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Short communication

Is a wind-power plant acting as a barrier for reindeer *Rangifer tarandus tarandus* movements?

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Reindeer herdsmen and authorities in Scandinavia fear detrimental effects from wind-power plants (WPs) on movements and area use of reindeer *Rangifer tarandus tarandus*. We tested the extent to which a WP represented a behavioural barrier for reindeer movement by comparing two neighbouring areas; one peninsula with and one without a WP. Both peninsulas had a parallel road and a power line bisecting them in a north-south direction. Presence of a larger or similar number of reindeer on the outer western compared to the inner eastern sections in both areas indicated no barrier effect from the WP. Furthermore, no clear barrier effects were found for reindeer movements during summer in the WP or neighbouring area, as reindeer have continued to cross back and forth between the inner and outer sections of the two areas. Contrary to our expectation, our finding contrasted with previous studies finding negative barrier effects from linear structures such as power lines and roads, suggesting considerable variation in the extent to which infrastructure acts as barriers.

Key words: behavioural barrier, Rangifer tarandus tarandus, reindeer, seasonal movements, summer pasture, wind-power plant

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A major increase in human-made structures, such as roads, hydroelectric dams, wind-power plants (WPs), power lines and buildings, has occurred in arctic regions over the last 50 years, especially in Scandinavia (Klein 2000). There is considerable concern for the ecological effects of human development, in particular for species that range over expansive areas such as reindeer *Rangifer tarandus tarandus* (Reimers & Colman 2006). Some studies report negative effects of roads and power lines for reindeer or caribou *Rangifer tarandus* when dispersing from one side of these linear structures to the other (Vistnes & Nellemann 2008), others are vague in their statements about barrier effects (Dahle et al. 2008), while some report lack of negative effects from these structures using indirect measurement on vegetation (e.g. Reimers et al. 2007). To further clarify, we needed first to separate the animals' reduced use of areas close to the infrastructure, due to avoidance behaviour, from the role of the infrastructure in acting as a barrier in the landscape to hinder movement from one side to the other. We define: 1) a physical barrier as an aspect in the landscape that creates a physical obstacle that an animal has difficulty in crossing, such as a fence, wall or road-divider, and 2) a behavioural barrier as a behavioural response to a stimulus or stimuli preventing an animal from crossing a 'zone' in the landscape, such as under power lines, past WPs or over roads. A behavioural barrier is not a physical obstacle but caused by the animals' reaction towards the anthropogenic stimuli in the landscape. This might be the case for linear corridors in forested areas where habitat characteristics are altered under power lines or along roads (e.g. Dodd et al. 2004), along with increased risk of predation (Frid & Dill 2002) related to such habitat/landscape alterations.

The demand for 'green energy' from WPs is increasing dramatically (EWEA 2008), while studies addressing effects of WPs on free-ranging ungulates are lacking. WPs can impact ungulates directly through visual dominance in the landscape and high turbulent noise, and indirectly through additional infrastructure (power lines and access roads) and human activity. Many sites for existing and planned WPs in Scandinavia are found within important reindeer habitat (NVE 2012). In Norway alone, six WPs have been built within semi-domestic reindeer (reindeer herded by Sami pastoralists) habitats and many more are in the planning (NVE 2012). When migrating into their summer habitat, reindeer in northern Norway cross into numerous peninsulas along the northern coast of Norway. The debate over large losses of outlying pastures found on peninsulas affected by infrastructure has been especially important because of the possibility for barrier effects impeding dispersal into the outer sections of the peninsulas. This is potentially a more severe effect of WPs than just avoidance of the immediate surroundings.

We tested for behavioural barrier effects of a WP on reindeer, as opposed to avoidance effects. Reindeer use two smaller peninsulas (Dyfjord and Skjøtningberg) on the west coast of the larger Nordkinn peninsula in Norway as their summer range. Both peninsulas have potential behavioural barrier effects from a road and a power line bisecting them in a north-south direction, but only one with a WP, making it possible to decipher the influence of the WP installations themselves. We tested the prediction that infrastructure on the two peninsulas affects the area use of the reindeer by 1) reducing the number of animals on the western, outer section of the infrastructure, and 2) reducing the number of animal crossings, both from the eastern and the western side of the infrastructure. We also tested whether the WP had added a stronger, cumulative behavioural barrier effect than the effects of the roads and power lines in both peninsulas, and whether this effect was strongest during the construction period.

