Assessing space use by pre-breeding white-tailed eagles in the context of wind-energy development in Finland

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ABSTRACT – The expansion of wind energy over large areas may be accompanied by major conflicts with birds, including birds of prey. Hence, it is desirable that the space use of species known to be vulnerable to wind energy be assessed in light of current and future developments. Here, we report on the large-scale dispersal movements of pre-breeding white-tailed eagles (*Haliaeetus albicilla*) in Finland, where a currently modest wind-energy capacity is expected to increase in the near future. We studied white-tailed eagle space use with a particular focus on the potential for annual power production (GWh) at specific locations, as estimated by the Finnish Wind Atlas. Also, we aimed to detect a potential human-wildlife conflict by assessing white-tailed eagle space use against the spatial distribution of existing and recently proposed wind farms. We found that, despite visiting a large proportion of the country, the eagles stayed primarily within coastal areas and islands, restricted to where human infrastructure was present only at very small amounts. Because of the distribution of wind resources, such areas were found to contain considerable potential for power production. The eagles visited most of the areas targeted for wind-energy development. However, these areas did not coincide with a higher-than-average eagle relocation frequency, suggesting that the existing and recently proposed wind farms do not represent an elevated threat to dispersing eagles. Caution should nevertheless be taken against interpreting that co-occurrence poses no threat at any given site, as site selection is paramount to avoid conflicts with avian conservation.

Keywords: raptors, turbine, renewable energy, conservation, landscape ecology, land use

1. Introduction

The use of wind energy is recognised as an important means to help reduce the consumption of fossil fuels, thereby contributing to the mitigation of climate change (Wiser et al. 2011). The wind industry continues to expand at a rapid pace, especially in Asia, Europe, and North America. In 2015, new wind energy installations accounted for nearly half of global electricity growth (Global Wind Energy Council, 2015).

Despite its benefits, wind energy can be detrimental to birds in terms of collision mortality, displacement, habitat loss, and barriers to movements (Drewitt and Langston 2006). As regards collision, comparisons with other man-made structures (*e.g.* buildings, communication towers, power lines) suggest the impact of wind turbines to be minor (Erickson et al., 2005; Loss, 2016). However, wind energy increases worldwide and concerns have been raised about development in areas inhabited by species of high conservation value. Large soaring raptors, together with *e.g.* swans, geese, ducks, waders and owls, appear to be at greatest risk of collision (Tosh et al. 2014). Golden eagles and other raptors have suffered high fatality rates at the Altamont Wind Resource Area in the USA (Smallwood and Thelander 2008), and griffon vultures in southern Spain (de Lucas et al. 2012). Given that raptors have long generation times and low reproductive output, additive mortality may prove harmful to population persistence (Drewitt and Langston 2006). Furthermore, the indirect effects produced by displacement, habitat loss or barriers to movements, difficult to assess in conjunction with direct mortality due to observational limitations, may lead to negative changes in survival and breeding success (Masden et al. 2010).

Site selection and strategic planning are critical to avoid or minimise undesirable impacts of wind energy on birdlife (Drewitt and Langston 2006). At the landscape scale, mapping avian distribution or space use allows the identification of areas containing vulnerable species, priority habitats or major flight paths (Hayes et al. 2015), providing guidance to developers early in the planning stage (see Bright *et al.*, 2008; Fargione *et al.*, 2012; Fielding *et al.*, 2006; Miller *et al.*, 2014). Early locational guidance, though not a substitute for Environmental Impact Assessment (EIA), may enable developments to be sited where risk of conflict is presumably lower.

Wind energy is an integral part of Finland's National Energy and Climate Strategy, with a goal to supply 8TWh of wind-derived electricity by 2030 (National Energy and Climate Strategy, 2016). In 2016, an installed capacity of *ca.* 1500 MW accounted for 3.5% (3 TWh) of the country's electricity consumption (Finnish Energy Industries, 2017). In 2011, a new Finnish Wind Atlas was produced to facilitate site selection by providing estimates of wind-energy potential (Tammelin et al. 2011). The Finnish Wind Atlas identified a 30-km wide coastal strip (including an extension to offshore zones), highlands, large lakes and fields as the most favourable areas for electricity generation. The coastal-offshore strip is the largest of such areas and contains most of the existing wind farms and development proposals (Finnish Wind Power Association, 2016). Coastal areas encompass a large extent of the white-tailed eagle (*Haliaeetus albicilla*) range in Finland, supporting an estimated 80-90% of its breeding population (Herrmann et al. 2011).

