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Wind of change

Wind power establishments correlate with changes in moose harvests in central Sweden and Norway

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Abstract

A growing concern for climate change puts high demands on electricity from renewable energy sources. Varying results have been reported on the impacts of wind power on terrestrial mammals, e.g. effects on migration corridors and grazing habitat of reindeer (*Rangifer tarandus tarandus*), increased stress-hormones in roe deer (*Capreolus capreolus*), lowered breeding success in wolves (*Canis lupus*), and lowered activity and habitat shifts for moose (*Alces alces*). Using a retrospective dataset of moose harvest (2012-2020) from Sweden and Norway, I examined how harvest at three management levels of various size (Moose Management Areas, Moose Management Units and Hunting team areas/Game management areas) was affected by the establishment of wind parks. Additional covariates were the occurrence of large predators (wolf and brown bear (*Ursus arctos*)), road densities, and 12-year accumulated forest loss. Harvest significantly correlated with wind park establishment at the small and middle levels of moose management. Harvest was affected by the distance to closest wind parks, the number of turbines in wind parks and, at the smallest management level, by the wind turbines height. At the small level, the number of turbines temporarily had a positive correlation with moose harvest during construction phase but shifted to negative during the operative phase. Such pattern was possibly resulting from allocated hunting efforts in relation to altered movement patterns of moose in response to wind park establishment. At the large level, while wind turbines had no significant effect, predator occurrence and gravel road density affected moose harvest. At the middle level, harvest density was affected by wolf occurrence and proportion of young forest stands, but not by occurrence of brown bear. Results show that wind power establishment can affect hunting, an important leisure activity for people on the countryside. Reduced harvests risk to increase browsing damages in forestry and moose-vehicle collisions. It is crucial to understand the effects of wind power establishment on moose and hunting for the green transition to be ecologically and socially sustainable. Deficient knowledge when evaluating suitability for wind parks can potentially cause distrust of green alternatives to fossil fuels and hinder important climate actions.

Key words: behavioral response, green energy, harvest, hunting, moose, wind turbine

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Introduction

Across the last decade, an increasing concern for climate change has made *'green energy'* a large stake in policy making globally (Pegels *et al*. 2017). Climate agreements and public opinion put high demands on governments and industries for renewable energy such as solar-, hydro- and wind-power to compensate the use of fossil fuels and mitigate the enlarged need of electricity required for extensive electrification (Rogelj *et al*. 2018; Swedish Environmental Protection Agency, 2019a). Extracting energy from water through hydro-power constructions is currently the largest source of energy in Norway (87%), and the second largest in Sweden (39%) beside nuclear power (Statistics Norway, 2021; Statistics Sweden 2019). However, due to the structural impacts of hydro-power on aquatic ecosystems and concurrent closures of nuclear plants in Sweden and Norway, in the last decades the need for additional sources of energy has been focused towards increased wind power production (Renöfält *et al*. 2009; Wagner & Rachlew 2016). During a 10-year period (2010-2019), wind power production increased by nearly 800% (from 3,502 to 27,526 GWh) in Sweden and is prognosed to increase further, possibly up to 156 TWh by 2050 (Swedish Energy Agency, 2021a; Swedish Energy Agency, 2021b). Similar trends apply for Norway, with an increased wind power-based energy production of roughly 600% (from 879 to 5,525 GWh) during 2010-2019 (Statistics Norway, 2021). From previously being a topic spatially linked mostly to coastal areas, the rapid expansion of wind power establishment has lately been extended to forest and mountain regions due to technical advantages and lowered cost of onshore wind power (Duffy *et al.* 2020).

It has previously been shown that infrastructural establishments can have substantial impacts on the spatial use and distribution of animals (Benítez-López *et al.* 2010). While dams and hydro-power constructions may hinder animals passage and migration routes in aquatic systems, linear infrastructures (e.g., roads, railroads, and power lines), urban areas and deforestation are known to interfere and impact on animal spatial use in terrestrial environments (Dynesius & Nilsson 1994; Vistnes *et al.* 2004; Coffin 2007; Borda-de-Água *et al.* 2017). For moose (*Alces alces*), anthropogenic landscape features such as roads and forest clear-cuts are known to be conceivable influencers of movement patterns and habitat selection (Courtois *et al.* 2002; Bartzke *et al.* 2015). The establishment of wind power can affect the surrounding environment in different ways, e.g., increased road density and traffic intensity, deforestation, power lines and power line corridors, noise and visual disturbance both during construction as well as in the operative phase of wind parks (Kuvlesky *et al.* 2007). Thus, extensive wind power establishment can be considered an immense alteration of the landscape.

Due to the technical and functional characteristics of wind power however, most previous studies have examined the effects on aerial organisms such as bats and birds (Kunz *et al.* 2007; Dahl *et al.* 2012). This has resulted in important knowledge on the risk for such species of colliding with wind turbines (Marques et al. 2014; Rydell *et al.* 2017). Impacts on terrestrial mammals, however, have rarely been the objective in studies on the effects of wind power constructions. A lack of scientific evidence increases the risk to preclude terrestrial mammals from being accounted for in planning and impact assessments for wind power establishments.

A recent case study on moose space use in northern Sweden suggests that moose activity, in terms of step-length, was lowered in proximity to wind turbines, with a threshold of 5 km (Berndt, 2021). Moose within this threshold also selected for forested areas to a larger extent compared to moose occurring further away from wind turbines. Moose occurring near turbines also adopted an avoiding behavior against human-associated infrastructures.

Skarin *et al.* (2015) examined the effects of wind power on GPS-collared semi-domestic reindeer (*Rangifer tarandus tarandus*) during the construction phase in northern Sweden. The movement corridors and grazing habitat used by reindeer decreased during construction compared to the pre-construction phase. Reindeer use of migration routes decreased by 76 % within 2 km from the wind power establishment. Preferred reindeer habitat during pre-construction phase turned into avoided habitat and reindeer activity was shown to increase significantly during construction phase within a 5 km buffer zone. The study also concluded that associated infrastructures, i.e., roads and power lines, may affect habitat selection, as reindeer showed avoidance for large roads but a preference for power line corridors. Skarin *et al.* (2018) presented results of reduced fecal pellet groups (used as a measure of reindeer habitat use) as an effect of wind power establishment during the operative phase compared to the pre-construction phase, suggesting an overall avoidance of wind power, which corresponds well with results found by Skarin *et al.* (2015). Contrary, results on reindeer in northern Norway from Colman *et al.* (2012) did not indicate any barrier effects from wind power, or associated infrastructures during the operative years.

Another study examined wind power effects on roe deer (*Capreolus capreolus*), focusing on stress-hormone levels related to nearby wind power constructions (Klich *et al.* 2020). They found the size of wind parks, both in terms of area and number of turbines, to correlate with higher stress-hormone levels. This effect showed to be stronger than stress-effects related to the occurrence of wolves. A study on Iberian wolves (*Canis lupus*) showed avoidance to areas of wind parks, resulting in lowered breeding success during the year of construction and the first year of operation (Ferrão da Costa et al. 2018).

Moose is considered one of the most culturally and economically valued game species in Scandinavia and moose hunting is an important leisure activity for many (Olaussen & Skonhoft, 2011). Hunting interests generally favor higher moose densities to enable increased harvest for meat yield and recreational purposes (Mattsson *et al.* 2014). In Scandinavia, the size, structure, and distribution of moose populations is greatly affected by hunting since harvest annually constitutes the largest cause of mortality (Ericsson *et al*. 1999; Jonzén *et al.* 2013). Moose is the primary prey for wolves and brown bears (*Ursus arctos*) in Scandinavia, thus, these predators constitute the second largest cause of moose mortality (Swenson *et al.* 2007; Sand *et al.* 2008; Wikenros *et al.* 2020). Wolves in Scandinavia have been shown to kill approximately 120 moose per wolf territory annually, with the majority being calves (Sand et al. 2005; Sand et al 2008). By increasing the proportion of bulls in harvest, hunters can potentially compensate for some of the wolf predation, however, occurrence of wolves inevitably affects the size and structure of moose populations and the harvest yield (Jonzén *et al.* 2013). Despite the omnivorous feeding plasticity of brown bear, moose calves also constitute important portions of their diet during calving season, with mean kill rate of 6 to 9 calves/year for mature female brown bears (Swenson *et al.* 2007; Rauset *et al.* 2012). Predation from brown bears can therefore potentially be an additional limiting factor on moose harvest yield.

Aim and hypotheses

With this study, I aim to examine the effects of wind power establishment on moose harvest in three spatially different moose management levels across five counties in Sweden and Norway. I hypothesize that moose density will be positively related to increased gravel road density preceding wind power establishment, in line with Bartzke *et al.* (2015) and Skarin *et al.* (2015) since roadsides can possess easily accessible feeding sources for moose (H1). A similar positive effect on moose density is expected for a high proportion of young forest stands. I therefore predict moose harvest densities to be higher in areas of higher gravel road densities and in areas with a larger portion of young forest stands (P1).

I further hypothesize that moose harvest will be lower in close vicinity to wind parks due to an increased human activity. Such activity may indeed limit, hinder, or disturb moose during the construction phase as shown for reindeer (Skarin et al. 2015) (H2). I therefore predict that moose harvest will be positively correlated to the distance to wind parks, and that this effect will be stronger during the construction phase compared to the operative phase (P2).

Also, I hypothesize that moose and moose hunters can be disturbed by a greater number of turbines, as well as by an increased height of turbines (H3). Increased turbine height and number of turbines can be correlated to more extensive construction work during the construction phase and be more visually disturbing for hunters during the operative phase. Therefore, I predict that both increased height and number of turbines will be negatively correlated with harvest density (P3).

Based on previous studies on moose predation by wolf and brown bear (Sand *et al.* 2005; Sand *et al.* 2008; Swenson *et al*. 2007) , I hypothesize that wolves and brown bears will negatively impact the moose harvest density through their predation pressure (Wikenros et al. 2015; Wikenros et al. 2020) (H4). I thus predict that the occurrence of both wolf and bear will have negative effects on moose harvest (P4).

Methods

Study area

The study includes data collected in Sweden (Dalarna, Gävleborg, Värmland and Örebro counties) and Norway (Innlandet county). Covering most of central Sweden and parts of Norway, the study area spans from the Swedish east coast in Gävleborg, to the central mountain regions of Norway in the west and to the Swedish lakes Vänern and Vättern in the south, (58°31'–62°45'N, 8°8'–17°36'E) (Figure 1).

