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ORIGINAL PAPER

Summer distribution of semi-domesticated reindeer relative to a new wind-power plant

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Abstract Wind-power plants (WPs) within reindeer (*Rangifer tarandus tarandus*) habitat may have negative effects on reindeer habitat use. Avoidance effects towards a WP were tested by comparing reindeer distributions on a peninsula where a WP was built in 2006 with a control peninsula without a WP. Distributions were measured by direct observations during construction period, and in four subsequent years, and limited faecal pellet group counts along transects before, during and after the WP construction (2005–2010). We predicted higher reindeer density in the control than the WP peninsula and at increasing distances from the WP when controlling for habitat quality. We found no avoidance effects from the WP, with significantly more reindeer in the WP than the control peninsula. Faecal pellet group data supported a lack of negative effects towards the WP after construction compared to before, while area within 100 m from the access road to the WP was avoided during the construction period and for 3 years afterwards. Reindeer avoided low-quality habitat both in the control and WP peninsulas. Our study indicates that WP development might have minor effects on habitat use if built in poor habitats, at least for semi-domestic reindeer. Our results cannot be used to infer effects of a WP built in higher-quality habitats or where large-scale movements are less restrictive than on a peninsula. Disturbance effects of human infrastructure likely are context-dependent, and management should thus be careful in planning of WPs to minimize adverse effects.

Keywords Avoidance · Infrastructure · Semi-domestic reindeer · Habitat quality · Peninsula · Wind-power plants

Introduction

Infrastructure has increased in arctic regions over the last 50 years (Forbes 2006; Klein 2000), especially in Scandinavia (UNEP 2001). With high demand for "green energy", wind energy development is a political goal in Norway, as well as in Europe (EWEA 2008). Additional infrastructure is expected and the consequences for wildlife remain a contentious issue. Wildlife's response towards disturbance stimuli can be viewed in the same framework as trade-offs between predation risk and foraging in high-quality habitats (Frid and Dill 2002; May et al. 2006). Areas of increased predation risk should be avoided only if the gain of decreased predation risk is smaller than the cost of the reduced use of high quality habitat. The costs of avoiding infrastructure might thus vary depending on habitat quality, resulting in varied responses towards disturbance.

Indeed, some studies focusing on reindeer (*Rangifer tarandus tarandus*) in alpine habitat showed strong avoidance effects from structures, such as roads, power lines and buildings (Klein 1991; Wolfe et al. 2000; Nellemann et al. 2001; Nellemann et al. 2003; Vistnes et al. 2004), and some

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are vague in their statements about the effects (e.g. Dahle et al. 2008). However, others report lack of negative effects from such structures using indirect measurements of pasture parameters (e.g. Reimers et al. 2007). More recent studies using global positioning system (GPS) marked semi-domesticated reindeer (Skarin et al. 2008; Anttonen et al. 2011) and woodland caribou (Polfus et al. 2011) found increasing avoidance effects to be positively correlated with increasing intensities of human activity in connection with the infrastructure in question. Access roads and service stations associated with wind-power plants (WPs) will increase human activities within the WP area, as well increase accessibility of areas outside the WP, thus acerbating potential negative effects from the structures themselves.

There has been a dramatic increase in semi-domestic reindeer populations in northern Norway over the last 30 years (Tømmervik and Riseth 2011). Semi-domestic reindeer are seasonally herded by Sami pastoralists in Scandinavia. With a total range of 56,686 km^2 in Finnmark county, northern Norway, the number of reindeer during winter, after harvesting by Sami pastoralists, increased from 90,000 in the mid-1970s to 210,000 in the mid-1980s (Kashulina et al. 1997). Since then, the population has remained between 150,000 and 250,000 reindeer (Reindriftsforvaltningen 2011). In Finnmark, Sami pastoralists move their reindeer over large distances between summer ranges along the coast and inland winter ranges. Large numbers of reindeer and their need for expansive areas for migration and foraging (Thomson 1977), coupled with progressive amounts of human infrastructure, increase the importance to understand how infrastructure may impact the spatial pattern of reindeer habitat use.

In Norway, six WPs have been built within semi-domestic reindeer summer ranges along the northern coast, and many more are being planned (NVE 2012). A similar situation can be found in semi-domestic reindeer grazing lands in Sweden (Helldin et al. 2012) and Finland (FWPA 2012). This has led to a conflict of interest between Sami reindeer pastoralists and WP developers, both of whom are dependent on large areas. Among reindeer management authorities and reindeer herdsmen, there is concern about how WPs affect reindeer movement patterns and habitat use. However, studies on how WPs affect habitat use of free-ranging reindeer are lacking.

To investigate different effects of a WP on reindeer, we first addressed and analysed the possibility of barrier effects (Colman et al. 2012) and found that the WP did not hinder reindeer movements past the WP in question. Now, we go into more detail about effects on reindeer distribution and habitat use by determining possible avoidance effects in the neighbourhood of the WP and other infrastructure. Avoidance refers to reduced use close to linear and nonlinear infrastructure (e.g. Reimers and Colman 2006). To test for avoidance effects towards a WP, we compared reindeer distributions on a peninsula where a WP was built in 2006 with a control peninsula without a WP. Distributions were measured by direct observations during construction of the WP in 2006, and in four subsequent years, and by faecal pellet group counts along transects before, during and after construction of the WP (years 2005–2010). Our main hypothesis is that the distribution of reindeer within a seasonal range follows the distribution of high quality habitat and that discrepancies from this can be explained by risk assessment and avoidance behaviour of reindeer in areas of disturbance from humans, other predators or parasitic insects (Reimers and Colman 2006; Reimers et al. 2006; Stankowich 2008). We predicted that (1) reindeer avoid use of a peninsula where there is a WP compared to a control peninsula (i.e. no WP), (2) lower densities of reindeer close to the WP in the year of construction than in the operative years and (3) lower densities of reindeer at decreasing distance from all infrastructure (WP, roads, power lines, settlements and buildings) within areas of similar habitat quality.