The white-tailed eagle is classified as a vulnerable species in the Finnish Red List (Tiainen et al. 2016), and is listed in Annex I of the EU's Birds Directive (Directive 2009/147/EC, 2009). The species can be negatively affected by wind farms. On the Norwegian island of Smøla, collision mortality and displacement of breeding pairs have been associated with a reduction in breeding success (Bevanger *et al.*, 2010; Dahl *et al.*, 2012). Collisions have also been reported in Germany (Krone and Scharnweber 2003), Poland (Zieliński et al. 2011), and Japan (Ueta et al. 2010), adding to the mortality attributed to other anthropogenic causes (*e.g.* lead poisoning; Krone *et al.*, 2003). In Finland, white-tailed eagles appear to be more likely to breed successfully when their territory is located farther from a facility (F. Balotari-Chiebao et al. 2016).

Adult white-tailed eagles of the Western Palaearctic are typically sedentary (Hardey et al. 2013), though breeding adults from *e.g.* inland territories in Northern Europe winter on the Baltic Sea coast; (Forsman 1999). Young birds disperse during their first years of life and may cover long distances before reaching maturity (*ca.* 5 yr.; Hardey *et al.* 2013). Bevanger *et al.* (2010) reported that juveniles from Smøla moved extensively along the coast of Norway, following a seasonal pattern in their return to the natal sites. Little is known of the dispersal movements of Finnish white-tailed eagles, especially in relation to wind energy. Here, we use long-term satellite telemetry data (1) to report on the large-scale movements of pre-breeding white-tailed eagles with a special reference to wind energy. In particular, we assess their space use in relation to site-specific annual power production potential (GWh), a relevant measure for wind-energy developers. Also, we (2) assess their space use against the spatial distribution of existing and recently proposed wind farms. Based on these two objectives, we provide information to developers and planning authorities on how to better consider the species in the planning process.

2. Materials and methods

2.1 Study species and turbine-related mortality

The white-tailed eagle is a diurnal raptor that breeds along sea coasts and by large rivers, lakes and reservoirs, feeding primarily on fish and waterfowl (Cramp and Simmons 1980). In Finland, despite being widely distributed, the species breeds in three main areas: the Archipelago Sea, the Quark, and Lapland (Stjernberg et al. 2005). In 2016, nearly 400 occupied territories were confirmed (Stjernberg et al. 2016). White-tailed eagles are exposed to direct mortality due to collision with wind turbines. In Finland, at least 10 fatalities have been reported based on opportunistic observations made by the general public (T. Stjernberg, personal communication, December 8, 2016). While this figure appears negligible, it underestimates the true impact of Finnish facilities, because a reliable estimate of turbine-related mortality requires systematic carcass searches (Smallwood 2007).

2.2 Satellite telemetry

A total of 14 nestlings were outfitted with a backpack-style 70 g Argos/GPS Solar Powered PTT (Platform Transmitter Terminal; Microwave Telemetry, Inc.) in 2009-2011 and 2013 (Fig. 1; Table 1). The PTT weighed *ca.* 100 g with an additional battery for data collection during winter. The total weight carried by an eagle was in accordance with recommendations on loading (Kenward 2001). The devices were programmed to transmit on an hourly basis mostly during daytime. Besides georeferenced points, the data included instantaneous speed, altitude, and course over ground. Maps and descriptions of individual movements are available at the website of the Finnish Museum of Natural History: http://www.luomus.fi/en/finnish-white-tailed-sea-eagles-satellite-tracking.

Since we were interested in studying white-tailed eagle movements at the landscape scale, we excluded GPS positions collected prior to the dispersal from the natal sites. In the predispersal period, the home range is characterised by a relatively small area around the nest (Balotari-Chiebao et al. 2016), and this restricted mobility would have caused bias due to location aggregation. Here, an eagle was considered to have dispersed when it stayed ≥ 5 km from the nest for at least 10 consecutive days. By the time the last observations were received (November 2015), none of the eagles had started breeding. Ringing and satellite tagging were conducted with permission from a local environmental authority, the Centre for Economic Development, Transport and the Environment (ELY).

