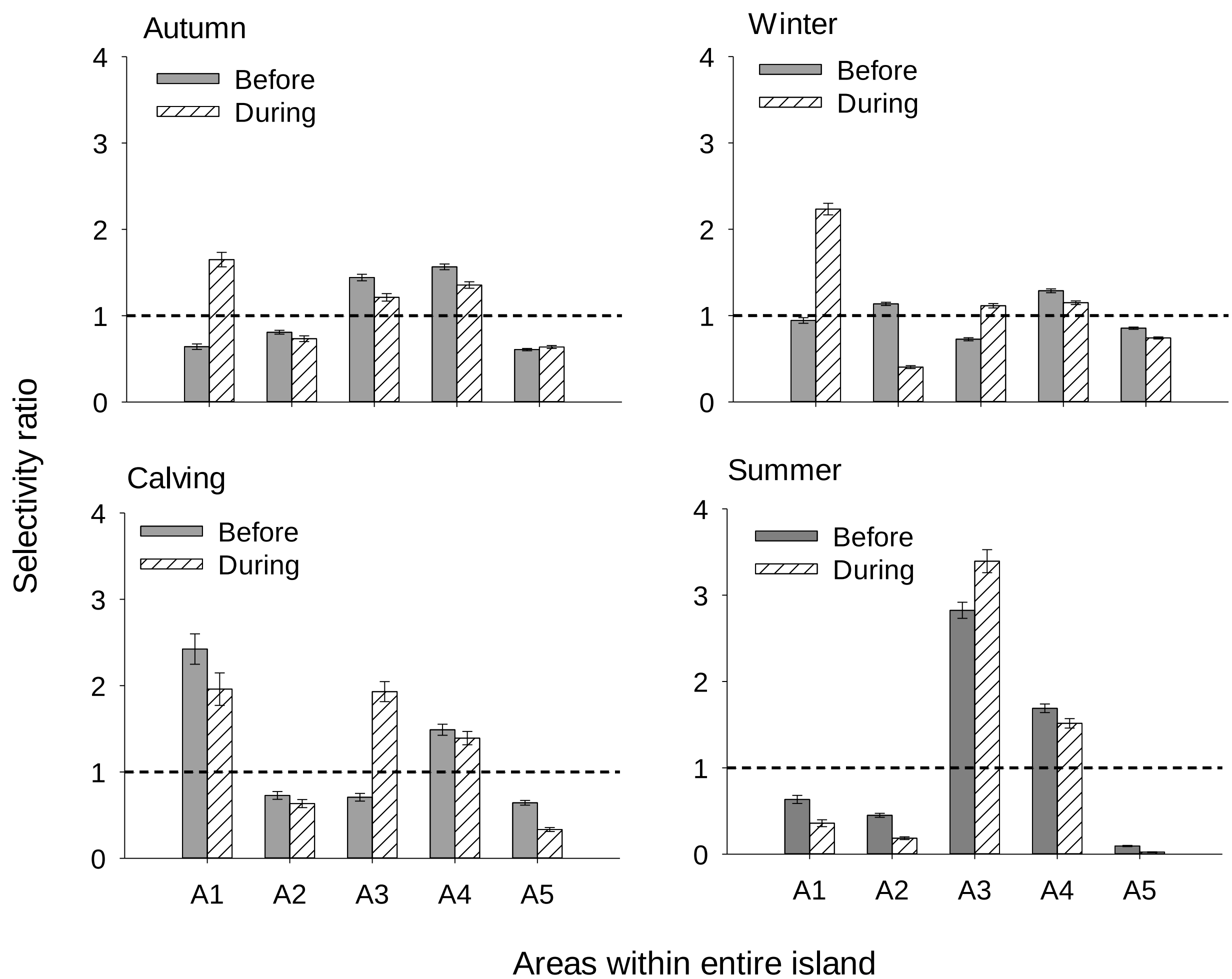
Autumn
Winter
Calving
Summer
Before
During
Selectivity ratio
0
1
2
3
4
A1
A2
A3
A4
A5
Areas within entire island