Materials and methods

Study areas

Fieldwork was conducted in Dyfjord and Skjøtningberg peninsulas, located on the larger Nordkinn peninsula, in Finnmark, northern Norway (Fig. 1). The two adjacent peninsulas are situated within the Olggut Corgas reindeer herding district's (Reindeer district number 9) summer range encompassing the entire Nordkinn peninsula (1,129 km^2). During the study period, the winter herd increased from 5,475 animals to 6,050 animals between 2005 and 2008 and then decreased to 5,538 animals in 2010 (equivalent to about 10,000 reindeer after calving on the summer ranges, i.e. there are approximately 80 % reproductive females in their winter herd averaged for the period 2005–2010) (Reindriftsforvaltningen 2011). Reindeer arrive on the Nordkinn summer range during April, before the onset of calving and remain until mid or late October. In connection with reindeer husbandry, there are variable short periods of herding while gathering for marking and harvesting the reindeer, but this did not affect the internal distribution of animals within our study area during our survey periods. During all our surveys, the reindeer on the western half of Nordkinn peninsula were free-ranging and could move freely in and out of the two peninsulas and the adjacent areas depending on their own choice of habitat. Most likely, large-scale movement (over 20 km) is influenced by wind direction, season, habitat conditions, herdsmen and human and predator disturbances. For example, during the peak of summer, most of the reindeer population on Nordkinn move to the eastern side of the Nordkinn peninsula and the Sattovarri/

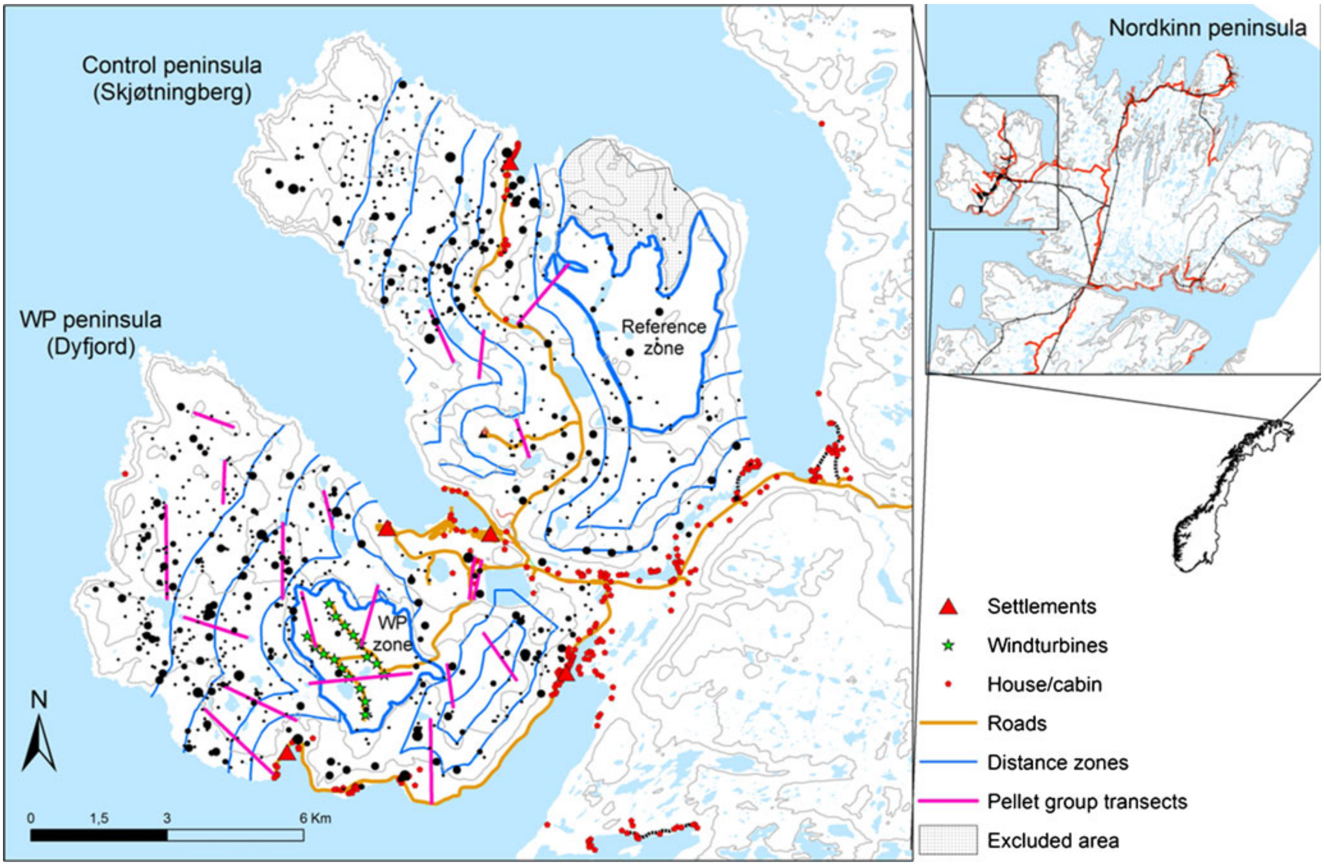

Fig. 1 Location map of the study areas showing the WP and other structures, distance zones from combined infrastructure and distribution of reindeer during 2006–2010. The size of the *circle* (<11, 11–20, 21–50 and > 50) for animal groups indicate group size

Sandfjellet Mountain. While having good pasture, these mountains (elevation up to 500 m a.s.l.) also provide windy areas with the only snow patches that last throughout the summer on Nordkinn for relief during periods of insect harassment (Reindeer district 9 area use description 2009, in Norwegian).