2.3 Study area and explanatory variables

We divided Finland into a grid of 5 x 5 km cells based on the Finnish Wind Atlas. Our response variable was the total number of eagle positions per cell. We applied the so-called queen's case to map areas of occurrence of the dispersing eagles, consisting of neighbouring cells with at least one position. The queen's case considers all eight neighbours of a focal cell for common boundary. Our aim was to compare the occurrence areas to identify and focus the analysis on a representative area within Finland, given our sampling constraints in terms of origin (limited distribution) and number of study eagles.

Based on the ecology of the species, we selected five explanatory variables that may influence its space use at the landscape scale. We calculated the Euclidean distance between the cell centroids and three landscape features: (1) the Baltic Sea, (2) the nearest waterbody (here, a river or a lake > 9 km^2), and (3) the natal nests. We included the sea and other waterbodies to account for the fact that the white-tailed eagle lives near open water. Similarly, the natal nests can be expected to have an influence on dispersal patterns (Bevanger et al. 2010). Since the data were analysed at the population level, we derived for each cell a single value to represent the multiple nests. To this end, we used the arithmetic mean: $\frac{1}{n}\sum_{i=1}^{n} d_i$, where d_i is the distance between a focal cell and the *ith* nest and n is the total number of nests. To characterise the cells in terms of human infrastructure and natural habitats, we calculated the percentage of all (4) artificial surfaces and (5) forests and semi-natural areas (hereafter forests), respectively. Forests are used here as a measure of natural habitats due to their importance to white-tailed eagles within this latitudinal range (Helander and Stjernberg 2002). We used the open-source CORINE Land Cover 2012 (20-m resolution) to obtain all the above variables.

To specifically address the question of wind energy, we used the Finnish Wind Atlas to extract an additional variable. The Finnish Wind Atlas provides a number of wind energy-related estimates, including potential power production (MWh) for turbines with a different nominal capacity (1MW, 3MW, and 5MW) at various heights above ground level. We selected (6) the estimated average annual production potential of a 3MW turbine with a hub height at 150 m above ground level (2.5-km resolution). Turbines with this nominal capacity are nowadays commonly proposed in Finland (Supporting Information).

2.4 Risk assessment

We assessed the space use of the dispersing eagles in relation to the spatial distribution of wind-energy development, with the aim to detect a potential human-wildlife conflict at the landscape scale. We derived a binomial variable (hereafter wind-farm presence) by identifying the cells that contained (coded as 1) or did not contain an existing or proposed facility (coded as 0). We then tested (see below) whether the facility-containing cells were selected or avoided by the eagles. Furthermore, we applied a *t*-test to compare the power production potential between cells with and without a facility. This comparison would indicate whether the cells so far selected for development have actually a greater potential.

We obtained the coordinates of existing turbines via a high-resolution map by the National Land Survey of Finland. Information on the proposed wind farms was supplied by the Finnish Wind Power Association (FWPA, Supporting Information). The supplied material contained specifications such as project phase, number of turbines, nominal capacity and estimated location of wind farms proposed for 2016-2020. Project phase refers to the stage in the planning and development process, ranging from proposal (*Phase 0*) to operation (*Phase 8*). The accuracy of locations typically increases as the project moves forward (FWPA, personal communication, April 20, 2016). Only proposals from *Phase 3* and above (*i.e.* with at least an Environment Impact Assessment [EIA] under process) were considered for analysis (Table 2). Data were carefully checked for duplicate information.

We calculated flight heights by subtracting the ground elevation from the altitude determined by the PTT. Ground elevation was estimated using the 30-m resolution Advanced Spaceborne Thermal Emission Radiometer (ASTER GDEM 2, a product of METI and NASA). Briefly, flight height estimation is influenced by GPS accuracy (± 18 m, according to manufacturer), elevation data accuracy (± 8.68 m for ASTER GDEM 2;(Gesch et al. 2012), and the interpolation between the two datasets (30 m, reflecting the elevation data resolution;(Katzner et al. 2012). Combing these sources of error, the accuracy of our estimates is ± 57 m. We computed mean flight height over the sea and over land, and the proportion of in-flight positions that occurred within a rotor-swept zone of 50-200 m above ground level.