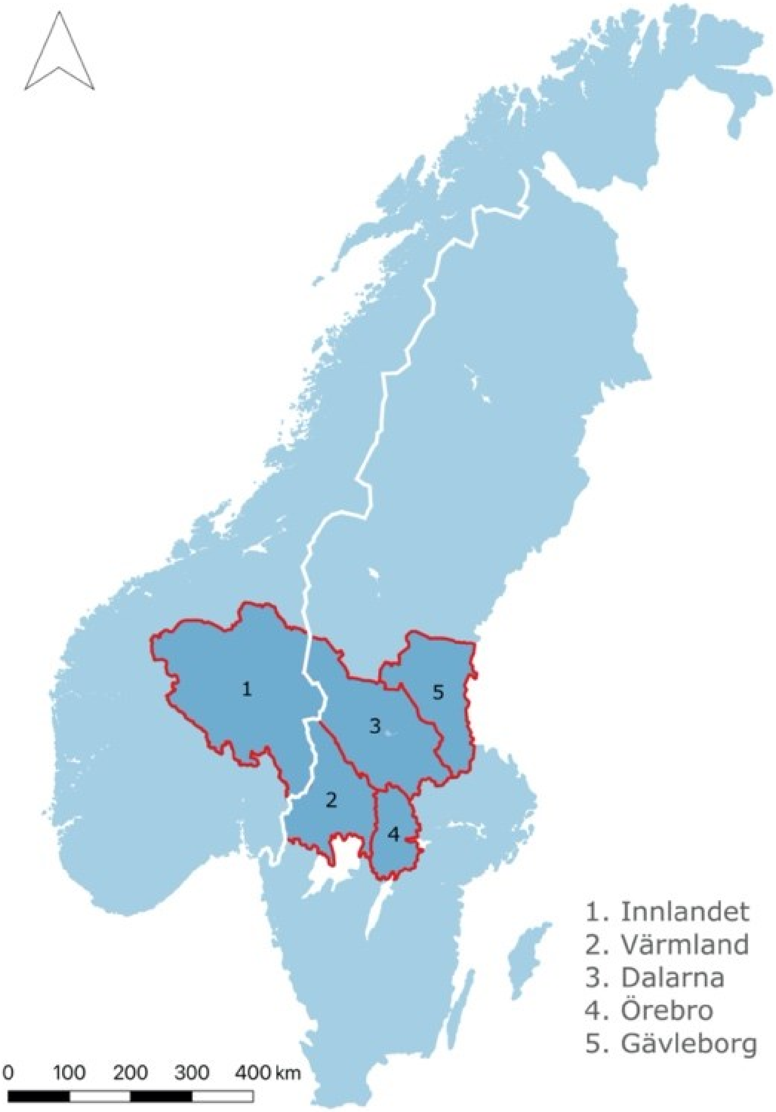

Figure 1. *The study covers moose harvest and wind power data from a cross-border area consisting of Innlandet county in Norway and Swedish counties Värmland, Dalarna, Örebro and Gävleborg.*

The lowland terrain in this part of Scandinavia mostly consists of silviculture forests of boreal and hemi-boreal type and varying degrees of arable land, lakes and bogs (Swedish Environmental Protection Agency, 2019b). Forested areas are characterized by large proportions of evergreen species consisting of Norway spruce (*Picea abies*) and Scot's pine, while birch (*Betula* spp.), aspen (*Populus tremula*), alder (*Alnus* spp.), and willow (*Salix* spp.) constitutes common species of the deciduous trees. The field layer mainly constitutes of bill berries (*Vaccinium myrtillus*), lingon berries (*Vaccinium vitis-idaea*) and heather (*Calluna vulgaris*) (Forest statistics, 2023). Mountain regions are found in western and northern parts of Värmland and Dalarna counties with the highest peaks in Dalarna reaching over 1000 meters and in parts of Innlandet with peaks reaching above 2000 meters (Lantmäteriet, 2019; Kartverket, 2023). Mean January temperatures range from -1 to -10 °C and mean July temperatures range from 11 to 17 °C within the Swedish part of the study area (Swedish Meteorological and Hydrological Institute, 1996–2020). The lowest mean temperatures are found in the northwestern mountain region, and the highest mean temperatures in the south. In Innlandet, mean January temperatures range from -15 to -4 °C, and mean July temperatures ranging from 3 to 18 °C (Norwegian Meteorological Institute, 2000–2020). Mean number of days with snow cover for the years 1961–1990 varied between 75 – 175 in the Swedish part of the study area (Swedish Meteorological and Hydrological Institute, 1961–1990). For the Norwegian part of the study area, mean number of days with snow cover was 209 days over the period 1971–2000 (Norwegian Meteorological Institute, 1971–2000).

Moose populations in Fennoscandia (Sweden, Norway, and Finland) have varied greatly during the last 100 years. From being heavily diminished during the beginning of the 20th century, populations and consequently harvest have increased (Lavsund et al. 2003). In the beginning of the 1980s, moose winter population was estimated to 314,000 individuals in Sweden with all-time annual harvest record of 174,709 in 1982 (Hörnberg, 1991; Lavsund et al. 2003). Total number of harvested moose in Sweden varied from 80,354 to 96,134 during the period 2012–2020. For the Swedish part of the study area, total moose harvest varied from 17,169 to 21,078 (www.viltdata.se). Total harvest in Norway varied from 30,466 to 34,288 during the period 2012–2020. In the Norwegian part of the study area, moose harvest varied from 8,084 to 10,316 (www.hjorteviltregisteret.no).

From being functionally extinct in Scandinavia during 1960's, wolves began to recolonize in 1980s by the reproduction of an immigrating pair from the Finnish/Russian population in Värmland county. Since then, additional immigrating events have contributed to the numeral expansion of the Scandinavian wolf population (Åkesson et al. 2016). The monitoring results from winter 2020/2021 present a total of 48 (Sweden = 39.5, Norway = 8.5) family groups and 27 (Sweden = 21.5, Norway = 5.5) territorial pairs, mostly concentrated in the five counties included in this study. These numbers can be converted to a total estimate of 480 individuals (Sweden = 395, Norway = 83 – 86) (Wabakken *et al.* 2020). In 2017, the brown bear population in Sweden was estimated to 2877 (2771 – 2980) individuals (Kindberg & Swenson 2018). Brown bear occurs in Sweden from the far north down to the northern parts of Värmland, Örebro, and Västmanland counties. In Norway, brown bears occur in counties bordering Sweden from Innlandet and Northwards (Kindberg & Swenson 2018).

Moose management systems

Moose hunting in Sweden is conducted from September or October to the end of January and is regulated by the Swedish hunting law (1987:259), the hunting ordinance (1987:905) and regulations and general advice from the Swedish Environmental Protection Agency (Swedish Environmental Protection Agency, 2002:19). In Norway, moose hunting is regulated by the wildlife law (LOV-1981-05-29-38) and hunting is conducted from September to December at the latest.

The current Swedish moose management occurs at three spatial and administrative levels with cross-level cooperation. The 20 counties subject to moose hunting are divided into moose management areas (in Swedish "Älgförvaltningsområden"), registered by the County Administrative Boards (CABs). The moose management areas are delimited by natural or anthropogenic barriers. Moose management areas should mainly comprise of its own moose population so that management can account for regionally aspects in terms of large predators, traffic, and browsing damage costs. Each moose management area consists of several moose management units (in Swedish "Älgskötselområden"), which are all registered by the CABs. The elected moose management groups in each moose management area are obliged to set and revise a three-year management goal of the local moose population to consult with moose management units and to coordinate population censuses and hunting. Each moose management unit is further divided into several hunting teams (in Swedish "Jaktlag") or game management areas (in Swedish "Viltvårdsområden"), which are the lowest levels of cooperative hunting in Sweden. Similar shifts in management responsibility have been applied for Norway, but instead of counties the main responsibility and decision-making regarding harvest and population goals today lies at the municipality level. Norwegian municipalities license moose management areas (in Norwegian "Vald") for the holders of hunting rights to hunt moose with quotas based on a management plan. These moose management areas are divided into smaller units (in Norwegian "Jaktfelt"). Hunting statistics are reported at this level, however, the spatial extent of this lowest spatial level was not available in digital form and was therefore not included in the study.

The harvest data consist of a retrospective dataset of number of moose harvested recorded at three management levels. In 2012, the Swedish parliamentary decided to change the Swedish moose management system towards a more adaptive and ecosystem-based system (Swedish government, Prop. 2009/10:239). To maintain a uniform dataset, harvest was delimitated by the period 2012–2020 in this study. Moose harvest data are reported annually for each moose management area ("Älgförvaltningsområden") (henceforth level 1) and moose management units ("Älgskötselområden/Vald") (henceforth level 2). These data, together with correlative ESRI shapefiles, were retrieved from Swedish CABs and from the database "Älgdata" (www.algdata.se). Norwegian harvest data for level 2 was retrieved from Norwegian Environmental Agencys' database "Hjorteviltregisteret" (www.hjorteviltregisteret.no). Aiming to also include data of the lowest level of cooperative hunting, i.e., hunting team areas ("jaktlag") and game management areas ("Viltvårdsområden") (henceforth level 3), the

Swedish Association for Hunting and Wildlife Management and private hunters was contacted, and some data for game management areas was collected from Swedish forestry companies database "Jaktrapport" (www.jaktrapport.se). The harvest data included the total number of moose harvested and the size of the hunting unit. Management units were retrieved as ESRI shapefiles or paper maps that were then digitalized and georeferenced in QGIS (v.3.24.2 'Tisler').

Areas of wind power and hunting

Wind power data were retrieved from Swedish CABs online database "Vindbrukskollen" and Norwegian Water Resources and Energy Directorates' online map service. Wind power parks (hereafter WP) established during 2014-2018 were used to delimitate which hunting areas to include in the analysis of level 2 and level 3. This temporal range allowed enough hunting data from two phases of WP-establishment and resulted in 23 WP distributed over the study area (Figure 2). The two phases of WP were classified categorically as *construction phase* (Establishment date - 1 year) or *operative phase* (all years past establishment date) (Table 1). The specified date of establishment, henceforth ED, varies between different production companies in the sense that the date may relate to different events in time. ED can relate to the day when: 1) the turbine is in place and is verified by the operator, 2) the operator announces that the entire project is commissioned, 3) the project is commissioned and handed over to the customer, or 4) start date for the allocation of electricity certificates (i.e., the day the wind turbine energy goes out to the power grid). Hence, the specified ED must be regarded as a rough approximation.