The Dyfjord and Skjøtningberg peninsulas are very similar in terms of geographical position, shape, size, location, vegetation, topography, wind and climate and therefore expected reindeer use. The climate in the area is oceanic, characterized by mild winters, low summer temperatures and a yearly precipitation around 500–700 mm (Moen 1998). The mean elevation is slightly higher on Skjøtningberg peninsula (187 m a.s.l.) compared to the Dyfjord peninsula (167 m a.s.l.). During 2006, a WP was built in the middle of Dyfjord peninsula (i.e. WP peninsula). The WP consisted of 17, approximately 152-m-tall wind turbines including rotor-blades with a potential combined maximum production level of 39.1 MW and an estimated yearly production of about 150 Gwh. The WP was located on top of Gartefjellet, positioned close to the centre of the WP peninsula (Fig. 1). The wind turbines were positioned in two lines in an east–west direction. The distance between the wind-turbines on the same line were approximately 250 m, while the distance between the two lines was approximately 700 m. An 8.5-km, 5-m-wide dirt road connects the wind turbines with the state road (Fig. 1). Power lines built in the late 1960s and crossing the WP peninsula in a north–south direction, traverse the east side of the WP and continue along the west side of the access road and into the small fishing town of Kjøllefjord (Fig. 1). The area around the WP was dominated by rocky and bare areas with a few 1–5-m strips of vegetation partially crossing lower sections of the mountaintop. On Skjøtningberg peninsula (i.e. control peninsula), a public dirt road (5-m-wide) connects the main state road and approximately 15 houses that are still used in connection with recreational activity during summer in the former fishing settlement of Skjøtningberg. The road crosses the entire peninsula in a south–north direction (Fig. 1). Power lines originating in Kjøllefjord follow along the west side of the road almost half way across the peninsula before crossing the road and continuing on the east side and down into the former fishing settlement of Skjøtningberg (Fig. 1). There is also a telecommunication tower in the south eastern part of the peninsula. The public dirt road, power lines and telecommunication tower have been there since the 1960s.

Methods

We used two data sets (direct reindeer surveys and reindeer faecal pellet group counts along transects) to evaluate the effect of WP development (built over a period of 1 year; end of September 2005–October 2006 and referred here after as construction period or 2006) and additional infrastructure (i.e. roads, power lines and buildings) on reindeer distribution and habitat use.

Direct observations of reindeer

We conducted surveys of reindeer distribution in the two peninsulas once a month during June to October for the years 2006–2010 through direct observation. We lack data from October in 2007 and 2008 and from June–August in 2010. Reindeer positions in the landscape were surveyed by ground observations using binoculars (×12–×42) (Downes et al. 1986; Colman et al. 2003). For each fieldtrip, the entire study area was covered, except some smaller areas along the coast and a small part of the northeastern side of the control peninsula, which were either not accessible to the reindeer (too steep) or very difficult for the observer to observe (Fig. 1). These areas were excluded from the analyses. We walked through the areas and targeted hilltops providing maximal visibility. 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 a topographic 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). Due to the low proportion of adult males in this herd (4 % averaged for the period 2005–2010 during winter) (Reindriftsforvaltningen 2011), groups of adult females with calves dominated our study area and our registrations. Surveys were conducted in both peninsulas simultaneously or in consecutive days during each fieldtrip.

The coordinates for each recorded position were embedded in ArcGIS version 9.3. Since reindeer were observed by walking in the terrain, we needed to keep our distance in order to avoid disturbing them. A group of reindeer could also be spread over many tens of meters, allowing observations to be precise enough to be placed in a 250×250-m grid system even while the centre of varying sized groups was mapped. The study areas were then divided into 2,205 grids (250×250 m), and the number of animal within each grid for each field period was calculated. Using ArcGIS, average elevation and distances from human structures (WP, roads, power lines and buildings) for each grid were calculated. Furthermore, information from existing vegetation satellite imagery data with resolution 30×30 m and 25 vegetation types (Johansen 2009) was used to calculate habitat quality. To relate the vegetation types to reindeer habitat quality, we assigned a value from 1 to 3 to each vegetation type according to the productivity of the vegetation following Mobæk et al. (2009) and Rekdal (2001): value 3 (i.e. grasses, heath, herbs), value 2 (marshes, leeside) and value 1 (impediment and exposed ridges, where impediment refers to areas covered either by rocks or sand/gravel with no vegetation). The average productivity value within each 250×250-m grid was then calculated and classified into three habitat qualities; "low" from 1.00 to 1.66, "medium" from 1.67 to 2.33 and "high" above 2.33.

To investigate the effect of the WP more closely, we identified a "WP zone" as the area around the wind turbines above an elevation of 220 m a.s.l. (Fig. 1). At this elevation, the habitat was mainly impediment with only dispersed patches or strips of vegetation. Areas above 220 m, but closer than 1,100 m to existing roads were not included to avoid confounding effects of the roads. The WP zone perimeter ranged approximately 350 to 1,100 m from the closest turbines. Furthermore, to compare this with a similar undeveloped area, we delineated a "reference zone" in the control peninsula having the same vegetation and terrain type, also with the minimum elevation of 220 m similar to the WP zone. To minimize the effect from existing roads and make the reference zone as comparable as possible to the WP zone, we did not include areas less than 1,100 m from the road to Skjøtningberg in the reference zone.