2.5 Data analyses

We used a Generalised Additive Mixed Model (GAMM) to study the relationship between number of eagle positions (response variable) and explanatory variables, including wind-farm presence for the risk assessment. We chose the negative binomial distribution to account for the overdispersion in the data, as the variance was considerably larger than the mean. We built a correlation matrix with all possible combinations of the variables to assess collinearity with Spearman’s correlation coefficient. GAMMs are sensitive to the inclusion of highly correlated variables (Zuur et al. 2009). Because the cells closer to each other had a more similar number of eagle positions than those farther apart (Fig. S1), we added to the model a spatial correlation structure.

The number of observations per individual varied greatly due to differences in tracking time (Table 1). To check whether the use of unequal sample sizes produced bias, we repeated the analysis based on a time period that was available for most birds, considering only first-year observations after dispersal ($\bar{x}$ = 2529 positions ± 791 SD; *n* = 14). Data analysis and graphical displays were performed in R 3.3.0 (R Core Team, 2016), with packages sp (Pebesma and Bivand 2005), rgeos (Bivand et al. 2013; Bivand and Rundel 2016), mgcv (Wood 2011), and raster (Hijmans 2016). MapInfo Professional 12.0 was used to produce Figure 1.

3. Results

The eagles were tracked for 75-2239 days after leaving the natal sites, which amounted to 83389 positions (73%) from Finland and 30381 positions (27%) from other Baltic Sea countries. The latter were excluded from all calculations, because we did not have equivalent information for other countries. By the end of the study period, four eagles had died from unknown causes. Details of the movement data for each eagle are provided in Table 1. We compiled 94 operational (1-22 turbines/site) and 229 proposed wind farms (1-90 turbines/site). Of these, 310 were onshore and distributed mostly in coastal areas, notably in Satakunta, Ostrobothnia, Central Ostrobothnia, and Northern Ostrobothnia (Fig. 2); these are all regions facing the Gulf of Bothnia. Thirteen facilities were offshore.

3.1 Space use

The dispersing eagles wandered widely across Finland, visiting regions considerably far from the nests, such as North Karelia and Lapland (Fig. 3). However, they occurred primarily and were most often located along the coast and nearby areas. This is indicated by the largest area of occurrence (totalling 2984 cells), which encompassed nearly the whole coastline and contained alone > 87% of all positions. Much smaller occurrence areas were seen in northern Lapland (Fig 3). There was considerable overlapping of individual space use, especially in parts of Ostrobothnia, where up to nine eagles used the same cells at different times (Fig. 3).

Given the representativeness of the largest area of occurrence, in terms of both size and relocation frequency, we restricted the analysis and risk assessment to that area. With a large coastal range, this area included grid cells with widely varying proportions of waterbodies and land surface. To test the influence on cell use of our two habitat variables, artificial surfaces and forests, we had to avoid the inclusion of cells with little or without land surface. We therefore created two sets of data for two separate analyses, one (1) for all cells and another (2) only for cells with ≥ 50% of land surface. The habitat variables were only analysed with the latter dataset.

3.2 Explanatory variables: collinearity and relationship with eagle movements

A correlation matrix revealed that power production potential was highly correlated (> |0.7|) with sea distance and waterbody distance. This is because wind energy has greater potential towards the sea, and generally lower potential towards lakes and rivers owing to their distribution in relation to the coastline. Given the general aims of this study, we retained power production potential and excluded the other two variables (separate model output is available for sea distance and waterbody distance as supplementary material; Tables S1 and S2). Differences in tracking time did not significantly influence the results (Table S3); hence, we present here only the results based on all observations.

3.2.1 Analysis on all cells

We found the space use of the dispersing eagles to be strongly associated with power production potential, as grid cell use increased sharply with an increase in the potential for power production (Table 3). However, this association was not linear. It humped around a power production potential of 50 GWh, reflecting the decreasing use of the more distant offshore cells, the cells with greatest potential (Fig. 4a). We also found that the eagles tended to be located in areas closer to the nests (Table 3).

3.2.1 Analysis on cells with ≥ 50% of land surface

When considering only cells with at least 50% of land surface, a large proportion of offshore cells were excluded from analysis. Hence, this time, grid cell use increased with increasing power production potential in a linear fashion (Fig. 4b). Similar to the previous analysis, areas closer to the nests were used more frequently than areas farther away. The cells where the eagles occurred had much more forests ($\bar{x} = 45.6\% \pm 31.1$ SD) than artificial surfaces ($\bar{x} = 3.7\% \pm 5.6$ SD). Despite their generally low surface area, there was a sharp decrease in the use of cells with increasing amounts of artificial surfaces, such as urban fabric and industrial units (Fig. 4b). No similar relationship was detected with forest areas.

