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SHORT NOTE

Wildlife response to infrastructure: the problem with confounding factors

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Abstract Understanding the effects of human infrastructure on wildlife is important for conservation and management and therefore widely studied. Challenges of many such studies are that they are often conducted after infrastructure establishment, when the exact consequence of the structure may be difficult to disentangle from other determinants of animal spatial use. To highlight these challenges, we use a case study of semi-domestic reindeer (*Rangifer tarandus tarandus*) spatial use within 5–6 km from an existing and a planned power line, using faecal pellet group counts in two areas in northern Norway. We found no relationship between pellet group density and distance to the existing power line, while the density of pellet groups decreased with increasing distance from the planned power line. Vegetation type was the main predictor of reindeer spatial use in the power line area, while elevation and vegetation cover accounted for the occurrence of reindeer in the area without power lines. Our results show that reindeer spatial use is a function of many aspects of the landscape, but not all of these are possible to control for. When this power line is built, what will an after-study of reindeer space use reveal? We underscore the importance of recording wildlife spatial use prior to, and after, infrastructure establishment for sound conclusions about animal response or lack thereof.

Keywords Avoidance · Faecal pellet distribution · Habitat use · Power line · *Rangifer tarandus* · Spatial variation

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Introduction

An understanding of the response of wildlife populations to anthropogenic activity and structures is essential for the conservation and management of wildlife habitat. Effects of human activity and infrastructure on wildlife are often difficult to measure and interpret (Theobald et al. 1997). Generally, studies on the effects of infrastructure on wildlife have been conducted post-construction with only correlative evidence backing conclusions (Johnson et al. 2005; Reimers and Colman 2006; Benitez-Lopez et al. 2010; Hovick et al. 2014). The placement of roads and power line corridors is mostly a function of economic, topographic and environmental considerations, often with little respect towards habitat values. Nevertheless, planners might consider adverse effects on wildlife to mitigate conflicts. After its construction, infrastructure can rarely be experimentally manipulated to see how wildlife respond; the best option is therefore to conduct before and after studies (DeBruyn et al. 2004; Kuvlesky et al. 2007; Nellemann et al. 2010; Mcnew et al. 2014; Colman et al. 2015). Studies with data from only the post-construction period that find more or less use close to infrastructure and conclude with attraction or avoidance may sometimes show what their study species were already doing prior to construction.

Industrial development and human activity in semi-domestic reindeer (*Rangifer tarandus tarandus*) habitat in Scandinavia have accelerated over the past decades, resulting in an increase in land use conflicts (Pape and Löffler 2012). Reindeer husbandry requires large amounts of land because reindeer move over large areas throughout the year to access seasonally available suitable range (Fryxell et al. 1988; Reimers and Colman 2006). Reindeer's negative reaction towards power lines is a major concern of reindeer herdsmen and management authorities. Some research contributes to these concerns (Vistnes and Nellemann 2008), including hypotheses that ultraviolet light from electrical discharge from power lines frightens these animals (Tyler et al. 2014, 2016; but see also Reimers et al. 2015). Recent studies, however, have failed to duplicate the same degree of response towards power lines after the construction period (Panzacchi et al. 2013; Colman et al. 2015; Eftestøl et al. 2016).

Reindeer use of the landscape is not only a function of human avoidance but also of plant phenology and cover (Skogland 1984; Iversen et al. 2014), avoidance of predators and insects (Reimers and Colman 2006), snow cover and ice in winter (Loe et al. 2007), and seasonal effects such as rutting and calving (Skogland 1984; Reimers and Colman 2006; Iversen et al. 2014). In areas with reindeer husbandry, herdsmen play a key role in the reindeers' movements and space use (Tveraa et al. 2007). It is therefore important to consider all these variables when testing for potential effects of human infrastructure, as some effects might be confounded (Reimers and Colman 2006). To investigate the interaction of these multiple variables, we surveyed faecal pellet groups as a surrogate for reindeer habitat use within 5 to 6 km from an existing and a planned power line right of way in two neighbouring herding districts in northern Norway. The objective of this study was to better understand the interaction of variables that influence reindeer use of these areas.