Both the WP and control peninsulas are relatively small, and anthropogenic structures were located relatively close to each other; it was therefore not possible to see the effect of each structure separately, i.e. difficult to separate areas affected by different structures independently for each structure. To test for avoidance at increasing distances, the areas outside the WP and reference zones were therefore divided into 1 km distance zones from combined infrastructure. However, when calculating the size of the areas in ArcGIS, we did not include single cabins located more than 1 km away from roads, i.e. they are likely very seldom in use and were never in use when we were in these areas. Furthermore, to investigate effects for a smaller spatial scale, we divided the first 1-km zone into two 500-m zones. For both peninsulas, the area further than 4 km away from infrastructure was relatively small and was therefore merged with the 3–4-km zone. Prior to data analysis, each of the two peninsulas was split into north and south blocks following the east to west gradient to account for variation in reindeer group sizes. Care was taken to make the two blocks similar in terms of terrain characteristics. Furthermore, we divided the study period in each year into two seasons, i.e. early summer (June–August) and late summer (September–October). We used separate analysis for each season, allowing us to use the late summer data from 2010. However, we were unable to include month in the model as a variable because of very few animals for some months in early summer and lack of data for some months in late summer for some years (ESM 1). Elevation was not included in the analysis because of its correlation with habitat quality ($r=-0.50$ and -0.61 for WP and control peninsulas, respectively).

Faecal pellet group surveys

In addition to direct observations, we counted reindeer faecal pellet groups along transects during late September/early October each year from 2005 to 2010. A total of 20 transects (ESM 2) with an average length of 1,396±470 and 1,197±324 m (mean±SD) in the WP and control peninsulas, respectively, was surveyed in late summer. On the WP peninsula, three transects were distributed within the WP zone and one transect parallel to both sides of the access road to the WP. Eight and three transects were placed west and east for the WP zone, respectively. Four transects were sampled for the control peninsula. We lacked direct observational data for 2005 and therefore used faecal pellet group distributions to determine the overall area use of reindeer during an entire summer season before, during and after the construction of the WP. Although few transects were surveyed, potential changes along the access road to the WP could also be tested. Faecal pellet groups were sampled by walking along a transect (with the help of a handheld GPS) and counting every reindeer faecal pellet group lying within 0.5 m on each side of the person's feet (a 1-m-wide path) (Burnham and Anderson 1984; Helle et al. 2012). The start and stop positions for transects were based on GPS positions and geographical landmarks, i.e. river outlets, large stones on hilltops, etc. A faecal pellet group was defined as a unified group of pellets or a unit of similar pellets (same shape, size, colour and texture) (Skarin 2007). The sum of faecal pellet groups counted along each transect was used as an observation unit in the data analysis. Because of the difficulty in estimating the age of faecal pellet groups, age was not included, as is the case in most studies using faecal pellet group counts (Helle et al. 2012). Therefore, changes in reindeer habitat use are measured gradually, either by a buildup or a decrease in number of faecal pellet groups over the years. For faecal pellet group transects, reindeer habitat quality was calculated in ArcGIS in the same way as for the direct observations.

Data analysis

We analysed the effect of infrastructure on reindeer distribution in three complementary ways: (1) a global model of reindeer density from direct observations, (2) peninsula-specific models of direct observations and (3) a global model and a specific model comparing the access road to the rest of the WP peninsula for reindeer faecal pellet group counts.

First, we analysed variation in the number of reindeer between the WP and control peninsulas by fitting the observed number of reindeer to a mixed effect model using the glmmADMB package. Ordinary mixed models using either Poisson or quasi-Poisson did not adequately fit our data. We therefore fitted a mixed model with a negative binomial distribution to account for over-dispersion (Martin et al. 2005; Zuur et al. 2009; Guo et al. 2010; Paluch 2011), and this yielded an adequate fit to our data as judged from residual plots as well as from the AIC and logLikelihood values. The glmmADMB package allows the incorporation of a random effect into the negative binomial model. Blocking was included as a variance component in the model to account for variation in group size and also for non-independence of observations. Site (WP vs. control peninsula), distance zone (0–500 m, 500–1 km, 1–2 km, 2–3 km and 3–4 km vs. a WP or reference zone), year (2006–2010 for late summer and 2006–2009 for early summer) and habitat quality (high, medium, and low) were used as fixed categorical variables in the model. We included area as an offset variable in the model to account for the variation in the size of the distance zones (i.e. the number of reindeer observed was offset by area of distance zones). We included a term for the interaction between site with distance and year in the initial models. Date of observation differed between years (ESM 1), and the year effect in the model also includes a date effect.

Secondly, we compared variation in the number of reindeer among the distance zones separately for each peninsula and seasons employing the same mixed effect model structure as above and using area as a fixed offset variable and block as random variable. In this model, distance zone (0–500 m, 500–1 km, 1–2 km, 2–3 km and 3–4 km vs. a WP or reference zone) and year (2006–2009 for early summer and 2006–2010 for late summer) were used as categorical explanatory variables. The non-significant terms ($P>0.05$) were removed from the final model, but in order to see whether the estimates are negative or positive, we kept the distance variable even if this was not significant.

Finally, we analysed numbers of reindeer faecal pellet groups between the control and WP peninsulas to test the effect of the WP before, during and after construction using a generalized mixed effect model with lme4 package. Number of faecal pellet groups was used as a response variable, whereas location (control vs. WP peninsula), year (2005: pre-WP construction, 2006: WP construction and subsequent operative years: 2007–2010) and habitat quality (high, medium, and low) were used as fixed categorical variables in the model. To specifically test for effects of the access road to the WP, we also compared numbers of reindeer faecal pellet groups within 100 m to the access road leading to the WP to the rest of the WP peninsula in relation to years. We included length of transect as an offset fixed variable in the model to standardize the number of faecal pellet groups with the length of the transect and transect as random variable. Control peninsula, pre-construction of WP (i.e. 2005) and low-quality habitat were used as reference levels for the location, year and habitat fixed categorical variables.