3.3 Risk assessment

A total of 185 of 2984 cells were found to contain an existing or proposed wind farm, of which 156 were visited by at least one eagle ($\bar{x} = 31$ positions ± 102 SD). Despite this high degree of co-occurrence (Fig. 5), the use of cells with a facility was not greater than that of cells without a facility (Table 3). In terms of power production potential, cells with a facility had a lower potential ($\bar{x} = 39.9$ GWh ± 7.9 SD) compared to the cells without a facility ($\bar{x} = 41.0$ GWh ± 10.8 SD). This indicates that wind-energy development has not targeted cells with greatest potential for electricity production ($t = 3.498$; df = 233.75; $p = < 0.001$).

Eagles flew at low to intermediate elevations over the sea ($\bar{x}$ = 90 m ± 151 SD) and land ($\bar{x}$ = 198 m ± 209 SD). A considerable proportion of over-sea (21%) and over-land flights (37%) were at a rotor-swept zone of 50-200 m. Around 43% of all flights occurred within 50 m above ground level.

4. Discussion

We used satellite telemetry to study the space use of white-tailed eagles during their several years long dispersal phase, focusing on a potential conflict with wind-energy development in Finland. Despite visiting a large proportion of the country, we showed that the eagles stayed primarily along the coast and nearby areas. More inland and distant offshore areas were used to a lesser extent. Because of the distribution of wind resources, the most frequently used areas by the eagles contained considerable potential for power production. However, the areas with an existing or proposed wind farm did not appear to have a higher-than-average eagle relocation frequency, suggesting that their site selection would not pose an elevated threat to dispersing eagles. Altogether, our results suggest that there are ways for achieving the 2030 national goal on wind energy without elevating the threat to dispersing white-tailed eagles (National Energy and Climate Strategy, 2016).

The strong positive correlation between the number of eagle positions and the potential for power production indicates a potential conflict with wind-energy development. However, the existing and recently proposed wind farms appeared not occur in areas used more by the eagles than other areas, though there are specific locations that merit a careful examination. For example, the island of Raippaluoto, part of the Kvarken Archipelago, holds a proposal with 9-36 turbines (Phase 4: EIA approved). The grid cell proposed for construction was visited by eight eagles (three of which coming from far-away nests: 200-340 km) and its surroundings were among the most used in the whole country. Thus, while cell use was not greater in the facility-containing cells, we caution against interpreting this finding as evidence for no potential impact at any given site. Our estimates suggest that the eagles were mainly flying at low altitudes over the sea and land and within a rotor-swept zone of 50-200 m, thus being at risk from onshore and offshore turbines depending on site selection.

Grid cells occupied by the eagles had a very low percentage of artificial surfaces, which in our study area consisted mainly of urban fabric and industrial and commercial units. This reflects the broader Finnish landscape, dominated by forests and waterbodies. We nevertheless showed that the greater the percentage of artificial surfaces, the lower the number of eagle positions. This pattern likely results from a combined effect of a lack of suitable habitats or feeding grounds in areas partially covered by human infrastructure, and the disturbance caused by human activities. In addition, as expected, cells closer to the nests were used more frequently than cells farther away, reflecting the tendency for the eagles to return to the natal areas (Bevanger et al. 2010).

Wind-energy development in Finland has targeted cells that, compared to non-targeted cells, had a lower power production potential. This is partly explained by a bias against development in offshore zones. According to our compilation, only 13 wind farms have been built or proposed offshore. Naturally, it should not be assumed that all of the remaining cells would actually be viable or available for turbine installation, a process which is subject to technical, environmental and social constraints (Aydin et al. 2010). The summed capacity of Finland’s proposed wind farms greatly exceeds what would be required to reach the national goal for 2030. More specifically, *ca.* 25% of the proposed capacity would be sufficient. Based on the estimated area of a wind-farm project, Zakeri *et al.* (2015) calculated that the installation of a 2-MW turbine requires 1.5 km^2 or 75 ha/MW (including an area not directly disturbed by the installation). If these estimates are representative, the installed capacity expected for 2030 would claim *ca.* 2335 km^2 (or 0.7% of the national land area). Tosh *et al.* (2014) noted that a turbine location is likely more influential than its specifications. Site selection is crucial to reduce the risk of collision with white-tailed eagles, as they may lack a behavioural response to avoid a wind farm overlapping with important habitats (see Dahl *et al.*, 2013). We showed that considerable wind resources are found outside the areas most used by the eagles. In cases of overlap with proposed facilities, it appears possible to obtain an equivalent output by building in alternative sites.