Fig. 4

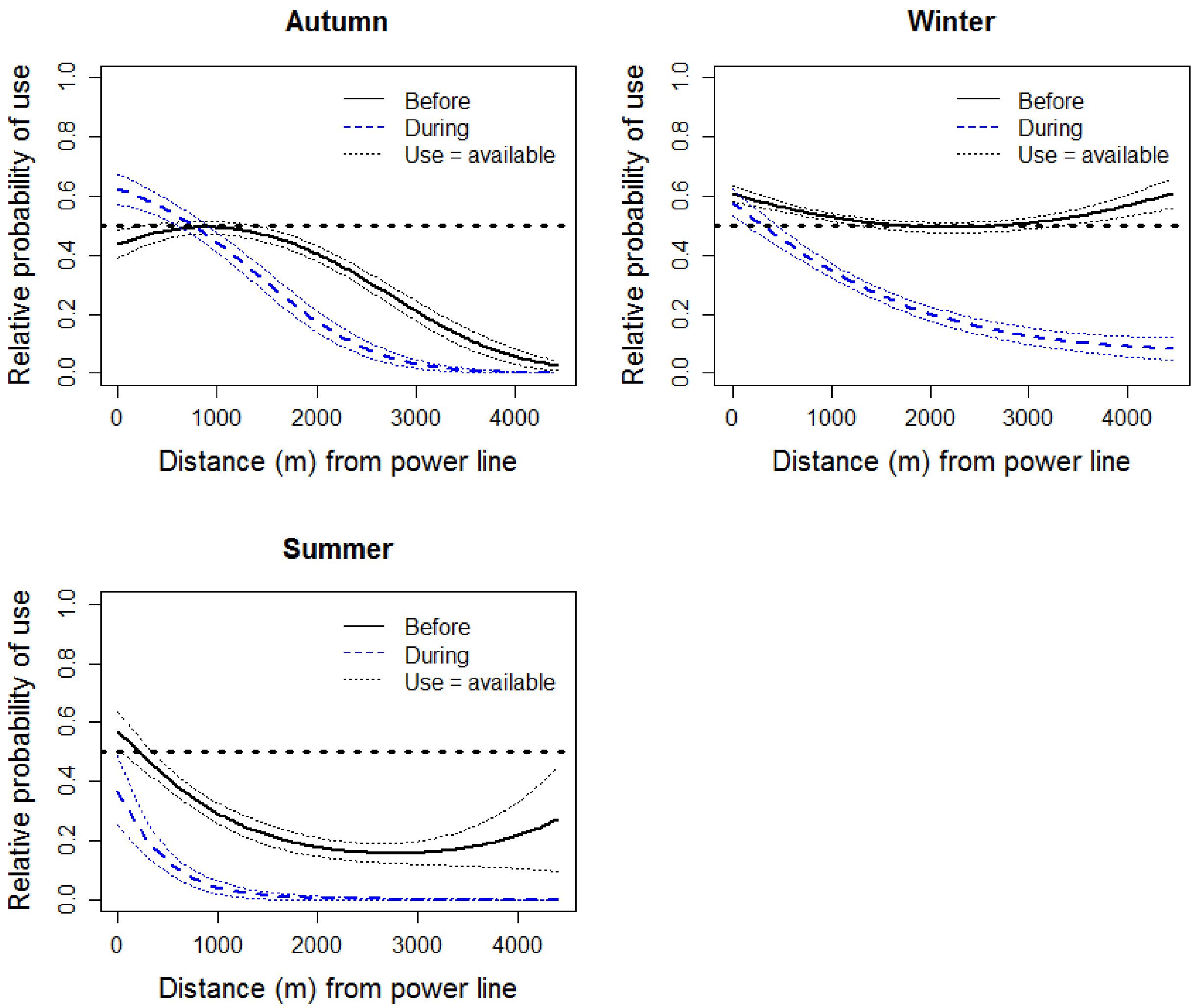
Autumn
Relative probability of use
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
Use = available
0
1000
2000
3000
4000
Distance (m) from power line
Winter
Relative probability of use
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
Use = available
0
1000
2000
3000
4000
Distance (m) from power line
Summer
Relative probability of use
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
Use = available
0
1000
2000
3000
4000
Distance (m) from power line

Fig. 5

Electronic Supplementary materials

Table S1 Overview of the number of observed reindeer per month within the Fakken study area (about 15 km^2, only one survey per month) and a power line area (upgraded along with the construction of WF). The official winter population of reindeer for all of Vannøy is given in the last row.