Materials and methods

Study areas

We studied semi-domesticated reindeer on two peninsulas; Dyfjord and Skjøtningberg on the larger Nordkinn peninsula in Finnmark, northern Norway (Fig. 1). Both peninsulas constitute good summer pastures approximately below 250 m a.s.l. (constituting 87% and 78% of the total area in Dyfjord and Skjøtningberg, respectively) with rocky low productive areas above this elevation. The average elevation is similar on Skjøtningberg (187 m a.s.l.) and Dyfjord (167 m a.s.l.). The climate is oceanic characterised by mild winters, low summer temperatures and a yearly precipitation between 500 and 700 mm (Moen 1998). The two peninsulas have a similar area (61.9 km^2 in Dyfjord and 71.0 km^2 in Skjøtningberg; see Fig. 1) excluding water, and both the landscape and vegetation follow a similar pattern along an east-west gradient. The vegetation types, including impediment (areas covered either by rocks or sand/gravel with no vegetation), are similar in the western parts of both peninsulas. However, the proportion of impediment in the eastern part of Skjøtningberg (29%) is relatively higher than in Dyfjord east (15%). Nevertheless, the impediment in Skjøtningberg east is located in the north-east and does not influence the movement across the barrier. Moreover, the proportions of other poor vegetation types (e.g. ridges) are high in Dyfjord east (20%) compared to Skjøtningberg east (7%) and therefore makes the difference in impediment even less significant. Because of the east-west alignment and the north-south bisecting infrastructure through the middle of both peninsulas, we were able to divide the study areas into east and west of the bisecting infrastructure (see Fig. 1). The existing power line on Dyfjord and both the existing power lines and dirt road on Skjøtningberg have existed since the 1960s.

Semi-domesticated reindeer in northern Norway experience close contact with herders during marking of calves, slaughtering and when herded between seasonal pastures (Tveraa et al. 2007). Otherwise, they are free-ranging, while occasional herding may occur if animals move into terrain outside their given pasture area. The reindeer in our study are actively herded into and out of the main Nordkinn peninsula where they spend the summer season. However, once

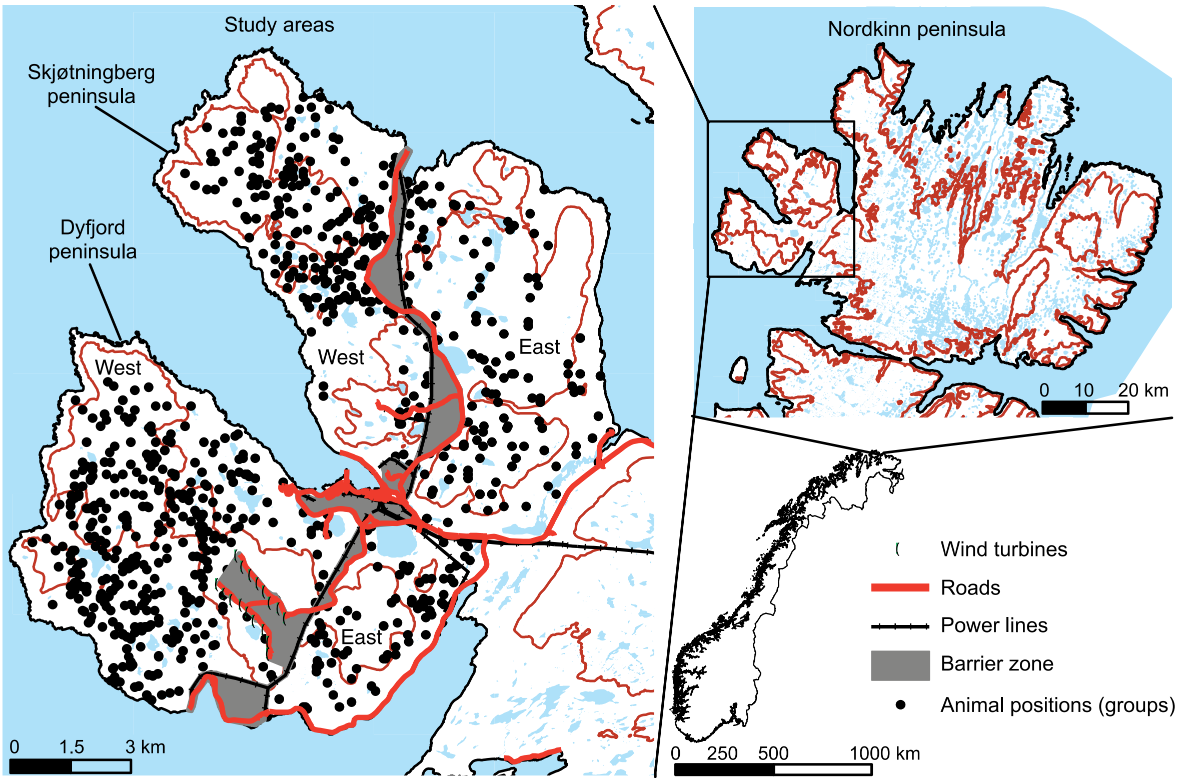

Figure 1. Location of our study areas showing animal positions in the inner eastern and outer western sections of the barrier zone (50 m to each side of existing infrastructure) on the Dyfjord and Skjøtningberg peninsulas during the summer seasons in 2006-2010, Finnmark, Norway.