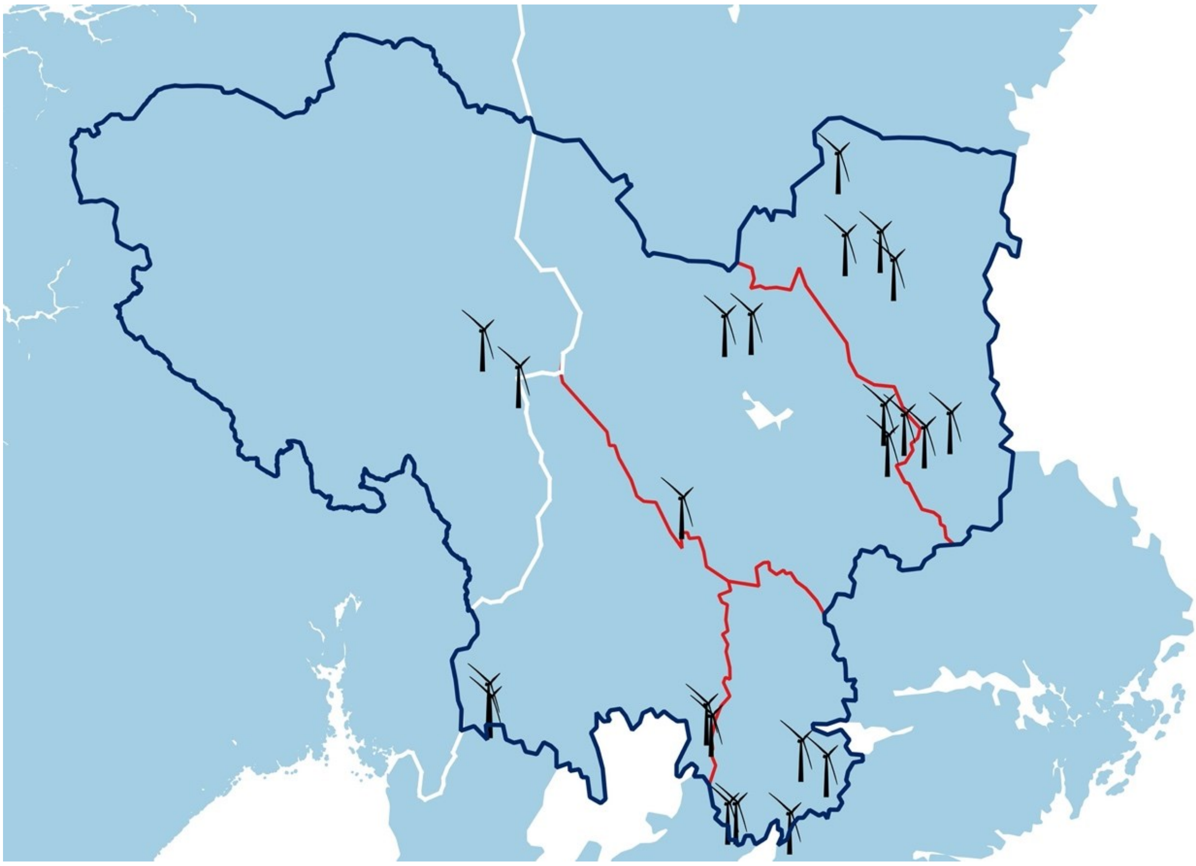

Figure 2. *Wind power parks included in the study were delimitated by study area and establishment dates during 2014 – 2018. This selection generated a total of 23 wind parks distributed across five counties in Sweden (Dalarna, Gävleborg, Värmland and Örebro counties) and Norway (Innlandet county). These wind parks were used to delimitate management units of level 2 and level 3 to include in the analysis. Each turbine in this map represents a wind park which often consists of several turbines. Blue line show study area, white line is country border and red line delimitates Swedish counties.*

Previous studies have found effects on reindeer and moose up to 5 km from the wind power establishments (Skarin et al. 2015; Berndt 2021). Therefore, for each WP establishment, a 10 km intersecting radius from the WP center point was used to delimitate the management units of the two lower spatial resolutions, i.e. level 2 and level 3. Information available for each WP include center point location, turbine height, number of turbines and ED.

Numbers and distances to WP were dealt differently at the three management levels (Table 2, Figure 3). For level 1, the total number of turbines within the management unit was counted for each year. For level 2 and level 3, the total number of turbines in all WPs within a 10 km radius from each hunting area and hunting year were calculated. For these two levels, I also calculated the distance to the closest WP, number of turbines in the closest WP, and height of the closest WP. In case the closest WP was located within the border of the management units, distance was set to zero.

Table 1. *Number of hunting years for level 2 (Moose Management Units) and level 3 (Hunting team areas and Game management areas). during construction and operative phase divided into 3-year periods. Wind park establishment date was used to categorize the different phases of wind power parks. Construction phase was set to start 1 year before establishment date. Operative phase was defined as all years past establishment date.*

	Level 2			**Level 3**		
	2012-2014	2015-2017	2018-2020	2012-2014	2015-2017	2018-2020
Construction phase	44	63	12	63	99	33
Operative phase	0	87	161	0	97	214

Table 2. *Minimum, 1st Quantile, mean, 3RD Quantile and maximum area and sample size (N) of the three management levels (Level 1 (Moose Management Areas), Level 2 (Moose Management Units) and Level 3 (Hunting team areas and Game management areas)) included in the study of effects from wind power establishment on moose harvest in Sweden and Norway, 2012-2020.*

	Area (ha)					
	Min.	**1st Qu.**	**Mean**	**3rd Qu.**	**Max.**	***N***
Level 1	25460	126558	210994	250484	583726	41
Level 2	1478	12118	38561	44621	191289	66
Level 3	121	1135	3117	4173	15211	83

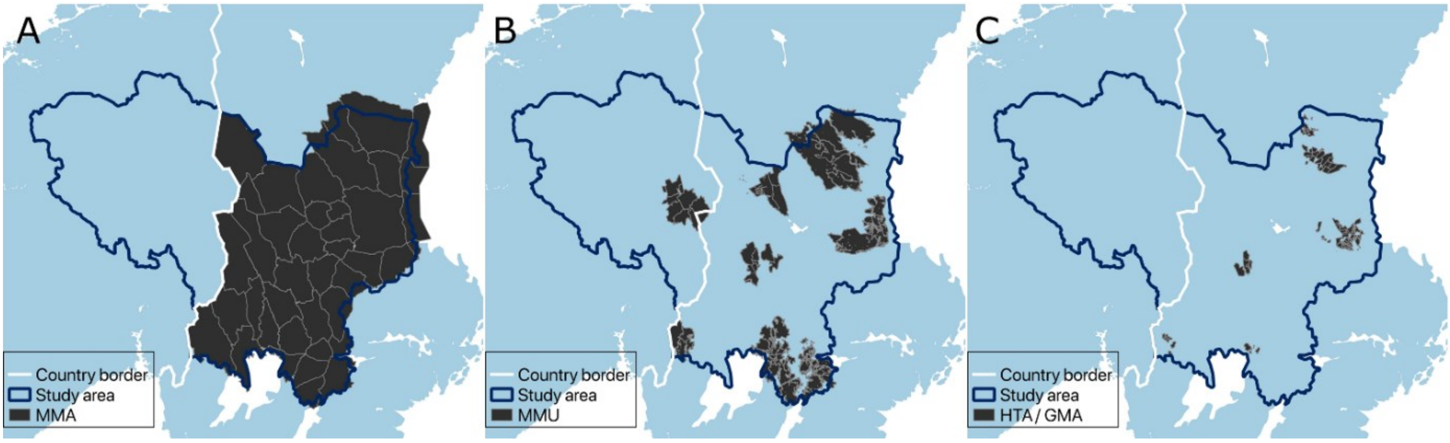

Figure 3. *Size and spatial distribution of moose management levels in Sweden and Norway 2012–2020 included in the study* ***A)*** *Level 1 (Moose Management Areas)* ***B)*** *Level 2 (Moose Management Units) and* ***C)*** *Level 3 (Hunting team areas and Game management areas).*

Occurrence of wolves and brown bears

The cross-border Scandinavian population of wolves is annually monitored from October to March by Swedish CABs, Norwegian Nature Inspectorate (SNO) and Inland Norway University of Applied Sciences with joint guidelines and instructions (Åkesson et al. 2022). To account for wolf occurrence, results from the annual monitoring, mainly based on snow tracking and DNA-collection, were used to distinguish established territories of wolf family groups and scent-marking pairs during the period 2012–2020. Applying the same approach as Wikenros *et al*. (2020), geographical centroids and an 18 km radius were created for all territories annually. This area represents the average size of Scandinavian wolf territories (1000 km^2) (Mattisson *et al.* 2013). An index of territory probability ranging between 1 and 0 (Figure 4A) was made based on the assumption of non-linear use of territory, where 1 represents the center of a territory and zero is outside of the territory. As wolves concentrate space use to core areas and use other parts of the territory to a lower extent, a parabolic decrease was used outwards the radius (Ciucci *et al*. 1997; Wikenros *et al.* 2020). As wolf monitoring is only conducted during winter, it was not possible to determine the timing of any changes in wolf territories in between seasons. Therefore, a wolf territory density-index was created from the mean of two consecutive winters, e.g., wolf territory density-index for 2012 is the mean of 2011 and 2012. Estimated territories were not allowed to overlap to account for density-dependence in terms of territorial behavior of wolves. In lack of territory borders from the annual wolf monitoring in Scandinavia, this approach provides comparative estimates on wolf territory density (Wikenros *et al.* 2020).