Our study was developed with the use of long-term and high-precision data, comprising the best information currently available. However, a number of caveats in the study design and data collection inevitably limit its application. Our study eagles came from two of the three major breeding areas for white-tailed eagles in Finland, *i.e.* the Archipelago Sea and the Quark, but they did not include Lapland. We found that as many as six eagles (from nests hundreds of kilometres away) visited sites in Lapland, suggesting the presence of important habitats for dispersing eagles. Lapland contained 13 existing and 18 proposed wind farms, and although no overlap was detected, additional data from eagles specifically from Lapland are needed for further investigation. Another source of limitation was the sample size of eagles, which was relatively small (14 individuals) due to the costs involved with satellite tagging. Also, the Kvarken Archipelago contained alone a third of the eagles. Given these limitations, our decision to restrict the analysis and risk assessment to the largest occurrence area may have helped us reduce the risk of erroneously drawing more general conclusions.

The freely-available Finnish Wind Atlas gave us a unique opportunity to study eagle space use in relation to a variable which is of relevance to wind energy, namely power production potential. Whenever available, its application may contribute to the study of birdlife-wind energy interactions. In view of an expanding wind industry, further research is needed to provide support for careful site selection and strategic planning, widely recognised as critical steps to avoid or minimise undesirable impacts on avian populations (Drewitt and Langston 2006).

Conclusions

The main areas used by pre-breeding white-tailed eagles during the dispersal period contained considerable potential for wind-energy generation. In different numbers and frequency, the eagles visited most of the areas with an existing or recently proposed wind farm. However, such areas did not appear to have a higher-than-average relocation frequency, suggesting that their site selection would not pose an elevated threat to dispersing eagles. Nevertheless, it should not be concluded that co-occurrence poses no threat to individual eagles at any given site. Available wind resources suggest that careful site selection may ensure the achievement of the 2030 national goal on wind energy without elevating the potential threat to dispersing white-tailed eagles.

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Figures and tables

Figure 1 Approximate nest locations of the satellite-tagged white-tailed eagles. The dashed circle around the Kvarken Archipelago indicates the area containing five nests which are undiscernible at the used scale due to the short distances between them. The Archipelago Sea is a stronghold of the species in Finland.

Figure 2 National estimates for the production potential of a 3MW turbine installed at 150 m above ground level, and the locations of the operational and proposed facilities for until 2020. The original estimates (at a 2.5-km resolution) were adapted to the 5-km resolution used in this study. Region boundaries are depicted. 1: North Karelia; 2: Northern Savonia; 3: Päijänne Tavastia; 4: Southern Savonia; 5: Lapland; 6: Kainuu; 7: Northern Ostrobothnia; 8: Uusimaa; 9: Kymenlaakso; 10: South Karelia; 11: Central Finland; 12: Central Ostrobothnia; 13: Southwest Finland; 14: Ostrobothnia; 15: Pirkanmaa; 16: Satakunta; 17: Southern Ostrobothnia; 18: Tavastia Proper; 19: Åland Islands. Existing (+) and proposed wind farms (o) for until 2020 are also indicated on the map.

Figure 3 Maps of Finland showing the number of positions for fourteen pre-breeding white-tailed eagles and the number of different individuals to have visited a given cell. Values are expressed at a 5-km resolution. Areas of eagle occurrence > 375 km^2 are indicated in bold.

Figure 4 Plots showing the effects of smoothed variables on grid cell use in (a) the whole of the largest occurrence area and (b) in cells with at least 50 % of land surface. The boxplot indicates the range, interquartile and mean values for power production potential in the cells containing an existing or proposed facility.

Figure 5 Observed grid cell use by pre-breeding white-tailed eagles in their largest area of occurrence, overlaid by the locations of the existing and (+) proposed wind farms (o) within this area.