We fitted alternative models starting with the most complex as well as simpler combinations of variables and selected the most parsimonious model based on AIC values for inference (ESM 3). All analyses were done in R version 2.14.0 (R Development Core Team 2011).

Results

Reindeer distribution and avoidance effects

We found a significantly higher density of reindeer in the WP peninsula than the control peninsula in both early and late summer (Table 1). The density of animals in the WP zone was more similar to the reference zone (0.64 vs. 0.48 km^{-2} early summer, 2.29 vs. 1.15 km^{-2}: late summer) relative to the density of the entire WP and control peninsulas, respectively (2.13 vs. 1.75 km^{-2}: early summer, 7.32 vs. 4.19 km^{-2}: late summer). Moreover, absence of site and distance zone interaction as well as no significant distance zone effect (Table 1) indicates no measurable avoidance towards the WP and other infrastructure. Reindeer distribution varied between the two peninsulas and among years for both early and late summer (Table 1).

In both peninsulas, reindeer density was significantly higher in high- and medium-quality habitats for both seasons regardless of distance zones from infrastructure (Tables 1 and 2; Fig. 2). We found an uneven proportion of habitat quality (i.e. high, medium and poor vegetation types for reindeer) across the distance zones in both peninsulas (Fig. 2). The WP and reference zones had higher proportions of poor-quality habitat relative to the rest of the distance zones (86 % WP vs. 74 % reference zones) (Fig. 2). Overall, the WP peninsula had a relatively higher amount of

Table 1 Comparison of reindeer distribution between the WP and control peninsulas (i.e. larger scale) in relation to infrastructure and habitat quality during the years 2006–2010, analysed using the negative binomial mixed model with glmmADMB package in R

Season	Variables	Coefficients	Estimate	SE	*Z* value	*P* value
Early summer	(June–August)	Intercept	−2.41	0.454	−5.31	<0.001
	Site (Ref. control peninsula)	WP peninsula	0.49	0.237	2.09	0.04
	Distance zones (Ref. WP or reference zone)	0–500 m	0.40	0.421	0.95	0.34
		500 m–1 km	0.34	0.419	0.81	0.42
		1–2 km	0.57	0.418	1.37	0.17
		2–3 km	0.44	0.441	1.01	0.31
		3–4 km	0.55	0.440	1.24	0.21
	Habitat quality (Ref. low)	Medium	1.28	0.287	4.45	<0.001
		High	1.92	0.318	6.04	<0.001
	Year (Ref. 2006)	Year 2007	1.57	0.328	4.78	<0.001
		Year 2008	1.36	0.335	4.06	<0.001
		Year 2009	0.09	0.330	0.28	0.78
Late summer	(September–October)	Intercept	−0.80	0.528	−1.52	0.13
	Site (Ref. control peninsula)	WP peninsula	0.52	0.528	2.12	0.03
	Distance zones (Ref. WP or reference zone)	0–500 m	0.55	0.246	1.23	0.22
		500 m–1 km	0.49	0.449	1.10	0.27
		1–2 km	0.38	0.455	0.83	0.41
		2–3 km	0.59	0.476	1.24	0.22
		3–4 km	0.32	0.464	0.68	0.50
	Habitat quality (Ref. low)	Medium	1.19	0.303	3.93	<0.001
		High	1.50	0.327	4.58	<0.001
	Year (Ref. 2006)	Year 2007	0.69	0.422	1.63	0.10
		Year 2008	0.53	0.425	1.26	0.21
		Year 2009	0.81	0.359	2.26	0.02
		Year 2010	0.59	0.427	1.39	0.17

We included block as a random variable and area as an offset in the model to standardize the number of animals with the area size of the distance zones. We removed the interaction terms between the predictor variables from the model because of absence of significant effect at the 5 % level. Ref. represents the levels of a categorical variable kept as a reference

Table 2 Distribution of reindeer within the WP and Control peninsulas (i.e. finer scale) in relation to infrastructure and habitat quality for the years 2006–2010, analysed using the negative binomial mixed model with glmmADMB package in R

Peninsula	Variables	Coefficients	Early summer (June–August)				Late summer (September–October)			
			Estimate	SE	*Z* value	*P* value	Estimate	SE	*Z* value	*P* value
WP peninsula		Intercept	−1.95	0.627	−3.11	0.002	−0.80	0.722	−1.11	0.27
	Distance zones (Ref. WP)	0–500 m	0.06	0.626	0.10	0.92	−0.66	0.675	−0.98	0.33
		500 m–1 km	0.51	0.604	0.84	0.40	−0.18	0.630	−0.29	0.78
		1–2 km	1.02	0.613	1.66	0.10	0.07	0.598	0.12	0.90
		2–3 km	0.63	0.652	0.96	0.34	0.11	0.691	0.16	0.88
		3–4 km	0.89	0.617	1.45	0.15	0.18	0.657	0.27	0.78
	Habitat quality (Ref. low)	Medium	1.14	0.410	2.79	0.01	2.32	0.459	5.06	<0.001
		High	1.97	0.457	4.31	<0.001	2.60	0.506	5.14	<0.001
	Year (Ref. 2006)	Year 2007	1.85	0.465	3.98	<0.001	0.50	0.574	0.87	0.39
		Year 2008	0.75	0.447	1.67	0.10	0.83	0.622	1.34	0.18
		Year 2009	−0.24	0.477	−0.50	0.61	1.30	0.518	2.50	0.01
		Year 2010	NA	NA	NA	NA	0.24	0.622	0.38	0.70
Control peninsula		Intercept	−3.06	0.590	−5.18	<0.001	−0.88	0.713	−1.23	0.22
	Distance zones (Rep. reference zone)	0–500 m	0.76	0.575	1.33	0.18	1.25	0.674	1.85	0.06
		500 m–1 km	0.12	0.589	0.21	0.83	0.81	0.636	1.27	0.21
		1–2 km	0.13	0.597	0.21	0.83	0.69	0.728	0.95	0.34
		2–3 km	0.38	0.612	0.62	0.54	1.06	0.711	1.49	0.14
		3–4 km	0.41	0.619	0.66	0.51	0.65	0.718	0.91	0.36
	Habitat quality (Ref. low)	Medium	1.92	0.421	4.57	<0.001	0.53	0.469	1.12	0.26
		High	2.37	0.452	5.25	<0.001	0.98	0.494	1.98	0.05
	Year (Ref. 2006)	Year 2007	1.26	0.452	2.78	0.01	0.99	0.592	1.67	0.10
		Year 2008	2.03	0.446	4.55	<0.001	0.41	0.590	0.69	0.49
		Year 2009	0.56	0.461	1.21	0.23	0.70	0.521	1.34	0.18
		Year 2010	NA	NA	NA	NA	0.85	0.579	1.46	0.14