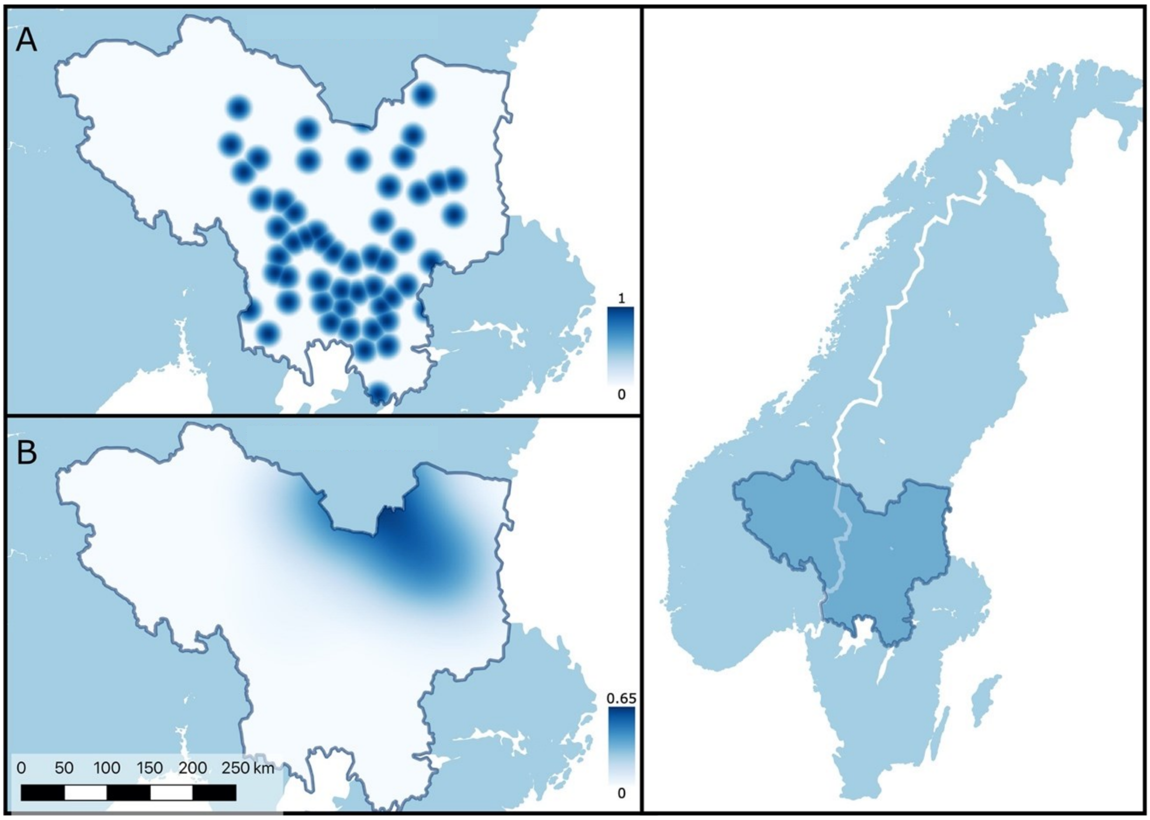

Figure 4. ***A)*** *Wolf territory density-index estimated from annual territories in the study area counted as a parabolic-shaped decreasing probability from territory center to an 18 km buffer, representing the average size of wolf territories in Scandinavia (Mattisson et al. 2013).* ***B)*** *Brown bear occurrence in the study area estimated from 1x1 km kernel density based on annually reported dead brown bears. Example given for the year 2012.* The right map shows the study areas extension in Sweden and Norway.

Since the brown bear population is not annually monitored, an alternative approach was used to estimate bear occurrence in the hunting areas based on data of dead brown bears registered during 2012–2020 (www.rovbase.no). Causes of death could be either license hunt or protective hunt. A raster of 1x1 km resolution based on the annual number of dead bears was used to create a Kernel density estimate of brown bear occurrence (Figure 4 B). For each management unit and year, a mean value of bear occurrence was extracted from the raster.

Environmental and anthropogenic covariates

Latitude of hunting areas, calculated from the centroid of each hunting area, was included to account for any latitudinal gradient effects on moose harvest. To account for the effect of anthropogenic landscape features, road density and proportion of young forest stands were included as covariates. Two types of road categories were included in the study: gravel roads and paved roads. Road data were collected from 1:100 000 GSD-roadmap (Lantmäteriet, Sweden) and N50 kartdata (Statens Kartverk, Norway). This data was quantified as density (km/km^2) of paved roads and gravel roads within hunting areas at the three levels. Accumulated forest loss per hunting area, management level and year from the last 12 years was included as measure of proportions of young forest stand. The online open data source service Global Forest Watch (GWF, www.globalforestwatch.org) was used to extract data on annual forest loss for the period 2012–2020. Based on Landsat imagery, GWF records and quantified loss and gains of forest cover, i.e., areas with ≥ 25 % canopy cover of ≥ 5 m stand height. The resolution of images used for in the dataset is approximately 30 meters. Each cell is valued either 0 (no loss) or o 1-22 (representing loss in a specific year 2001-2022. Eventhough all kinds of canopy loss is recorded, including wild fires and storms, this dataset has proven to be a useful measure in terms of forest logging with high overall accuracy in Scandinavian boreal system (Rossi *et al.* 2019).

Statistical analyses

The statistical analyses were conducted in R (R Core Team (2021). For each management level, linear mixed regression models in R package ‘lme4’ (Bates et al. (2015) were used to analyse correlations of the covariates on moose harvest. For level 1, harvest density (moose/1000 ha) was the response variable. The response variable for level 2 and level 3 was calculated as the difference in harvest density (moose/1000 ha) between level 1 and the geographically smaller level 2 or level 3. A difference in harvest density = 0 indicates the same harvest density, harvest difference > 0 indicates a larger harvest density and harvest difference < 0 indicates a lower harvest density compared to the corresponding higher level of management unit. By doing this, the response variable at the lower two levels accounts for regional differences in terms of e.g. management goals decided in moose management areas and moose densities.

For level 1, a 3-year categorical covariate (2012–2014, 2015–2017, 2018–2020) was used to detect possible temporal changes. Numerical covariates included for level 1 were occurrence of wolf and brown bear, gravel road density, paved road density, 12-year accumulated forest loss and total number of WP turbines within the management areas. For level 2 and 3, management areas were included during the years when the closest WP was either in construction phase or operative phase. Numerical covariates for level 2 and 3 included the distance to closest WP, height of turbines in closest WP, number of turbines in closest WP, WP-phase (construction/operative), brown bear occurrence, wolf occurrence, gravel road density, paved road density and 12-year accumulated forest loss. For level 2 and 3, candidate models also included interactions between WP phase and the other WP characteristics: height, distance, and number of turbines. This was due to my assumption that WP phases would generally differ in range and in terms of disturbing activities in relation to the number and height of turbines in the WP.

For all levels, I tested for correlation between numerical covariates through Pearson correlation tests in R-package ‘ltm’. These were gravel road density – paved road density, bear occurrence – latitude, and gravel road density – forest loss. Covariates were considered correlated at values $-0.6 \leq \rho \leq 0.6$ In cases where a significant correlation between covariates was detected, I chose only to include the one of best fit for models by comparing second order Corrected Akaikes Information Criterion (AICc) values for each model. The AICc was as well used to determine whether Year or Management unit ID was the best random variable for level 2 and level 3 (lowest AICc value). For level 1, management unit ID was used as random variable since a 3-year category was included as covariate.

Regression models were weighted with the size of the management unit as small units are more susceptible to random changes from year to year. AICc was further used to determine the highest ranked model (lowest AICc value) from a set of candidate models (listed in Table S2) for each management level. I applied a 0.05 threshold in probability value to determine significance of correlation. Correlations with p-values between 0.05 and 0.1 were considered tendency of correlation.

Results

Level 1 - Moose management area

A total of 154,805 moose were harvested in the 41 moose management units during 2012–2020. Pearson correlation tests indicated significant correlation between latitude and brown bear density, paved road density and gravel road density as well as gravel road density and forest loss. Models on harvest density including the covariates gravel road density and brown bear density resulted in lower AICc-values than corresponding models including forest loss, paved road density and latitude. AICc-values also indicated that using hunting area ID as random variable resulted in a better model fit than to use year as random variable.

Highest ranked model of harvest density for level 1 included the 3-year category (2012–2014, 2015–2017, 2018–2020), wolf occurrence, brown bear occurrence, gravel road density, and number of turbines within the hunting area (Figure 5, Table S2). Moose harvest density varied significantly between the 3-year periods. Wolf ($p < 0.01$) and brown bear ($p < 0.01$) occurrences had both a significant negative correlation on the harvest density. Gravel road density ($p = 0.01$) showed instead a significant positive correlation. The total number of WP-turbines ($p = 0.085$) indicated a tendency of a negative correlation.

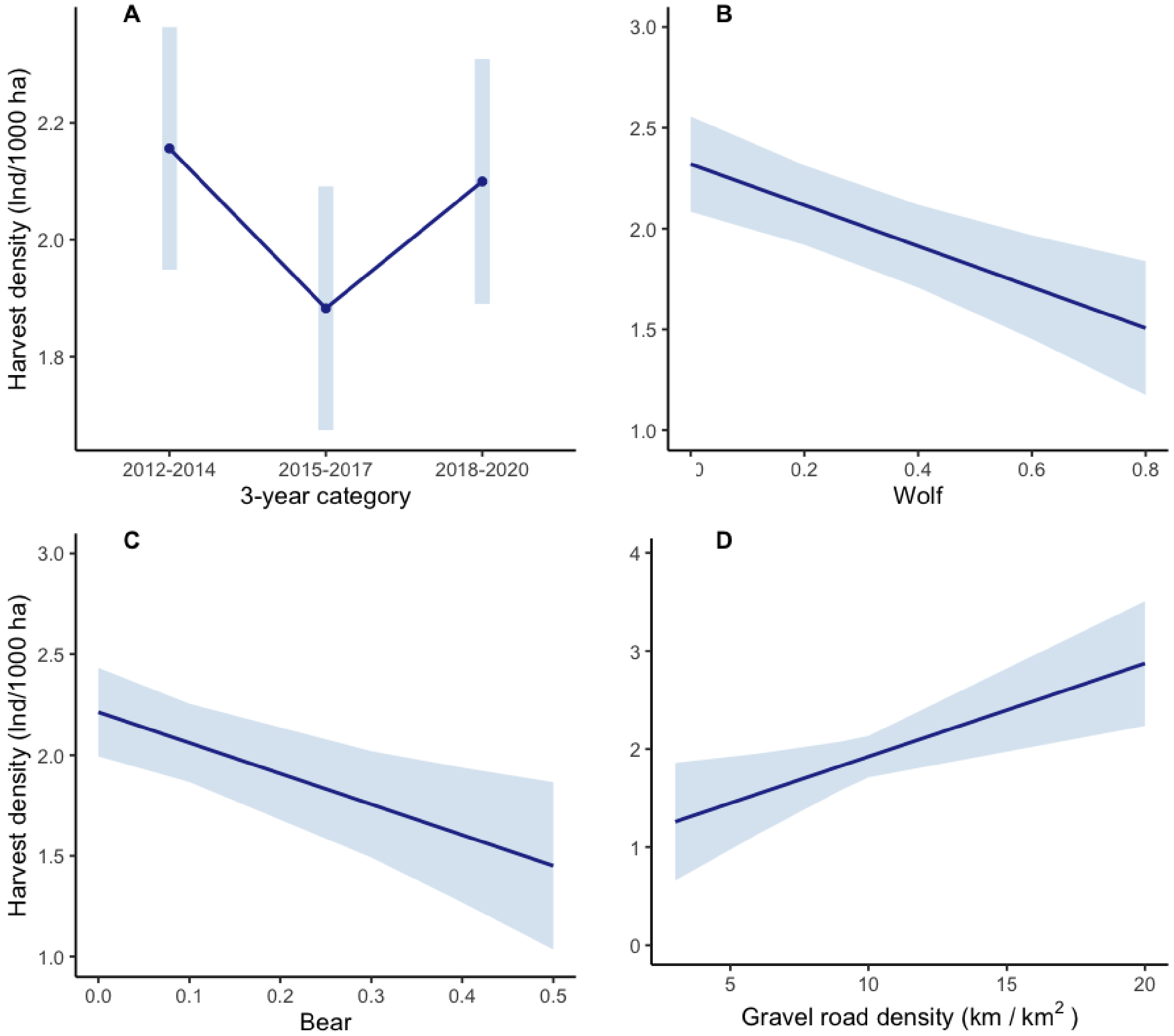

Figure 5. *Correlation plots for highest ranked model on moose harvest density in level 1 (Moose management areas 'Älgförvaltningsområden'). **A)** Harvest density varied between all 3-year categories. **B)** Wolf occurrence and C) brown bear occurrence was negative correlation with moose harvest density, and D*) Gravel road density was positively correlated with harvest density.