Materials and methods

Study areas

The study was conducted in July 2010 on the summer ranges of two reindeer herding districts in Northern Norway (Fig. 1). One area was transected by two parallel 132-kV power lines and was referred to as "the power line area". In the second area, a new 420-kV power line was planned, and we consequently named this "the planned power line area" (Colman et al. 2009). Both study areas were dominated by lichen, heaths, rocks and gravel and consisted of a mixture of alpine ridge vegetation, fens and early/late snow patch vegetation. Elevation differed slightly between the two areas (power line area: 520–740 m; planned power line area: 920–1200 m). In both areas, reindeer were herded during the migration period in spring (northerly direction) and autumn (southerly direction), but grazed freely during the summer season. The power line area was located in Kvænangen Municipality (69°45′N, 22°33′E; Fig. 1). Two parallel 132-kV power lines crossed both summer pastures and migration routes. Other Sami reindeer herding districts also migrated through this area to reindeer summer pastures along the coast (Colman et al. 2009). The planned power line area was located in Kåfjord Municipality (69°20′N, 20°47′E; Fig. 1), and the planned power line will cross central parts of reindeer summer pasture, comprised of calving areas and migration routes (Colman et al. 2009).

Study design

We counted faecal pellet groups to estimate and test reindeer spatial use in relation to the existing and the planned power lines. We used a point transect survey design (Skarin et al. 2004; Skarin 2007) and counted pellet groups in plots along 39 parallel transects. Transects were oriented north and south of the power line or planned power line (Fig. 1). Each transect ranged 5 to 6 km and was separated by a distance of 500 m (Fig. 1). In total, our transects traversed 214 km.

Each plot was located 250 m apart along each transect up to a distance of 2 km from the power line and then 500 m apart until the end of the transect. At each plot, three circular subplots of 15 m^2 (radius 2.18 m) were examined. The centre subplot was directly on the transect line and the two others were 20 m on each side at 90° angles from the transect line.

Within each subplot, all pellet groups were counted, both fresh and old. However, faecal material may represent the combined use of an area by reindeer for at least 3 years (Skarin 2008), as decomposition in the Arctic is relatively slow. We defined a pellet group as $\geq$10 pellets with similar features in colour, size and shape (Colman et al. 2013). We used the nearest distance to the existing or planned power line to test for differences between the treatment and control areas. We recorded habitat characteristics including elevation, vegetation type and cover (%) in each subplot. We classified vegetation types in the field ("Online Resource", ESM_1) according to a revised version of vegetation class categories developed by Johansen et al. (2009).

Statistical analyses

Statistical analyses were performed using Programme R 3.2.2 (R Core Team 2015). For each area, a generalised