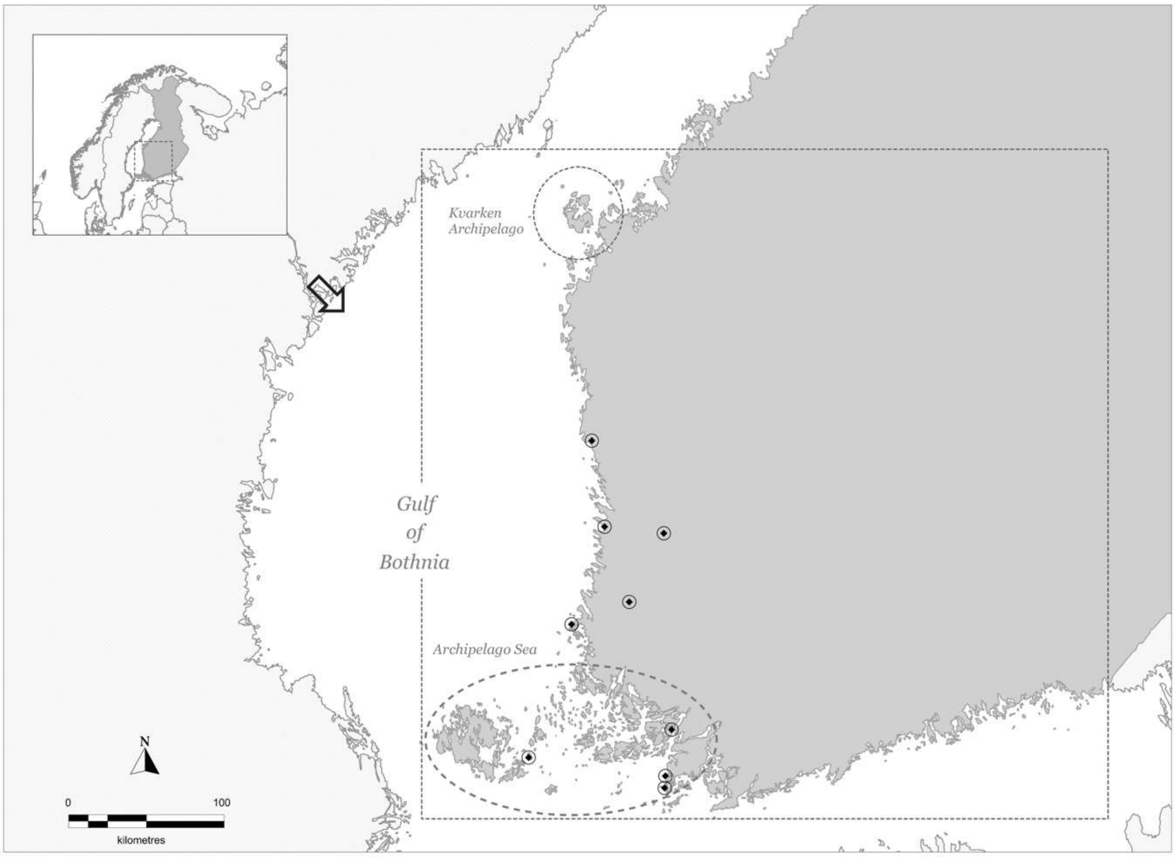
Kvarken Archipelago
Gulf of Bothnia
Archipelago Sea
N
0
100
kilometres