Level 2 - Moose management unit

A total of 30,267 moose were harvested in the 66 management units at level 2 during the years when closest WP were in construction- or operative phase. Similar to level 1, Pearson correlation tests showed a positive correlation between latitude and brown bear occurrence. Models on harvest density including brown bear occurrence resulted in lower AICc-values than models including latitude. AICc-values also indicated that using hunting area ID as random variable resulted in better model fit than to use year as random variable.

Mean difference in moose harvest compared to level 1 was 0.54 (± 0.93 Std. Dev) during construction phase and 0.62 (± 1.16 Std. Dev) during the operative phase of wind parks. Thus, the harvest density for management units in level 2 was generally much higher than the average harvest densities in corresponding level 1 (Figure 6).

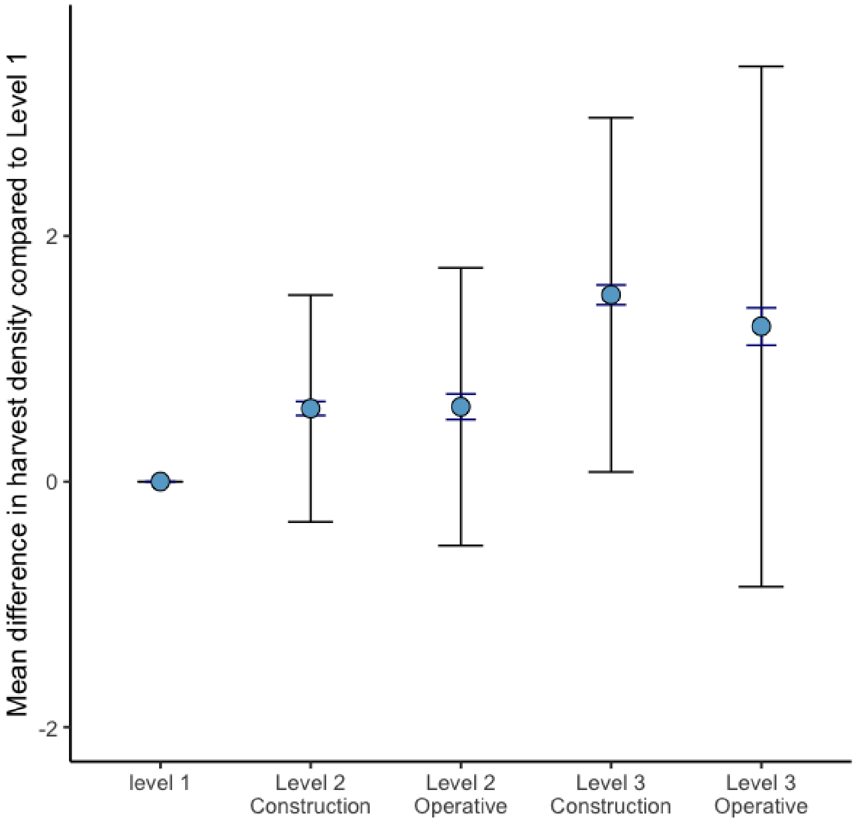

Figure 6. *Mean difference in harvest density in level 2 (Moose management unit) and level 3 (Hunting team areas/Game management areas) compared to the reference level (level 1, Moose management area) harvest density. Mean values for both spatial levels during wind park construction- and operative phase were above 0, indicating that the average management units included in this study harvested more moose than the corresponding moose management area at level 1. Blue bars show Standard Error, black bars show Standard Deviation.*

Highest ranked model for explaining temporal variation in harvest density at level 2 included wolf occurrence, proportion of young forest stand, the number of turbines in the closest WP and the interaction between phase of closest WP and distance to closest WP. Wolf occurrence ($p = 0.03$) and number of turbines in closest WP ($p = 0.03$) showed a significant negative correlation with the difference in moose harvest density. The 12-year accumulated forest loss had a significant positive correlation with the difference in harvest density (p = 0.2). Distance to closest wind parks had a significantly positive correlation (p = 0.02) with differences in harvest density during construction phase, but not during operative phase (p = 0.14) and the correlation was stronger during the construction phase than the during the operative phase (Figure 7, Table S3).

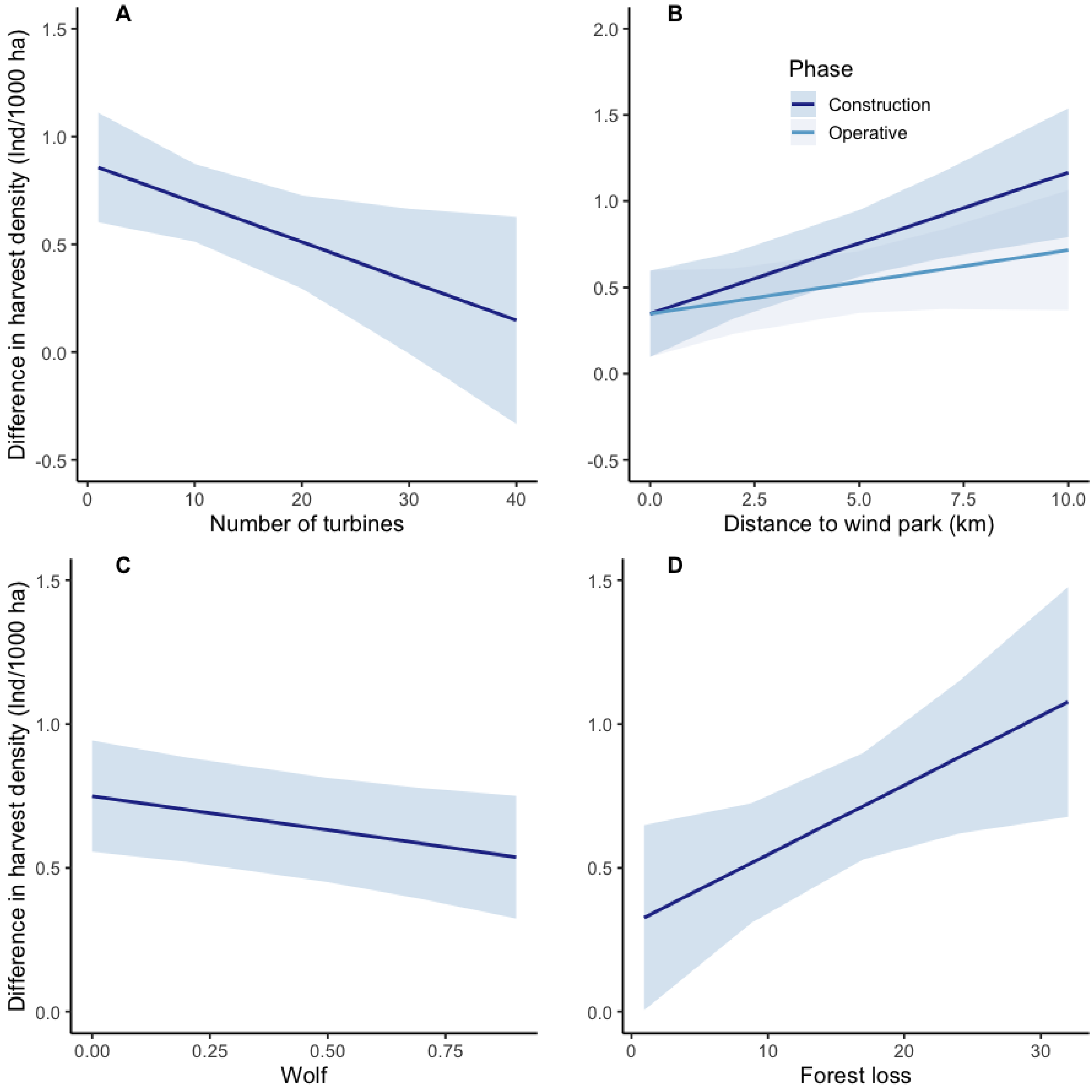

Figure 7. *Correlation plots for highest ranked model on moose harvest density in level 2 (Moose management unit).* ***A)*** *Number of turbines was negatively correlated with difference in harvest density* ***B)*** *Distance to wind parks was positively correlated with difference in harvest density, this correlation was stronger in the construction phase, and non-significant during operative phase.* ***C)*** *Wolf occurrence was negatively correlated with difference in moose harvest density.* ***D)*** *12-year accumulated forest loss was positively correlated with differences in moose harvest density.*

Level 3 – Hunting team areas and Game management areas

For the smallest management units (level 3), data collection resulted in 83 units with a total sample size of 506 hunting years and 4140 moose harvested during the closest WPs construction- and operative phases. Pearson correlation tests indicated a significant correlation between latitude and brown bear. Neither gravel road density and forest loss nor gravel road density and paved road density were correlated. Models including brown bear density resulted in lower AICc-values than models including latitude. AICc-values also indicated that using hunting area ID as random variable resulted in better model fit than using year as random variable.

Mean difference in harvest density compared to level 1 was 1.52 (± 1.44 Std. Dev) during construction phase and 1.26 (± 2.11 Std. Dev) during the operative phase of wind parks (Figure 6). The highest ranked model for level 3 included paved road density, phase of wind park in interaction with turbine height and phase of wind park in interaction with number of turbines (Table S4). Model results show that turbine height had a significantly ($p < 0.001$) negative correlation with the difference in harvest density during the construction phase, but this correlation was non-significant ($p = 0.31$) during the operative phase. Number of turbines showed a significant ($p < 0.001$) positive correlation with difference in harvest density during construction phase, and a significant ($p = 0.03$) negative correlation during the operative phase (Figure 8). Paved road density tended to have a weak negative correlation ($p = 0.09$). Wolf and brown bear occurrence were not included in any of the top ranked models, and gravel road density was not included in the overall best model.