We included area as an offset in the model to standardize the number of animals with the area size of the distance zones. We removed the interaction terms between the predictor variables from the model because of absence of significant effect at the 5 % level. Ref. represents the levels of a categorical variable kept as a reference

high-quality habitat (34 %) compared to the control peninsula (25 %) (ESM 1). There were no clear trends showing avoidance towards the WP or other infrastructure (Table 2).

We found some significant variations in reindeer density among years (Tables 1 and 2). The construction period (2006) had lower reindeer density than 2007 and 2008 in both peninsulas, particularly during the early summer season. However, the yearly variation did not show any interaction with site, which could have indicated avoidance effects.

Faecal pellet group surveys

Overall, the faecal pellet group counts gave no evidence for avoidance effects towards the WP (Table 3). There was an increasing trend for faecal pellet group density with time from 2005 to 2010 for both peninsulas, except a slight reduction in the WP peninsula in 2006 (during the construction of WP) and in 2008 compared to 2005 (Table 3). However, faecal pellet group counts within 100 m to the access road to the WP zone were significantly lower during the construction period (2006) and three successive operative years (2007 and 2009) compared to 2005 (pre-construction) (Table 3). Compared to the rest of the WP peninsula, faecal pellet group counts were significantly higher along the access road before the construction of the WP (Table 3). Similar to the reindeer survey data, habitat quality significantly affected the distribution of the faecal pellet groups, with higher counts in high- and medium-quality habitats (Table 3).

Discussion

The reindeers' distribution was mainly related to the distribution of habitat quality, with no clear avoidance effects from a WP and combined infrastructure. However, the WP

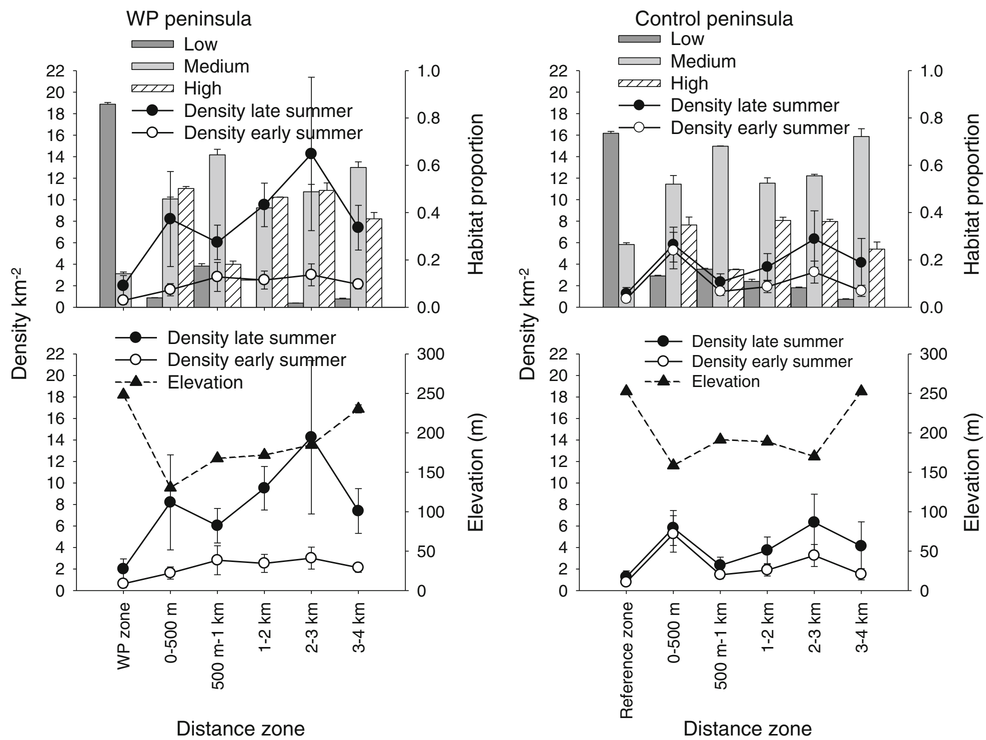

Fig. 2 Relationship between reindeer density and habitat quality in relation to distances from combined infrastructure within a WP and control peninsulas during 2006–2010. Density was summarized within each zone and is given per square kilometre

access road, built through an area with high-quality pasture, had an apparent effect, as reindeer faecal pellet group counts showed a proportionally lower use of reindeer within approximately 100 m to the access road. Thus, our first (i.e. reindeer avoid use of a peninsula where there is a WP compared to a control peninsula) and second (i.e. lower densities of reindeer close to the WP in the year of construction) predictions were rejected. Our third prediction was lower densities of reindeer at decreasing distance from infrastructure within areas of similar habitat quality, and the only findings lending limited support to this was fewer faecal pellet groups along the WP access road.