on the peninsula, the reindeer are allowed to disperse freely in and out of, within and between the two peninsulas during the entire summer season, up until the autumn gathering when they are herded back to their winter range. There is one gathering period during September for calf marking and slaughtering when the reindeer are herded into corrals. Before and after this, they are free ranging. We did not conduct any fieldwork within at least one week after these gathering periods in the end of September or beginning of October.

In 2006, a WP was built in the middle of Dyfjord, while no infrastructure was built on Skjøtningberg during the course of our study (2006-2010). The WP consisted of 17 wind turbines with a base height of 70 m and a rotor diameter of 82.4 m and was connected by an internal road located on top of Gartefjellet, positioned close to the centre of the Dyfjord peninsula (see Fig. 1). An 8.5 km dirt access road (5 m wide) connected the WP with the state road. Assuming the infrastructure in our study areas represented potential behavioural barriers, we defined a buffer zone of 50 m on either side of the barrier. Because herded reindeer can be assumed to have similar or less fright and flight reactions towards anthropogenic activities as wild reindeer, we based this 50-m zone on approximations to the shortest fright and flight reactions of wild reindeer in Norway (Reimers et al. 2009). It was assumed that when reindeer were outside of the barrier zone, they could be considered on one side or the other, while if they were inside the zone, we could not be certain whether they would cross it or not.

Data collection

Reindeer positions in our entire study areas were surveyed by direct observations from the ground using binoculars (12×42; Colman et al. 2003). This was done one day in each month from June to October 2006-2010 on both peninsulas, except for October 2007-2008 and June-September 2010. We followed a predetermined route and targeted hilltops providing optimal visibility. The locations of reindeer were marked on a map using GPS, in combination with compass direction, topographic information in the field and estimated distance between ourselves and the animals. When reindeer were in groups of any number of individuals interacting with each other and moving together, the position of the middle of the group was mapped.

Data analysis

We performed two analyses to assess the possibility for barrier effects impeding reindeer movements in relation to east and west of the infrastructure, excluding reindeer < 50 m away from these. First, we compared the observed and expected numbers of reindeer east and west of the peninsulas for each year using a test comparing expected density based on area available (Neu et al. 1974, Cronin 1998) for testing our first prediction of reduced number of animals on the western side of the infrastructure. The size of the area east and west of the barrier was used to calculate the expected number relative to the observed numbers, removing areas covered with water. We assumed that all areas were equally available to reindeer.

Secondly, we analysed the proportion of reindeer crossings (our second prediction) to test differences between the WP construction period (2006) and operative years after construction (2007-2009) using a generalised linear model. We used an indirect measure of crossings, i.e. proportional change in number of reindeer from month to month. We calculated the proportion of reindeer crossings as follows: $P_i = |(M_{i+1} - M_i)|/(M_{i+1} \text{ or } M_i)$, where P_i refers to the proportion of reindeer crossings in two consecutive months, M_i refers to the number of animals in the ith month and M_{i+1} refers to the number of animals for the consecutive month. Either of the M_i or M_{i+1} that had the largest number was used as a denominator, as this was the maximum number of reindeer in the area in the course of the two consecutive months. The year 2010 was excluded from this analysis as data was recorded only for October. In the model, we included site (Dyfjord vs Skjøtningberg), years (2006 vs operative years after the construction), and the interaction between site and year. The analyses were performed in R statistical software version 2.12.0 (R Development Core Team 2011).

Results

We observed more reindeer relative to available area on Dyfjord compared to Skjøtningberg in all years, but in 2008 the numbers for both peninsulas

Table 1. Use-availability analysis for reindeer distribution in relation to the inner eastern and outer western sections of the barrier on the Dyfjord and Skjøtningberg peninsulas, summer 2006-2010. Available area, excluding the barrier zone and water, was 14.20 km^2, 40.13 km^2, 35.80 km^2 and 30.50 km^2 for East Dyfjord, West Dyfjord, East Skjøtningberg and West Skjøtningberg, respectively. The letters in parenthesis in the body of the table indicate whether the number of reindeer observed was similar to expected (E), significantly less (L) or more (M) than expected from availability. In 2010, observation was made only for October.