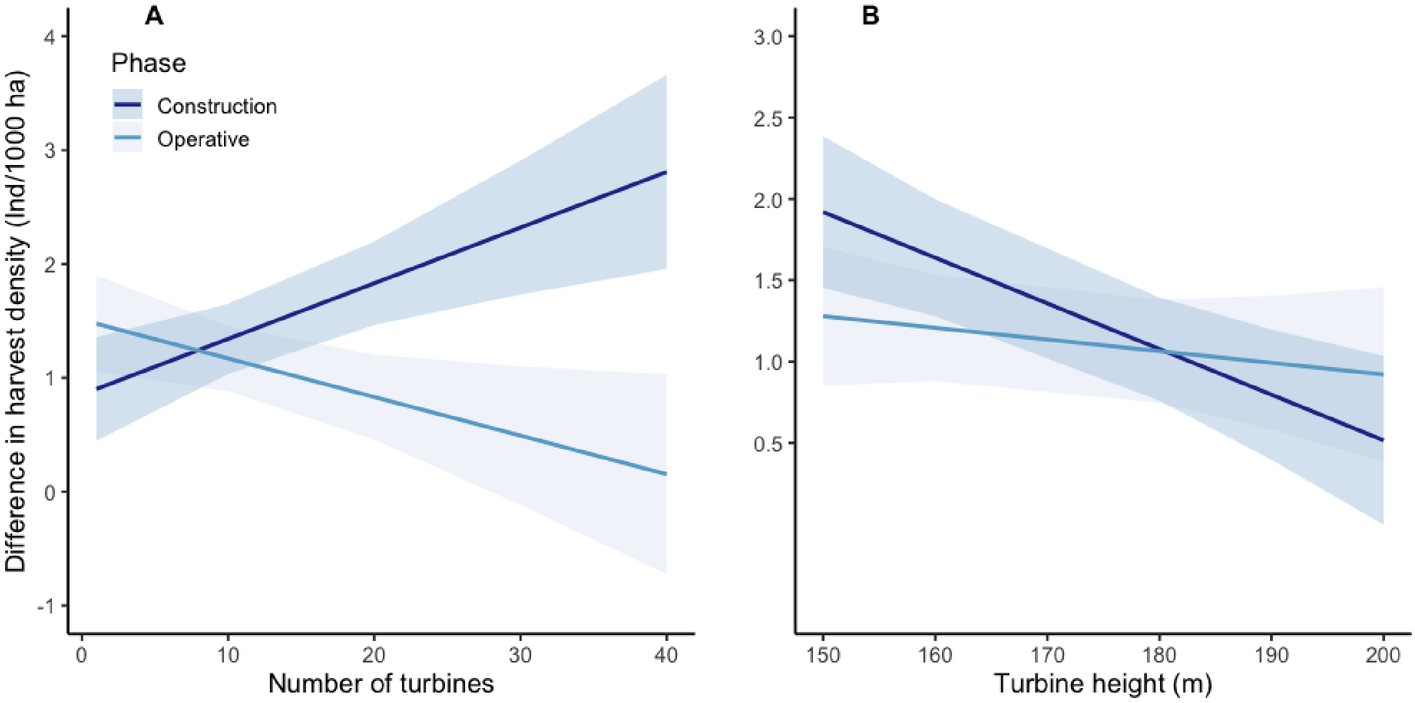

Figure 8. *Correlation plots for the highest ranked model on difference in moose harvest density in level 3 (Hunting team areas/Game management areas)* ***A)*** *Number of turbines was positively correlated with difference in harvest density during construction phase, and negatively correlated during operative phase.* ***B)*** *Turbine height was negatively correlated during construction phase, but non-significant during operative phase.*

Discussion

Predictions

My prediction of moose harvest densities being positively correlated with gravel road densities and proportion of young forest stands (P1) was met for level 1 where gravel road density was included in the best model, and for level 2 where young forest stands was included in the best model. None of these covariates were included in the best model of level 3.

Model results further show that increased distance to wind parks resulted in a positive correlation with moose harvest at management level 2. The correlation was significant during the construction phase but not during the operative phase, which corresponds with my prediction (P2). Distance was not a significant covariate in level 3.

The prediction of harvest being negatively affected by increased turbine height and numbers (P3) was met in level 2 and level 3, with a significant correlation from number of turbines. In level 3 however, the correlation was positive during construction phase and did not correspond with my prediction. Turbine height was included for level 3 and as predicted was negatively correlated to harvest density.

My prediction of wolf and bear occurrence having a negative effect on moose harvest (P4) was met for level 1 and partly for level 2. Brown bear occurrence was included in the best model for level 2. For level 3, none of the predatory covariates were included in the best model.

Temporary effects during WP construction phase

Varying effects of turbine characteristics and distance to turbines could either be explained by moose avoiding turbines and associated infrastructures as previously been shown (Berndt, 2021), or a hunter-driven response to wind turbines, e.g. lowered harvest effort near wind turbines. Previous studies have found logging and roads causing behavioral responses of moose to human activity (Eldegard et al. 2012; Gagnon et al. 2023). A temporary increase of human associated disturbance is likely to also be a driving effect regarding lowered harvest density during wind park construction. The effect of disturbances to moose and/or hunters is likely to be largest during the construction phase of wind parks, when increased traffic, deforestation and assembly work occur. Moose have previously been shown to lower their activity and select for forested areas while avoiding infrastructures near turbines, which may also contribute to reduced harvest (Berndt, 2021). However, it is also possible that moose hunters reallocate hunting efforts away from wind park constructions as the turbines or associated activity may be perceived as disturbing, visually or audibly.

For the construction phase of WPs, the results for level 3 showed that the number of turbines was positively correlated with harvest density during construction phase, a somewhat surprising result opposite to my prediction (P3). Possible explanations to this could have been the result of an associated increase in deforestation or gravel roads, which can temporarily increase leaf-bearing shrubs and young trees, an appreciated nutrition to moose. Meanwhile, hunters can make use of these clear view fields or roads during the hunt. Since neither forest loss nor gravel road density were included in the best model of level 3, the effect is however more likely to be a response from moose or hunters to the WP itself. An alternative explanation may therefore be found in the limitations of areas suitable both for moose and hunting. Wind power turbines require extensive space and are often positioned several hundred meters apart in order to be effective. Wind parks may therefore theoretically occupy areas from a few hectares up to a couple of thousand hectares, which may well affect a large portion of the hunting ground in a hunting team area. The mean size of level 3 management areas included in this study was 3100 hectares. It is also likely that disturbance perceived by moose, or hunters, exceeds the actual boundaries of the area covered with wind turbines (Berndt, 2021).

If hunters and moose avoid areas near wind parks during construction phase due to perceived disturbance, the areas suitable for both moose and hunting teams are locally reduced and may therefore potentially increase chances of moose-hunter-encounters during the hunt, which could explain the temporary positive correlation on harvest density during construction phase. The negative effect during the operative phase however needs an alternative explanation. This is potentially the result of either moose or hunters perceiving operative wind turbines as disturbing, visually or audibly. If only one party – moose or hunter – returns to the areas near wind park after construction, the chances of moose-hunter-encounters during the hunt would decrease. Based on this hypothetical explanation, the effect of WP establishment on moose harvest could be a function of WP size, size of the management areas, and proportion of the management area being affected by the perceived disturbance for moose and hunters. This explanation comes with the prerequisites that 1) Moose and hunters both avoid wind parks during construction phase, and 2) Either moose or hunters return to the areas near wind parks during the operative phase. The reason that this temporary effect could only be observed in the smallest management level likely has to do with the proportion of the affected management units being too small in larger management levels.

For level 2 and level 3, the negative correlation of height and positive correlation of distance to harvest density was significant during construction phase but not during operative phase. This could be explained by a stronger disturbance during construction phase for moose or hunters, causing avoidance that results in lowered harvest, as predicted (P2, P3). Difference in turbine height is less prominent at larger distances, thus, only moose harvest close to the WP area is being affected by higher wind turbines, potentially explaining why height was included in the best model for level 3 but not for level 2. Based on these two covariates, the strongest negative impact on moose harvest would theoretically occur near WP with high wind turbines during construction phase.

My results further show that increased distance to wind parks resulted in a positive correlation with moose harvest at management level 2. This correlation was significant during the construction phase but not during the operative phase. Yet again, the phase-dependent effect suggests that this was mainly due to construction rather than the drift of wind turbines.

Effects from predator occurrence, road densities and forestry

Predatory covariates of wolf and brown bear occurrence had considerable effects on moose harvest density in level 1, which corresponds well with previous studies (Rauset et al. 2012; Wikenros et al. 2015; Wikenros et al. 2020) and my prediction (P4). Wolf also had a significant effect on moose harvest in level 2. The observed effects are explained by wolves and brown bears being the primary predators on moose, with additive effects where both predators occur (Tallian et al. 2021). Hence, wolf and brown bear are the largest competitors to moose hunting harvest. The negative effect of predators, especially wolves, may also be a result of hunters' response. Moose hunters might in some cases relocate the hunting effort to areas with lower wolf density or change to less effective hunting methods to minimize the risk for hunting dogs to be injured by wolves. Effects of wolf or brown bear was not seen in level 3. The explanation to this is likely that wolves and brown bears use larger areas, and that predatory effects therefore are 'spread out' across different management units. Mean size for wolf territories in Scandinavia is 1000 km^2 (Mattisson et al. 2013), mean size for management level 3 included in this study was ~31 km^2, whereas mean size for level 1 and level 2 were ~2100 km^2 and ~ 385 km^2. Another explanation might be that the WP establishment could negatively correlate with wolves and brown bears through perceived disturbance, reducing their occurrence in smaller management units near WP establishment. Wolves have indeed previously been shown to avoid areas of WP construction in Portugal (Ferrão da Costa et al. 2018).

Moose occurrence and densities have been shown to be positively correlated with Scots pine and young forest stands (< 30 years) but to decrease in proximity to gravel roads (Månsson, 2009; Ausilio et al 2021). In this study, young forest stand was considered as 12-year accumulated forest loss (due to lack of longer data series of forest loss). For level 1, this variable was correlated with gravel road density and therefore not included in the candidate models. Possibly, the negative effect of gravel road is smaller than the positive effect of forest stands and as easily accessible and overviewed hunting ground, resulting in the net positive correlation displayed in gravel road density-variable. For level 2, young forest stands had a significant positive correlation with moose harvest, in line with previous studies (Månsson, 2009). These types of areas have a positive effect on moose harvest and good overview for hunters to spot and shoot moose (Månsson, 2009).

Further studies

Still, the scientific area regarding WP establishments effect on terrestrial organisms is scarce. More and wider knowledge is needed to evaluate the effects and potential consequences that extended onshore WP establishments can have on terrestrial wildlife as well wildlife management of important game species like moose.

Further studies should focus on determining whether the observed effects from wind power establishment on moose harvest are due to responses in moose behavior, in hunters' behavior, or in both. Moose have been found to be less active near wind turbines, within a threshold of 5,000 meters (Berndt, 2021). This could imply that moose are not affected by wind turbine occurrence, since they did not increase their movement rates in proximity to them (Berndt, 2021). Another study, however, has shown decreased movement rate in another large ungulate, elk (*Cervus elaphus*), and higher selection for safer areas, when human hunting was allowed during fall, suggesting a cautious adaptation (Paton et al. 2017). Therefore, a preferable approach for future studies would be a combination of interview studies with hunters and GPS-tracking of moose in areas near forthcoming wind parks or already operative wind parks. It would be especially interesting to use the outcome of such studies to examine my previously discussed theory of WP in operative phase giving rise to diverging allocation of moose and hunters, resulting in lowered moose harvest at the lowest management level 3.