Our results contrast with studies indicating strong avoidance effects of human infrastructure for *Rangifer* in alpine habitat (Klein 1991; Nellemann et al. 2000, 2001, 2003; Wolfe et al. 2000; Vistnes et al. 2001, 2004; Vistnes and Nellemann 2008). It is therefore clear that a better framework for understanding the variable responses of wildlife towards human infrastructure is needed. Fright and flight responses are weaker in wild reindeer with a domestic ancestry, suggesting that a genetic component partially determines *Rangifer's* vulnerability towards human disturbance (Reimers and Colman 2006; Reimers et al. 2007, 2012). Our results cannot therefore be used for inference for a similar situation with wild reindeer. Studies on avoidance towards infrastructure performed on semi-domestic reindeer (Skarin 2007; Skarin et al. 2008; Anttonen et al. 2011; Vistnes and Nellemann 2001) show different levels of avoidance, suggesting that indeed also other factors such as predation risk (Frid and Dill 2002), insect harassment (Reimers and Colman 2006; Skarin 2007) and habitat quality (Forbes 2006) are important. During periods of insect harassment, *Rangifer* are less reactive towards human activities and infrastructure, concentrating all their attention on finding relief from attacking, parasitic flying insects (Reimers and Colman 2006). However, due to our sampling of both areas within days of each other, this should not affect the spatial comparison being our primary objective. Furthermore, our data was gathered during periods with little or no insect harassment and in an area with less important insect relief habitat than highly elevated, snow covered mountains in the eastern part of the summer range. Therefore, both our methods represent mostly free ranging reindeer without the potential effects of insect harassment on their behaviour reactions towards the infrastructure in question.

We found strong evidence, supported by data from two sampling methods gathered over a 5–6-year period, that reindeer selected high-quality habitat with productive vegetation types, as previously reported by Skarin et al. (2008) and Anttonen et al. (2011). The distribution of habitat with different qualities seemed far more important than the distribution of infrastructure when explaining the reindeers' distribution. However, large positive estimates at distance zones 1–2, 2–3 and 3–4 km compared to the distance zones closer to the WP or other infrastructure may suggest a weak avoidance effect at short distances. For the control peninsula, large positive estimates closer to the infrastructure (Table 2) could be because the zones closer to the road and power lines are in lower elevation where the quality of vegetation within each habitat type is higher (Fig. 2). The positive effect of high-quality

Table 3 Distribution of reindeer faecal pellet groups between WP vs. control peninsula, habitat quality and year (i.e. 2005: pre-WP construction, 2006: WP construction and subsequent operative years: 2007–2010) and along access road to WP vs. rest of the WP peninsula in relation to year, analysed using generalized mixed model with lme4 package in R

Model	Coefficients	Estimate	SE	*Z* value	*P* value
1. Between Peninsulas	Intercept	−4.51	0.21	−21.27	<0.001
	Peninsula (Ref. control peninsula)				
	WP peninsula	−0.06	0.20	−0.31	0.76
	Habitat (Ref. low)				
	Medium	0.74	0.17	4.29	<0.001
	High	0.68	0.16	4.26	<0.001
	Year (Ref. 2005)				
	2006	0.61	0.13	4.66	<0.001
	2007	0.33	0.14	2.43	0.02
	2008	0.89	0.12	7.17	<0.001
	2009	1.13	0.12	9.42	<0.001
	2010	1.23	0.12	10.29	<0.001
	Peninsula × year				
	WP peninsula × 2006	−0.07	0.14	−0.48	0.63
	WP peninsula × 2007	0.19	0.15	1.24	0.22
	WP peninsula × 2008	−0.27	0.14	−1.92	0.05
	WP peninsula × 2009	0.26	0.13	1.94	0.05
	WP peninsula × 2010	0.01	0.13	0.07	0.95
2. Between access road and the rest of WP peninsula	Intercept	−3.38	0.32	−10.64	<0.001
	Location (Ref. road)				
	WP peninsula less access road	−0.81	0.34	−2.37	0.02
	Year (Ref. 2005)				
	2006	−0.76	0.22	−3.42	0.001
	2007	−0.35	0.19	−1.82	0.07
	2008	−0.42	0.20	−2.12	0.03
	2009	0.59	0.16	3.82	0.0001
	2010	1.29	0.14	9.12	<0.001
	Location × year				
	WP peninsula less access road × 2006	1.43	0.23	6.17	<0.001
	WP peninsula less access road × 2007	0.98	0.21	4.75	<0.001
	WP peninsula less access road × 2008	1.16	0.21	5.55	<0.001
	WP peninsula less access road × 2009	0.90	0.17	5.37	<0.001
	WP peninsula less access road × 2010	−0.06	0.15	−0.40	0.69

We included length of transect as an offset in the model to standardize the count of faecal pellet groups with the lengths of the transects. We also included the sampled transects as a random factor to avoid pseudo replication

habitat apparently outweighs eventual negative effects towards human made structures. This may also explain why the WP peninsula, with slightly better vegetation, had an overall higher density of animals (Fig. 2, ESM 1). Some studies reporting strong avoidance effects from infrastructure have likely failed to include the effect of vegetation (e.g. Reimers and Colman 2006), or conclude from sampling in too short of a time span to include seasonal and yearly variations in area use (Vistnes and Nellemann 2001, 2008). Less use of an area does not automatically indicate that an area is being avoided, as reindeer clearly prefer some areas offering preferable habitat characteristics more than others, even when availability is controlled for (Thomson 1977; Bråthen et al. 2007; Skarin 2007). The lowest densities of reindeer were found in the highest elevated areas dominated by impediment and with the lowest habitat quality (Fig. 2), i.e. in the WP zone of the WP peninsula and the reference zone of the control peninsula.