			2006		2007		2008		2009		2010	
Site	Location	Proportion of available area	Number observed	95% CI	Number observed	95% CI	Number observed	95% CI	Number observed	95% CI	Number observed	95% CI
Dyfjord	East	0.261	146 (E)	(0.24, 0.27)	375 (E)	(0.26, 0.32)	162 (E)	(0.19, 0.27)	467 (M)	(0.27, 0.34)	17 (L)	(0.03, 0.10)
	West	0.739	648 (E)	(0.72, 0.75)	932 (E)	(0.66, 0.78)	557 (E)	(0.69, 0.87)	1077 (E)	(0.65, 0.75)	274 (M)	(0.79, 1.11)
Skjøtningberg	East	0.540	81 (L)	(0.38, 0.41)	180 (L)	(0.23, 0.33)	482 (E)	(0.53, 0.66)	245 (L)	(0.30, 0.40)	95 (L)	(0.24, 0.39)
	West	0.460	218 (M)	(0.59, 0.63)	474 (M)	(0.64, 0.82)	335 (E)	(0.34, 0.47)	458 (M)	(0.59, 0.73)	215 (M)	(0.58, 0.83)
Both peninsulas	East Dyfjord	0.118	146 (E)	(0.16, 0.17)	375 (M)	(0.17, 0.21)	162 (E)	(0.09, 0.12)	467 (M)	(0.19, 0.23)	17 (L)	(0.02, 0.05)
	West Dyfjord	0.333	648 (M)	(0.46, 0.49)	932 (M)	(0.44, 0.51)	557 (E)	(0.33, 0.40)	1077 (M)	(0.45, 0.52)	274 (M)	(0.39, 0.53)
	East Skjøtningberg	0.297	81 (L)	(0.13, 0.15)	180 (L)	(0.08, 0.11)	482 (E)	(0.28, 0.35)	245 (L)	(0.10, 0.12)	95 (L)	(0.13, 0.20)
	West Skjøtningberg	0.253	218 (L)	(0.21, 0.23)	474 (E)	(0.22, 0.27)	335 (E)	(0.19, 0.25)	458 (L)	(0.18, 0.23)	215 (M)	(0.31, 0.42)
Overall	All Dyfjord	0.45	794 (M)	(0.63, 0.65)	1307 (M)	(0.62, 0.72)	719 (E)	(0.43, 0.51)	1544 (M)	(0.64, 0.73)	291 (E)	(0.42, 0.56)
	All Skjøtningberg	0.55	299 (L)	(0.35, 0.37)	654 (L)	(0.31, 0.37)	817 (E)	(0.49, 0.58)	703 (L)	(0.29, 0.34)	310 (L)	(0.45, 0.59)

Table 2. Proportion of reindeer crossings in reference to the outer western section of the barrier on the Dyfjord and Skjøtningberg peninsulas. Skjøtningberg and year 2006 (wind-power plant construction period) were used as reference levels for site and year categorical variables.

Coefficients	Estimate	Standard error	t value	P value
Intercept	0.83	0.16	5.32	< 0.001
Dyfjord	-0.34	0.21	-1.64	0.12
2007	-0.33	0.22	-1.48	0.16
2008	-0.12	0.22	-0.55	0.59
2009	-0.06	0.21	-0.30	0.77
Dyfjord*2007	0.40	0.30	1.34	0.20
Dyfjord*2008	0.33	0.30	1.11	0.28
Dyfjord*2009	0.17	0.28	0.60	0.56

were similar to expected (Table 1). Comparing the four locations together, Dyfjord west had more reindeer than expected for all five years except 2008, which was as expected, while the number of animals observed for the other three areas varied among years (see Table 1). Despite the lower densities on Skjøtningberg, we observed a higher number of animals than expected west of the infrastructure when we compared east and west of Skjøtningberg alone (for all years except 2008; see Table 1). Considering only Dyfjord, the number of reindeer west of the WP was as expected in all years, but was more than expected in 2010. Similarly, the number of reindeer east on Dyfjord was as expected for all years, except some variation in 2009 (more) and 2010 (less; see Table 1).

Dyfjord and Skjøtningberg had no significant difference in the proportions of reindeer crossings (Table 2). However, the estimates were negative during the construction period for Dyfjord (see Table 2) and in all years for Skjøtningberg except for 2006. The proportion of reindeer crossings on Dyfjord was relatively lower during the WP construction period (2006; 49%) compared to the operative years after the construction period (2007-2009; 62%). However, a positive trend during the operative years in Dyfjord suggests absence of a barrier effect from the WP (see Table 2). On Skjøtningberg, crossings did not vary significantly between the construction period (2006; 74%) and operative years (2007-2009; 67%).