Further, upcoming studies should ideally account for moose management goals, to see if harvest is intentionally lowered over time or not. If harvest goals are not achieved despite hunters' commitment to do so, the response of wind park establishment is likely to be related to moose rather than hunters.

An improvement of this analysis could be an alternative way to account for WP turbine density on the landscape level. This could be done by creating an index of WP-turbines, similar to the index used for wolf and bear occurrence in this study. This would probably have given more comparative results between level 1 and the two lower levels. It would be a good idea to construct such density index for construction and operative phase independently since the different phases were shown to have different effects on moose harvest.

Conclusions

Effects on moose harvest are elementary information for moose management and browsing damage reduction. In this study, I show that wind power characteristics and location can have a reducing effect on moose harvest, which is an important leisure activity for people on the countryside. Reduced harvests also risk increasing browsing costs for forestry and moose-vehicle collisions. It is crucial to understand the effects of onshore wind power establishment on moose and moose hunting for the green transition to be ecologically and socially sustainable. Deficient knowledge when evaluating a locations suitability for wind parks and other energy-source establishment can potentially cause distrust of green alternatives to fossil fuels and hinder important climate actions.

Acknowledgment

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Lastly, I would like to thank my family, especially my mom for being the best grandmother to Gillis. Without your support, I would not have had the possibility to finish this report. And Ylva, thank you for sharing the adventure of parenthood and life with me. With you, every day is the best!

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Additional sources of data or information

Hjorteviltregistret (Norwegian national database of data from ungulate hunting).

Viltdata (Swedish association for hunting and wildlife management database for statistics of hunting and harvest data).

Älgdata (Swedish County administrative boards website with maps, information, and statistics regarding Swedish moose management and hunting).

Jaktrapport (Swedish forestry companies database and report system for hunting and harvest statistics).

Swedish meteorological institute (National institute of meteorology in Sweden)

Norwegian meteorological institute (National institute of meteorology in Norway)

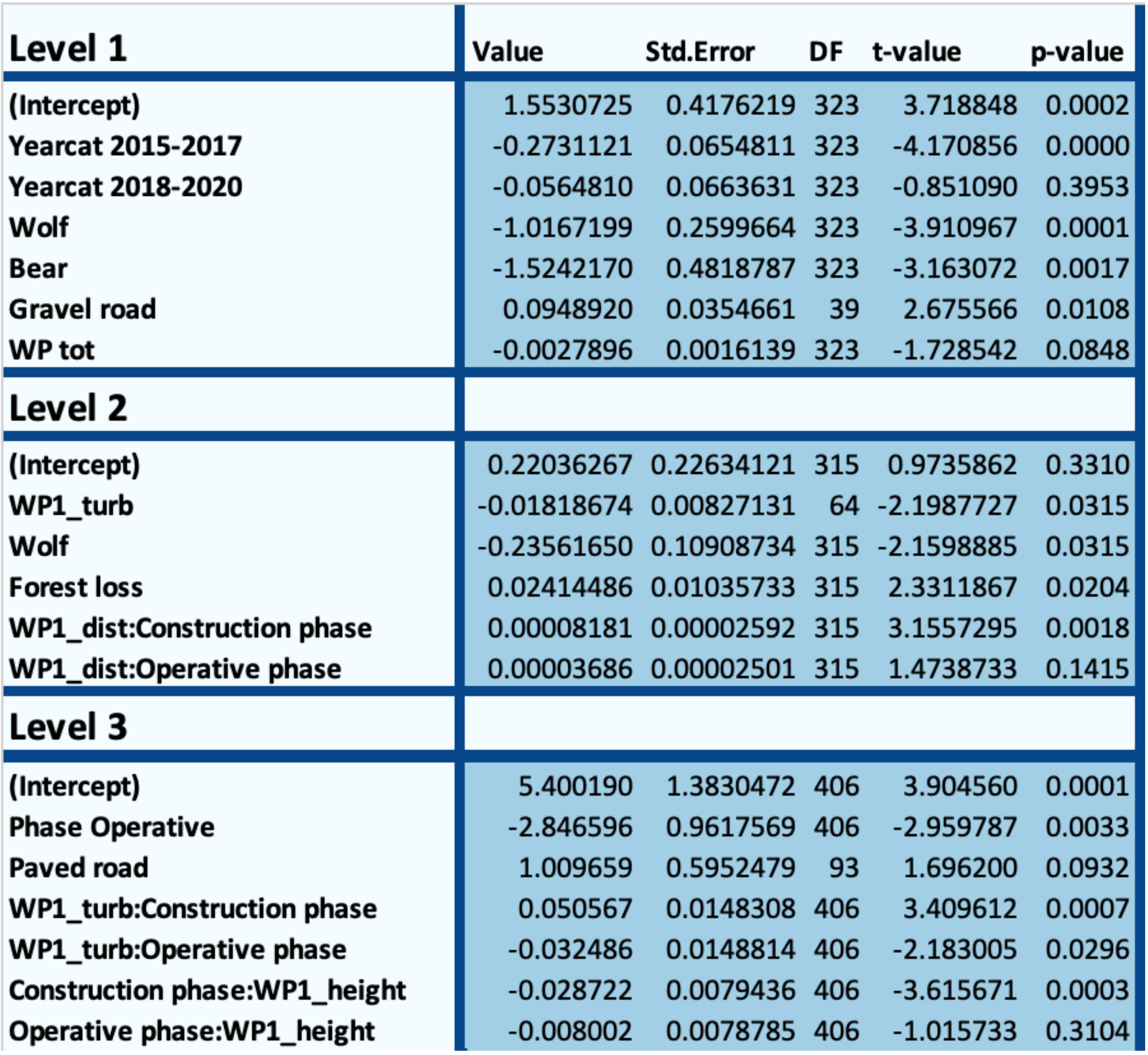
Vindbrukskollen (Swedish County administrative board interactive map of wind power parks)

Statistics Sweden (official statistics of Sweden)

Statistics Norway (official statistics of Norway)

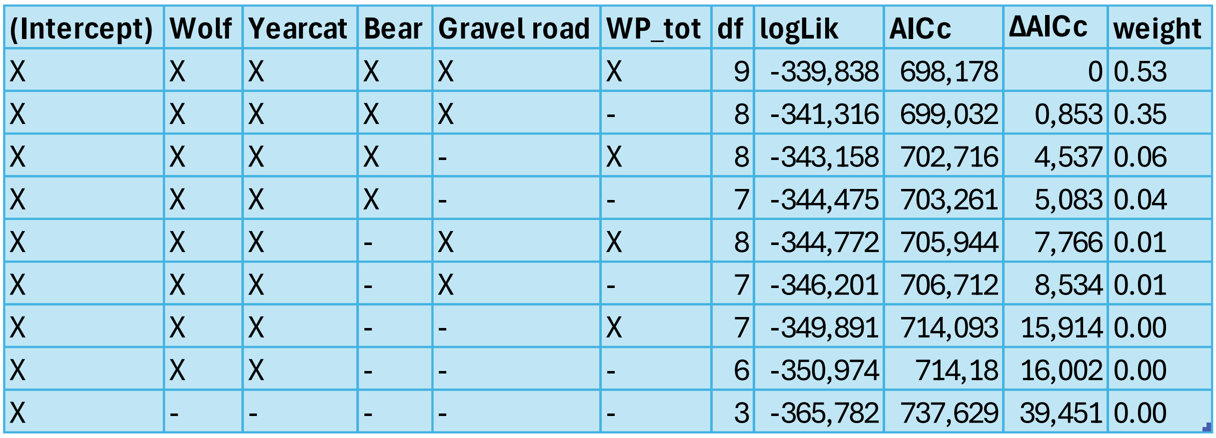
Supplementary material

Table S1. Summary of the best models used to explain harvest density (moose/1000 ha) for level 1 and difference in harvest density (Δ Moose/ 1000 ha) for level 2 and level 3 compared to level 1. In analysis of level 1, Wolf occurrence was measured as the average wolf territory density of the management units for the last two consecutive years. Bear occurrence was estimated as Kernel density estimates from data of dead bears during the period 2012-2020. Gravel road density and paved road density was measured as kilometers per kilometer^2. Forest loss was 12-year accumulated forest loss for each management unit as measure of young forest stand. WP tot in level 1 was the total number of turbines within the management area. WP1_turb, WP1_dist and WP1_height at level 2 and level 3 was the number of turbines, distance to, and height of turbines in the wind park closest to the management unit. Operative phase was all years after the closest wind parks date of establishment. Construction phase was the year prior to date of establishment. All models were constructed with function LME with management unit ID as random variable and weighted with the inverted areal of management unit = I (1 / areal)



Level 1	**Value**	**Std.Error**	**DF**	**t-value**	**p-value**
(Intercept)	1.5530725	0.4176219	323	3.718848	0.0002
Yearcat 2015-2017	-0.2731121	0.0654811	323	-4.170856	0.0000
Yearcat 2018-2020	-0.0564810	0.0663631	323	-0.851090	0.3953
Wolf	-1.0167199	0.2599664	323	-3.910967	0.0001
Bear	-1.5242170	0.4818787	323	-3.163072	0.0017
Gravel road	0.0948920	0.0354661	39	2.675566	0.0108
WP tot	-0.0027896	0.0016139	323	-1.728542	0.0848
Level 2					
(Intercept)	0.22036267	0.22634121	315	0.9735862	0.3310
WP1_turb	-0.01818674	0.00827131	64	-2.1987727	0.0315
Wolf	-0.23561650	0.10908734	315	-2.1598885	0.0315
Forest loss	0.02414486	0.01035733	315	2.3311867	0.0204
WP1_dist:Construction phase	0.00008181	0.00002592	315	3.1557295	0.0018
WP1_dist:Operative phase	0.00003686	0.00002501	315	1.4738733	0.1415
Level 3					
(Intercept)	5.400190	1.3830472	406	3.904560	0.0001
Phase Operative	-2.846596	0.9617569	406	-2.959787	0.0033
Paved road	1.009659	0.5952479	93	1.696200	0.0932
WP1_turb:Construction phase	0.050567	0.0148308	406	3.409612	0.0007
WP1_turb:Operative phase	-0.032486	0.0148814	406	-2.183005	0.0296
Construction phase:WP1_height	-0.028722	0.0079436	406	-3.615671	0.0003
Operative phase:WP1_height	-0.008002	0.0078785	406	-1.015733	0.3104