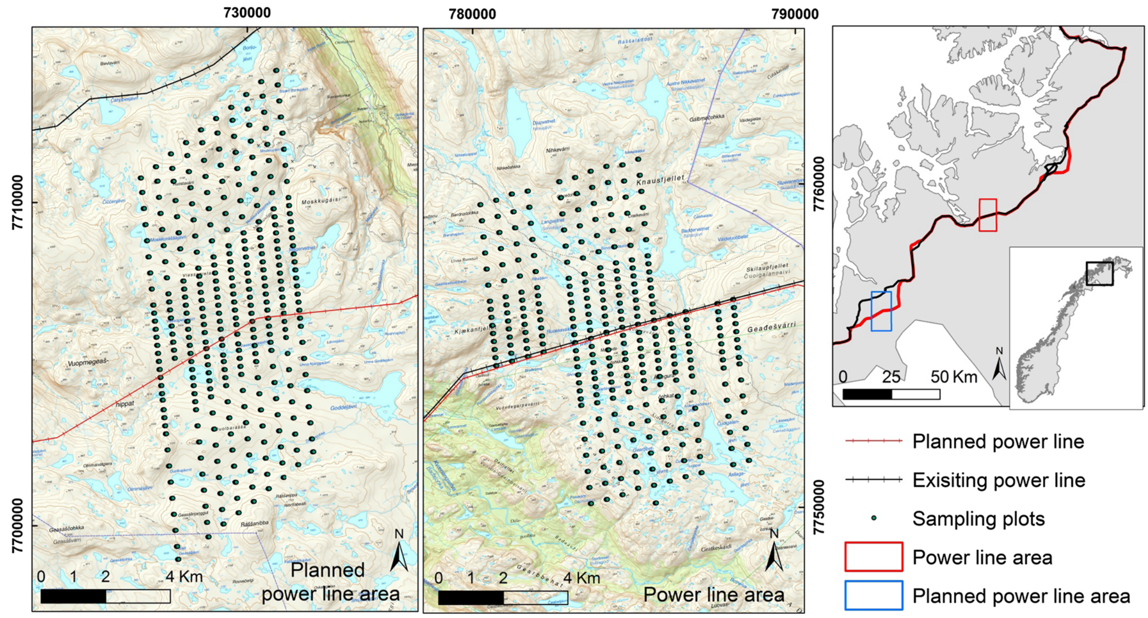

Fig. 1 Study area map showing existing 132-kV and planned 420-kV power lines connecting Balsfjord and Hammerfest in northern Norway (coordinates in UTM, Zone 33 N). The map depicts the power lines, transect lines and sampling plot distributions along transect lines

linear mixed effect model was fit by the Laplace approximation using the library lme4 (Pinheiro and Bates 2000) to evaluate the relationship between pellet group count (response variable) and explanatory variables with a Poisson distribution. The explanatory variables included distance to the power line or the planned power line, elevation, vegetation type (categorical with five levels: 'exposed alpine ridge', 'heather-rich alpine ridge', 'heather and grass vegetation', 'mire' and 'early/late snow patch') and cover (continuous values between 0 and 100 %). Subplots were nested within plots, and plots were nested in transects and used as a random variable to avoid pseudo-replication (Zuur et al. 2009; Bates et al. 2014). We identified the most parsimonious models based on backward elimination using Akaike's information criterion adjusted for small sample sizes (AICc; Burnham and Anderson 2002), but we retained the distance to the power line as an explanatory variable in the final models regardless of the AICc value because the power line was the main focus of this study. We did multiple comparison tests to compare the different levels of vegetation types using the package 'predictmeans' in R (R Core Team 2015).

Results

Out of 1821 preselected sampling subplots, we only sampled a total of 1554 subplots (84.3 %) because of accessibility problems. Some plots were not accessible (14.7 %) as they were covered with water or snow or in deep, wet mires. Of the 1554 sampled subplots, 704 were in the power line area (7–13 July 2010) and 850 subplots in the planned power line area (21–28 July 2010). However, to avoid possible confounding effects from other infrastructures, we excluded 146 subplots sampled within 4 km distance from another existing power line located in the northern part of the planned power line area (Fig. 1). The distribution of commonly occurring vegetation types in relation to the number of pellet groups and distance to real/planned power lines varied between areas ("Online Resource", ESM_2).

Numbers of reindeer pellet groups strongly decreased with increasing distance from the planned power line, but no differences were found in relation to the distance to the existing power line (Table 1; Fig. 2). For the planned power line, the significant effect of interaction between elevation and distance indicated that higher elevated areas were less preferred with increasing distance from the line, not the lower lying areas (Table 1). Number of pellet groups strongly varied between vegetation types in the power line area (Table 1). In the power line area, the vegetation type 'exposed alpine ridge' had a significantly lower number of pellet groups than the other types of vegetation, with the exception of 'mire', whereas 'early/late snow patch' had higher numbers of pellet groups than all other vegetation types except heather alpine ridge (Table 1). In the planned power line area, vegetation type had no effect on reindeer spatial use, but use in general decreased with increasing elevation (Table 1). In both areas, number of pellet groups increased with increasing vegetation cover (Table 1).