Discussion

Contrary to our predictions, there was no clear evidence for a barrier effect from the WP and associated infrastructure that could potentially cut off the Dyfjord peninsula for reindeer use. Presence of lower number of animals using Dyfjord west relative to Skjøtningberg west except in 2008 and 2010 when looking at each peninsula separately, may indicate a slightly decreased preference for using Dyfjord west, relative to Skjøtningberg west. However, a smaller number of animals than expected for Skjøtningberg west compared to Dyfjord west (for three out of five years) when comparing the four halves showed the opposite effect. The preference was thus not consistent among locations and varied between years, and more importantly, the lack of a significant difference in the proportions of reindeer crossings for both areas supported our inference of no clear evidence for a barrier effect. The decision to construct a WP at the Dyfjord peninsula in Kjøllefjord brought concern among reindeer management authorities and the local reindeer herdsmen, for reindeer pasture being lost due to a barrier effect from the WP (Colman et al. 2002). This concern was emanated from studies showing negative barrier effects for reindeer towards linear structures like roads and power lines (Klein 1991, Wolfe et al. 2000, Dyer et al. 2001, Vistnes et al. 2001, Nellemann et al. 2003, Vistnes & Nellemann 2008).

Generally, reindeer continued using both sides of the WP during both the construction period (2006) and after (2007-2010). It is thus unlikely that the WP had a major negative effect on movements of reindeer within the summer grazing areas of the Dyfjord peninsula. We expected a strong barrier effect during the WP's construction period, with considerable ground transportation, construction work and human activity, but the number of reindeer west of the barrier on Dyfjord in 2006 was not affected. However, a lower proportion of reindeer crossings in 2006 than in other years (but not significantly different) on Dyfjord suggested a weak barrier effect during this period. The construction work might have influenced the reindeer from going back east, crossing the barrier, once they had moved into the western section of Dyfjord. Nevertheless, we did not find significant differences in the proportion of reindeer crossings when comparing the two peninsulas. Importantly, a higher number of reindeer more than expected, coupled with a positive trend in the proportion of reindeer crossings on Dyfjord during the operative years supported the absence of a barrier effect from the WP. Unfortunately, no survey data before the construction of the WP were available. Our comparison between the two peninsulas controlled for potential yearly variation within each separate peninsula, as suggested by Reimers & Colman (2006).

Rangifer habitat use, movement patterns and feeding preferences are governed by a complexity of natural interacting factors (Reimers & Colman 2006, Skarin et al. 2010). The barrier and the avoidance effects are two key aspects of ungulate disturbance-reactions relating to linear structures like roads and power lines. Unless limiting or preventing crossings all together (the barrier effect: Forman & Alexander 1998, Trombulak & Frissell 2000, Nellemann et al. 2001, Vistnes et al. 2004), linear and non-linear structures, like cabins, may cause an avoidance of or aversion towards adjacent areas (e.g. Nellemann et al. 2001, Vistnes et al. 2001, Vistnes & Nellemann 2008). The barrier and avoidance effects can occur in unison or independently, and the 'strength' of either effect can vary considerably with time and in spatial scale. In our study, we have focused on the behavioural barrier effect only, as it may be particularly important in our setting if WPs limit reindeer use of entire peninsulas. *Rangifer* and other ungulates are also well known for their ability to habituate towards many types of stimuli, including anthropogenic activities and structures (e.g. Reimers & Colman 2006, Stankowich 2008). Based on aerial surveys of the distribution of reindeer and lichen measurements, Reimers et al. (2007) reported that reindeer crossed underneath, and grazed under and on both sides, of a 66 KV power line transecting the range of wild reindeer in northern Ottadalen, Norway. However, a negative barrier effect is expected to be especially strong for progressive, cumulative effects from parallel roads and power lines and when expansive structures like WPs are concerned (see review by Vistnes & Nellemann 2008). Despite this, we found no cumulative effects of the new access road built parallel to existing power line, or the WP. However, we were unable to determine whether the east-west alignment of the wind turbines in our study may have influenced the reindeers' perceptions towards the WP.

The potential loss of outlying pasture on peninsulas is especially important in the discussion of management of reindeer and other wildlife. The reindeer in our study are semi-domesticated and may therefore be less susceptible to negative behavioural reactions towards human activities compared to wild reindeer (Reimers & Colman 2006). Nevertheless, our study suggests that this WP does not represent a behavioural barrier for the movements of reindeer on summer pasture, while further analyses are needed to determine whether local avoidance might exist in the neighbourhood of the WP and its associated infrastructure.

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