The strength of avoidance effects may vary depending on population density and dispersal relative to resource levels, i.e. how the availability of preferred habitat is distributed in relation to disturbed areas compared to undisturbed areas. With increasing densities, ungulates increase use of lower-quality habitat (Mobæk et al. 2009; McLoughlin et al. 2010). As argued by Gill et al. (2001), animal populations that have alternative undisturbed areas within their home range may show stronger avoidance effects than populations having no undisturbed areas within their range, thereby being forced to live within an area with a disturbance. We found a significantly higher density of reindeer in the WP peninsula, while the faecal pellet group density increased across years in both peninsulas, except along the access road to the WP. The proportionally lower faecal pellet group density closer to the access road to WP during construction and the first three operative years is likely due to increased human activity along the road, especially transportation during the construction phase. Since the herd size has remained relatively stable during the study period (Reindriftsforvaltningen 2011), the increasing density of faecal pellet groups in both areas supports an increment in the relative use of these western areas in the reindeer's entire summer range on the large peninsula of Nordkinn. The increasing density with time may also be due to persistence of previous years droppings. Skarin (2008) reported pellet group persistence up to 4 years in dry habitats. As shown by Skarin (2008), precipitation may affect the decomposition rate of faecal pellet groups. Data from a meteorological station showed higher mean summer precipitation for some years, especially in 2005, possibly affecting buildup of faecal pellet groups along the transects within certain years. A potential effect due to variable decomposition rates would be equal when comparing between the different areas, both within the WP peninsula and between peninsulas. This is the strength of having a control area. Clearly, we cannot fully control for the problem of decay rates affecting our estimates, but we found changes in spatial distribution of faeces over time, which cannot be explained by accumulation, but rather by changes in reindeer distribution between years. We conclude that high-quality habitat found on both the WP and control peninsula remains important parts of the reindeers' summer range even after the construction of the WP (see also Colman et al. 2012).

A WP represents a substantial new aspect to the environment due to visual dominance in the landscape, high turbulent noise levels and increased human activity along the access road and road network connecting the turbines. Flydal et al. (2004, 2009) found no negative effects of wind turbines and power lines on reindeer within enclosures and argued that the stimuli of such large permanent structures were unlikely to trigger anti-predator responses in reindeer, while human activity in a WP area or along a road certainly could. Some recent studies have been able to separate periods of high human activity from periods of low human activity in association with some structures, showing how increasing amounts of human activity lead to increased avoidance effects in areas with solitary houses, camping and holiday cottages (Skarin et al. 2008), population centres, main roads and single buildings or groups of buildings (Anttonen et al. 2011) and mines, cabins and camps (Polfus et al. 2011). We predicted therefore an increased avoidance response as the level of human activity in the WP peninsula and/or along the access road increased during and after construction compared to before. Moreover, a negative effect is expected to be especially strong for cumulative effects when roads, power lines, buildings and a WP are in close proximity to each other. Rønning (2009) reported that 16 % of the inhabitants of Kjøllefjord increased their use of WP peninsula after the construction of the WP. Despite this, the reindeer surveys provided little evidence to support less use by reindeer overall on the WP peninsula, although we found significant negative effects along the access road to the WP. The avoidance measured here constitutes less severe avoidance, both spatially and temporally, than many previous studies reporting avoidance effects for *Rangifer* towards infrastructure ranging from 1 km to over 10 km and for periods of up to decades (Vistnes and Nellemann 2008).

One might argue that the effect of building a WP should be compared to a control without any infrastructure, as a WP necessarily comes with a road as well. This is a valid perspective, but was not the context of our study, which was the addition of a WP. Again, the key point is indeed to make the inference within the context of a given study, and not extrapolate or generalize individual studies beyond their limitations, as seem to frequently be the case. Our study should thus not be used to infer that building a WP in general does not cause avoidance in reindeer, especially if built in other areas than a peninsula where large-scale movements are less restrictive, or in areas with better habitat quality. Nevertheless, it seems valid to infer that if building a WP on poor-quality habitat in reindeer summer ranges, the effect on semi-domestic reindeer will only lead to local avoidance and quite similar habitat use when compared to an area with an established road. Importantly, more WPs will be built, and trying to limit their impact is a crucial goal.

Conclusions

This study demonstrates the importance of including the effect of habitat quality in animal distributions when studying avoidance for wildlife towards human activities and infrastructure. Our findings are highly relevant for conservation and management, since existing and planned WPs in coastal areas of northern Norway are often located in similar high elevated terrain with low-quality habitat in order to exploit optimal wind conditions. A WP-development in northern Norway and possibly elsewhere in Scandinavia might have minor effects on reindeer habitat use if it is built within poor-quality habitat and if the intensity of human activity within the WP area or the neighbouring areas with higher-quality habitat is minimized. The access road appeared to be avoided by reindeer, likely because of high human activity on the road, especially during the construction period. The variable results shown for semi-domestic reindeer avoidance towards anthropogenic structures beckon additional studies in new areas with both similar and different conditions before generalizations can be found. Care should therefore be taken to infer our results in a situation where WPs are being built in higher-quality habitats, larger geographical areas other than a peninsula or in other seasonal ranges such as calving and winter areas. Disturbance effects of human infrastructure likely are context-dependent, and management should thus be careful in planning of WPs to minimize adverse effects.

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