Table 1 Number of reindeer pellet groups (response variable) in relation to distance to the power line or planned power line, elevation, vegetation type and cover analysed using the generalised linear mixed model fit by the Laplace approximation (family = Poisson)

Fixed effects	Planned power line area				Power line area			
	Estimate	SE	*Z* value	*P* value	Estimate	SE	*Z* value	*P* value
Intercept	−0.111	0.046	−2.410	0.015	0.232	0.139	1.666	0.096
Distance from power line	−0.139	0.043	−3.227	0.001	0.032	0.029	1.076	0.282
Elevation	−0.204	0.038	−5.340	<0.0001				
Vegetation cover	0.655	0.038	17.190	<0.0001	0.150	0.042	3.622	0.0003
Distance × elevation	−0.108	0.042	−2.576	0.01				
Heather-rich alpine ridge					0.471	0.144	$3.277^{a,b}$	0.001
Heather and grass vegetation					0.376	0.155	$2.419^{b,c}$	0.016
Mire					0.197	0.174	$1.133^{c,d}$	0.257
Early/late snow patch					0.602	0.154	3.900^{a}	<0.0001

Z values labelled with different superscript letters indicate significant difference between the levels of vegetation types (i.e., heather-rich alpine ridge, heather and grass vegetation, mire and early/late snow patch) other than the exposed alpine ridge, obtained through multiple comparison test using the package 'predictmeans' in R. Exposed alpine ridge was used as a reference level for the vegetation categorical variable

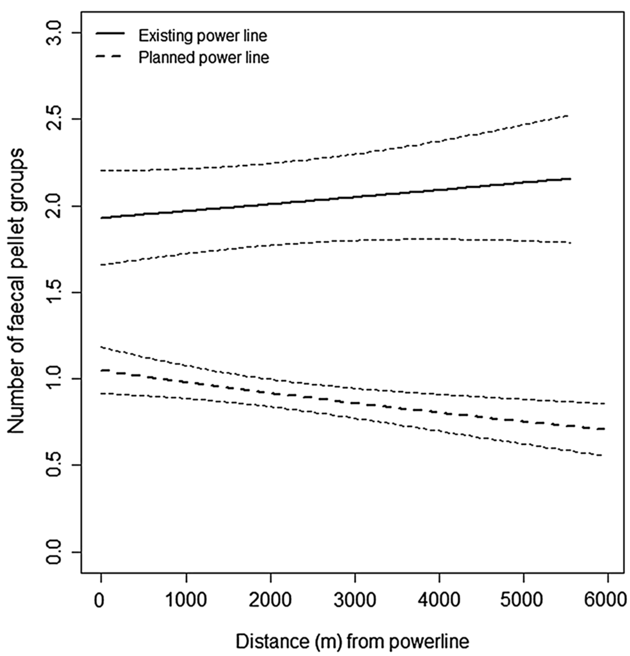

Fig. 2 Predicted number of faecal pellet groups (mean per plot ±95 % CI) in relation to distance to power line or planned power line. The prediction was based on the models from Table 1. For the planned power line model, elevation and cover were kept at their mean. For the power line model, cover was kept at its mean and one of the levels of the vegetation categorical variable (i.e., heather-rich alpine ridge) was included in the prediction

Distance to the power line, vegetation type, vegetation cover and random terms (transect and plots) explained reindeer spatial use in the power line area because it had the least AICc and highest Akaike weights [0.56 Akaike weights, 2.67 times larger than the next best model ("Online Resource", ESM_3)]. There was insufficient evidence to consider elevation and a squared term for the distance variable and interaction terms [all had a ΔAICc > 2 and had far less Akaike weights compared to the selected model ("Online Resource", ESM_3)]. In the planned power line area, a model that included an interaction term between elevation and distance to the planned power line, in addition to vegetation cover and random terms (transects and plots), was selected as the best model (Akaike weights = 0.49, which is 2.13 times larger than the next best model) ("Online Resource", ESM_3).