Table S2. *Constructed candidate models and null model for the effects on harvest density in level 1 (Moose Management Areas 'Älgförvaltningsområden'), in Sweden (2012–2020) as linear mixed models (LMM). Fixed covariates included wolf occurrence, 3-year category (2012–2014, 2015–2017, 2018–2020), brown bear occurrence, gravel road density and total number of wind turbines within the management unit. Random variable for all models was the ID of the hunting area. Models were weighted with management unit area in hectares. For each model, the table show AICc weight, degrees of freedom (df) and difference in AICc compared to the highest ranked model (ΔAICc).*



(Intercept)	Wolf	Yearcat	Bear	Gravel road	WP_tot	df	logLik	AICc	ΔAICc	weight
X	X	X	X	X	X	9	-339,838	698,178	0	0.53
X	X	X	X	X	-	8	-341,316	699,032	0,853	0.35
X	X	X	X	-	X	8	-343,158	702,716	4,537	0.06
X	X	X	X	-	-	7	-344,475	703,261	5,083	0.04
X	X	X	-	X	X	8	-344,772	705,944	7,766	0.01
X	X	X	-	X	-	7	-346,201	706,712	8,534	0.01
X	X	X	-	-	X	7	-349,891	714,093	15,914	0.00
X	X	X	-	-	-	6	-350,974	714,18	16,002	0.00
X	-	-	-	-	-	3	-365,782	737,629	39,451	0.00

Table S3. *Model selection of constructed candidate models for the effects on difference in harvest density in level 2 (Moose management unit, 'Älgförvaltningsgrupper/vald') for Sweden and Norway (2012-2020) as linear mixed models (LMM). Fixed covariates included distance to closest WP, height of turbines in closest WP, number of turbines in closest WP, brown bear occurrence, wolf occurrence, gravel road density, WP-phase (construction/operative), interaction between WP phase and distance to closest WP, interaction between WP phase and number of turbines in closest WP, interaction between WP phase and turbine height in closest WP, 12-year accumulated forest loss and paved road density. Random variable for all models was hunting area ID. Ranking and selection was based on lowest AICc-values. For each model the table show AICc weight, degrees of freedom (df) and difference in AICc compared to the highest ranked model (ΔAICc)*

(Intercept)	WP1_dist	WP1_height	WP1_turb	Bear	Wolf	Gravel road	Phase	Phase:WP1_dist	Phase:WP1_turb	Phase:WP1_height	Forestloss_long	Paved road	df	logLik	AICc	ΔAICc	weight
X	-	-	X	-	X	-	-	X	-	-	X	-	8	-438,381	893,144	0,000	0.26
X	-	-	X	-	X	-	-	X	X	-	X	-	9	-438,037	894,553	1,409	0.13
X	-	X	X	-	X	-	-	X	-	-	X	-	9	-438,159	894,798	1,654	0.11
X	-	-	X	-	X	-	-	X	-	-	X	X	9	-438,196	894,872	1,728	0.11
X	-	-	X	X	X	-	-	X	-	-	X	-	9	-438,308	895,095	1,951	0.10
X	-	-	X	-	X	-	-	X	X	-	X	X	10	-437,834	896,255	3,111	0.05
X	-	X	X	-	X	-	-	X	-	-	X	X	10	-437,886	896,360	3,216	0.05
X	-	-	X	X	X	-	-	X	-	-	X	X	10	-438,048	896,684	3,540	0.04
X	X	-	X	-	-	-	-	X	X	-	X	-	8	-440,524	897,432	4,288	0.03
X	X	-	X	-	-	-	-	X	-	-	-	-	6	-442,662	897,546	4,402	0.03
X	X	-	X	-	-	-	-	X	X	-	-	-	7	-442,001	898,299	5,155	0.02
X	X	-	X	-	-	-	X	X	-	-	-	-	7	-442,259	898,815	5,670	0.02
X	X	-	X	-	-	-	-	X	X	-	X	X	9	-440,386	899,252	6,108	0.01
X	X	-	X	-	-	-	-	X	-	-	-	X	7	-442,521	899,339	6,195	0.01
X	-	-	X	-	-	-	-	X	-	X	-	-	8	-441,645	899,672	6,528	0.01
X	X	-	X	-	-	-	X	X	X	-	-	-	8	-441,972	900,327	7,183	0.01
X	-	-	-	-	-	-	-	X	-	X	-	-	7	-443,303	900,903	7,759	0.01
X	X	-	X	-	-	-	X	-	-	-	-	-	6	-445,994	904,209	11,065	0.00
X	-	-	-	-	X	-	X	-	X	-	X	-	8	-444,469	905,320	12,176	0.00
X	X	-	X	-	-	-	-	-	-	-	-	-	5	-447,595	905,349	12,205	0.00
X	X	-	X	-	-	-	-	-	-	X	-	-	7	-445,635	905,568	12,423	0.00
X	X	X	X	-	-	-	-	-	-	-	-	-	6	-447,205	906,632	13,488	0.00
X	-	-	X	-	-	-	-	-	-	X	-	-	6	-447,488	907,199	14,054	0.00
X	X	-	X	-	-	X	-	-	-	-	-	-	6	-447,509	907,239	14,095	0.00
X	X	-	X	X	X	-	-	-	-	-	-	-	7	-446,692	907,680	14,536	0.00
X	-	-	-	-	-	-	X	-	X	-	-	-	6	-447,877	907,976	14,832	0.00
X	-	-	X	-	X	-	-	-	X	-	X	-	7	-446,885	908,067	14,923	0.00
X	-	-	-	-	-	-	-	-	-	-	-	-	3	-451,586	909,235	16,091	0.00

Table S4. *Model selection of constructed candidate models for the effects on harvest density in level 3 (Hunting team areas/Game management areas 'Jaktlag och viltskötselområden') for Sweden (2012-2020) as linear mixed models (LMM). Fixed covariates included WP-phase (Operative/Construction), wolf occurence, bear occurrence, gravel road density, paved road density, 12-year accumulated forest loss, turbines in closest wp, distance to closest WP, height of turbines in closest WP, interaction between WP-phase and distance, interaction between and distance and interaction with WP-Phase and height. Random variable for all models was hunting area ID. Ranking and selection was based on lowest AICc-values.*

(Intercept)	Phase	Wolf	Bear	Gravel road	Paved road	Forest loss	WP1_turb	WP1_dist	WP1_height	Phase:WP1_dist	Phase:WP1_turb	Phase:WP1_height	df	logLik	AICc	ΔAICc	weight
X	X	-	-	-	X	-	-	-	-	-	X	X	9	-903,999	1826,361	0	0.31
X	X	-	-	-	-	-	-	-	-	-	X	X	8	-905,438	1827,166	0,805	0.21
X	X	-	-	-	X	X	-	-	-	-	X	X	10	-903,713	1827,87	1,509	0.15
X	X	-	-	-	-	X	-	-	-	-	X	X	9	-904,99	1828,342	1,982	0.11
X	X	-	-	-	X	-	-	-	-	X	X	X	11	-903,215	1828,965	2,604	0.08
X	X	-	-	-	-	-	-	-	-	X	X	X	10	-904,684	1829,812	3,451	0.05
X	X	-	-	-	X	X	-	-	-	X	X	X	12	-902,892	1830,416	4,056	0.04
X	X	-	-	-	-	X	-	-	-	X	X	X	11	-904,187	1830,909	4,548	0.03
X	-	-	-	-	-	-	-	-	-	-	X	X	7	-909,923	1834,071	7,711	0.01
X	-	-	-	-	X	-	-	-	-	X	X	X	10	-907,608	1835,66	9,299	0
X	-	-	-	-	-	-	-	-	-	X	X	X	9	-909,163	1836,689	10,328	0
X	-	-	-	-	-	X	-	-	-	X	X	X	10	-908,706	1837,857	11,497	0
X	X	-	-	-	-	-	-	-	X	-	X	-	7	-912,608	1839,442	13,081	0
X	X	-	-	-	-	-	-	X	X	-	X	-	8	-911,942	1840,173	13,813	0
X	X	-	-	X	-	-	-	-	X	-	X	-	8	-912,046	1840,383	14,022	0
X	X	-	-	-	-	X	-	-	X	-	X	-	8	-912,312	1840,915	14,554	0
X	X	-	-	-	-	X	-	-	X	-	X	-	8	-912,312	1840,915	14,554	0
X	X	-	-	X	-	-	-	X	X	-	X	-	9	-911,56	1841,482	15,121	0
X	X	-	-	-	-	X	-	X	X	-	X	-	9	-911,61	1841,583	15,222	0
X	X	-	-	-	-	-	-	-	-	X	X	-	8	-913,825	1843,939	17,578	0
X	-	-	-	-	-	-	-	-	X	-	X	-	6	-922,64	1857,449	31,089	0
X	X	-	-	-	-	-	X	-	X	X	-	-	8	-951,853	1919,995	93,634	0
X	X	-	-	-	-	-	X	X	-	X	-	-	7	-954,789	1923,803	97,442	0
X	X	-	-	-	-	-	-	X	X	-	-	-	6	-957,084	1926,336	99,975	0
X	X	-	-	-	-	-	X	-	X	-	-	-	6	-957,396	1926,96	100,6	0
X	X	-	-	-	-	-	-	-	-	-	-	-	4	-960,829	1929,737	103,376	0
X	X	-	-	-	-	-	-	X	-	-	-	-	5	-960,121	1930,361	104,001	0
X	X	-	-	-	-	-	X	-	-	-	-	-	5	-960,785	1931,691	105,33	0
X	X	-	-	-	-	-	X	X	-	-	-	-	6	-960,103	1932,374	106,013	0
X	-	-	X	-	-	-	-	-	-	-	-	-	4	-964,802	1937,684	111,324	0
X	-	-	-	-	-	-	-	-	X	X	-	-	6	-966,673	1945,514	119,154	0
X	-	-	-	-	-	-	X	X	X	-	-	-	6	-966,687	1945,541	119,181	0
X	-	-	-	-	-	-	-	-	-	-	-	-	3	-969,826	1945,7	119,339	0
X	-	-	-	-	-	X	-	-	-	-	-	-	4	-969,508	1947,095	120,735	0
X	-	-	-	-	-	-	X	X	-	-	-	-	5	-968,908	1947,937	121,576	0
X	-	-	-	X	-	-	X	X	-	-	-	-	6	-968,555	1949,279	122,918	0
X	-	-	-	-	-	-	X	X	-	X	-	-	6	-968,666	1949,501	123,14	0
X	-	-	-	X	-	-	X	-	-	X	-	-	7	-968,332	1950,888	124,527	0
X	-	X	-	-	-	-	-	-	-	-	-	-	451	-294,084	9040,242	7213,881	0