Area	Season	Month	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
Fakken peninsula	Autumn	August	7	4	33	43	10	26	26			21
		September	42	34		34	34	17	13			29
		October		46	26	6	38	5	17			23
	Winter	November		20	36	38	49	52	41			39
		December		27	37	19	48	28	29			31
		January	40		38	38	45	35	37	37		39
		February	22	30	17	32	34	38	55	46		34
		March	53	26	28	40	18	32	31			33
		April	49	55	41	40	28	45	42		42	43
	Calving	May	47	41	31	18	33	22	44		18	32
	Summer	June	4	47	0	0	0	0	0		0	6
		July	0	5	0	0	0	3	4			2
		Average	22	30	26,	26	28	25	28	42	20	28
Power line area	Autumn	August			14	25	4	1				10
		September				39	7					18
		October			29	36	9					21
	Winter	November			22	25	37					6
		December			0	2	20					2
		January			6	3	16	6				14
		February			0	4	6	0				9
		March			2	33	9	22				24
		April			7	12	3	18				9
	Calving	May			0	28	18	27				16
	Summer	June			20	41	2	47				28
		July			0	52	0	7				13
		Average			9	25	13	16				16
Official number Vannøy in wnter*			366	353	369	325	305	346	379	356	387	354

* Source: Reindriftsforvaltningen 2015, in Norwegian

Table S2 Overview of active GPS transmitters “before” and “during” the construction of WF in different seasons within the study area (i.e., WF and power line areas) and the rest of Vannøy island. Numbers in parenthesis are total number of GPS locations for that period.

Area	Period	Season			
		Autumn (1 August-30 October)	Winter (1 November-30 April)	Calving (1-31 May)	Summer (1 June-31 July)
WF area	Before (19 Sep. 2009 - 14 Oct. 2010)	2 (622)	3 (1480)	3 (577)	10 (285)
	During (15 Oct. 2010 - 1 Feb. 2012)	3 (895)	4 (3159)	2 (290)	4 (107)
Power line area	Before (19 Sep. 2009 - 31 Jan. 2011)	8 (1579)	9 (4369)	2 (388)	2 (488)
	During (1 Feb. 2011 - 1 Feb. 2012)	5 (1228)	7 (2201)	1 (248)	1 (142)
Rest of Vannøy	Before (19 Sep. 2009 - 14 Oct. 2010)	14 (9814)	14 (14007)	11 (2011)	12 (5082)
	During (15 Oct. 2010 - 1 Feb. 2012)	12 (5194)	12 (12731)	8 (1463)	8 (3649)

Table S3 Proportion (%) of four vegetation groups and impediment, based on observation from about 200 routes within Vannøy island and Fakken peninsula (for details see Colman et al., 2014 and Rapp and Røthe, 2014,'unpublished results"). According to Virtanen et al. (1999), Vanøy is characterized by a zonation pattern where low altitude *Calluna* heaths grade into oroarctic vegetation, the highest slopes reach the upper oroarctic zone with patches of the *Ranunculus glacialis-Gymnomitrion* type.

Elevation class	Grass/sedge (%)	Heather (%)	Shrub (*Salix/Betula*) (%)	Herbs/mosses (%)	Impediment (%)
0-100 m	25	40	5	30	0
101-200 m	27	43	7	23	0
201-300 m	30	53	7	8	2
301-400 m	12.5	70	12.5	2.5	2.5
401-500 m	15	60	20	0	5
501-600 m	5	30	15	0	50
601-1000 m	~0	~0	~0	~0	100
Proportion for Fakken	21	45	21	8	5
Proportion for the island (excluding Fakken)	22	47	10	11	10