Discussion and conclusions

Overall, we found that the reindeer spatial use was related to elevation and vegetation cover/type, two factors that are commonly associated with reindeer habitat preferences (Iversen et al. 2014). Despite the inclusion of these variables, distance to the planned power line area was important in the model and provided a significant effect. The results from the planned power line area illustrate how some unknown and thus uncontrolled variables were also important, as the power line itself does not exist.

Our results show a clear and significant relationship between reindeer spatial use and the planned power line (i.e., more faecal pellet groups closer to the power line). Such results underscore the importance and challenges when studying wildlife responses towards infrastructure. To conclude that reindeer are affected by a proposed power line would be a mistake; however, reindeer use was found to be strongly correlated with the proposed power line right of way for reasons that were not addressed by our study. For example, herding activities could be important, as well as the presence or absence of predators, such as Golden eagle (*Aquila chrysaetos* L.). In both areas, reindeer were herded during the migration period in spring (north) and autumn (south) and grazed freely during the summer season. We were unable to detect a reindeer response to the existing power line. However, to conclude that reindeer are unaffected by power lines, given the "effects" we found in the planned power line area, would be unfounded. Without baseline data prior to power line construction, we are unable to accurately interpret results that might have otherwise indicated a response. Therefore, before and after studies are central to aiding proper interpretation of observed patterns.

There have been numerous studies of reindeer as well as other wildlife response to infrastructure (e.g., Johnson et al. 2005; Reimers and Colman 2006; Benitez-Lopez et al. 2010; Hovick et al. 2014; Skarin and Åhman 2014). In general, most have been conducted after infrastructure was already established and not surprisingly conclusions varied from strongly negative (avoidance up to 12 km) to no effect and even to positive effects (Skarin and Åhman 2014). In contrast, Colman et al. (2015) and Eftestøl et al. (2016) found negative effects only for the construction period, with minimal or no negative effects from high voltage power lines shortly after their construction. Beyond problems cited here, there are other methodological challenges when studying animal response to anthropogenic activity. Direct observations can yield detailed habitat use and behavioural data, but such data are often not collected on a 24-h or annual basis or over longer (many years) time periods. GPS data are useful for depicting continuous spatial use but are expensive. For this work we employed pellet group counts as a surrogate of reindeer activity because pellets accumulate over several years (Skarin 2008) and are an inexpensive method for studies of wildlife response to infrastructure. However, season, vegetation and other potential differences in pellet decomposition may pose a methodological challenge. Irrespective of the method used, our results show that it is difficult to draw clear conclusions unless studies are conducted prior to and after infrastructure establishment. Additionally data collected before project construction may help to minimise potential negative effects.

We documented challenges related to the prediction of wildlife response to infrastructure development. We do not claim to say anything about reindeer's actual response toward infrastructure based on this study. Rather, it sheds light on the difficulties with confounding factors when studying wildlife spatial use in relation to infrastructure. We have shown that correlative studies may not be particularly useful and even arrive at erroneous conclusions, even when using a multivariate approach. Unfortunately, the vast majority of information on the response of wildlife towards infrastructure development is based on data collected after infrastructure establishment. Knowledge on individual species' response to infrastructure and human activity is a powerful tool that can be used in biodiversity management and conservation globally (Alkemade et al. 2009). Precise knowledge of potential negative effects from infrastructure is important for guiding planners and managers, and it is therefore paramount to generate data from pre- and post-infrastructure establishment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no potential conflict of interest.

Ethical responsibilities of authors The research reported here has been conducted in an ethical and responsible manner and complies with all relevant legislation. All authors agree with the contents of the manuscript and its submission to the journal.

Human and animal rights statement All procedures performed in this study were in accordance with the ethical standards of the institutions or practice at which the study was conducted. This article does not contain any studies with human participants performed.

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