Fig. 1

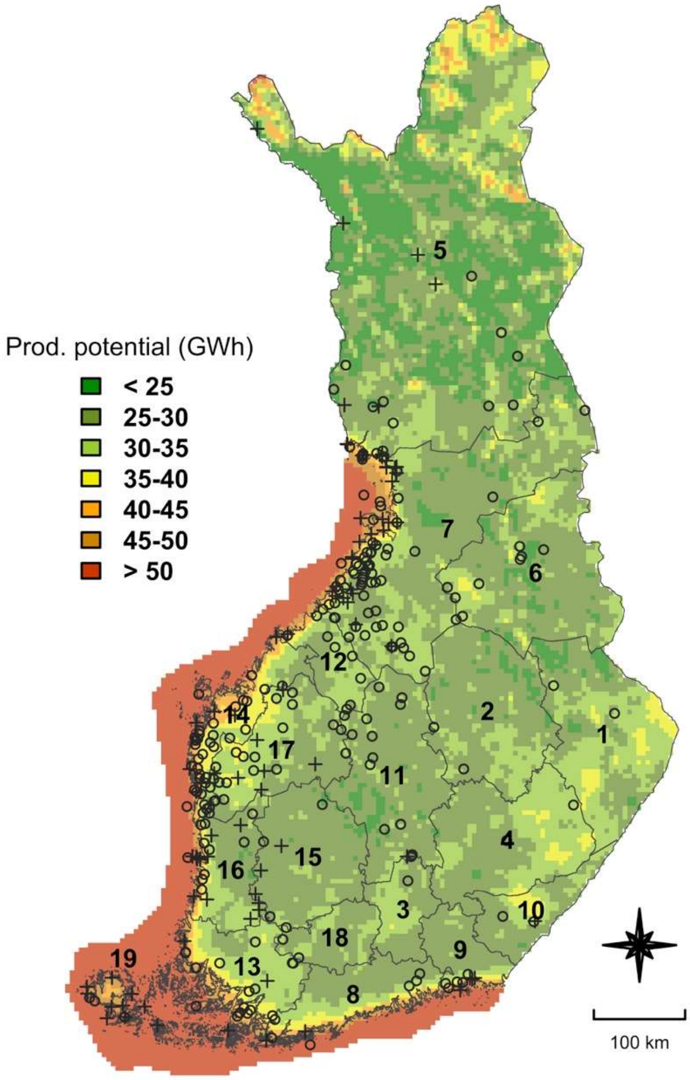
Prod. potential (GWh)
< 25
25-30
30-35
35-40
40-45
45-50
> 50
5
7
6
12
2
1
14
17
11
4
15
16
3
10
18
9
19
13
8
100 km

Fig. 2

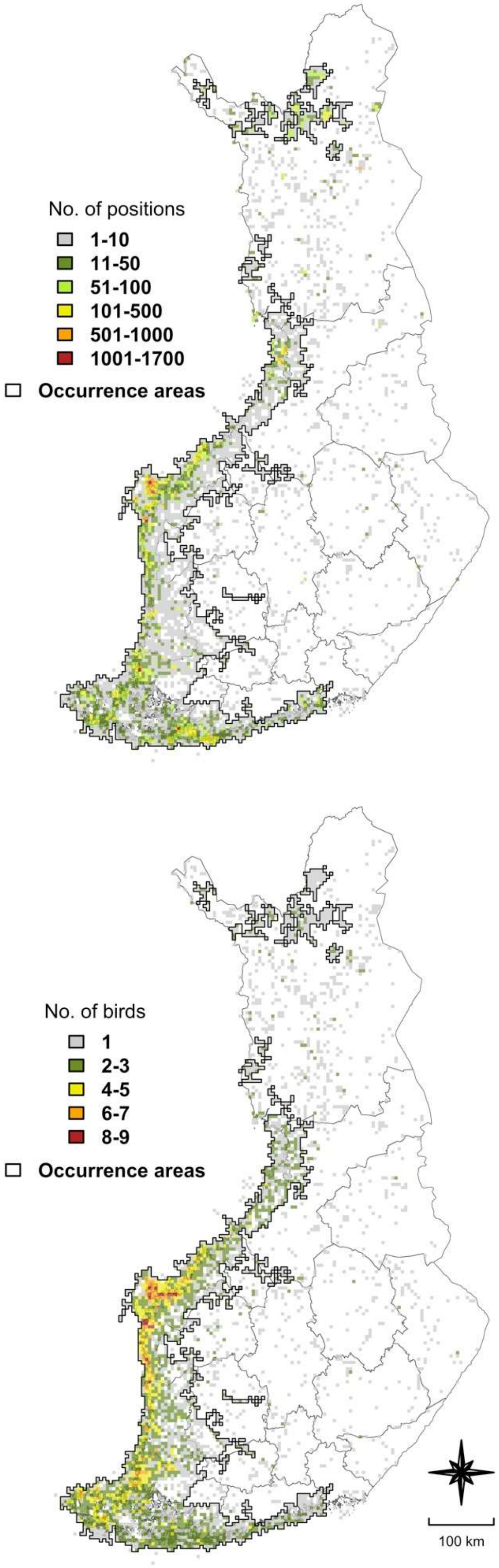
No. of positions
1-10
11-50
51-100
101-500
501-1000
1001-1700
Occurrence areas
No. of birds
1
2-3
4-5
6-7
8-9
Occurrence areas
100 km

Fig. 3

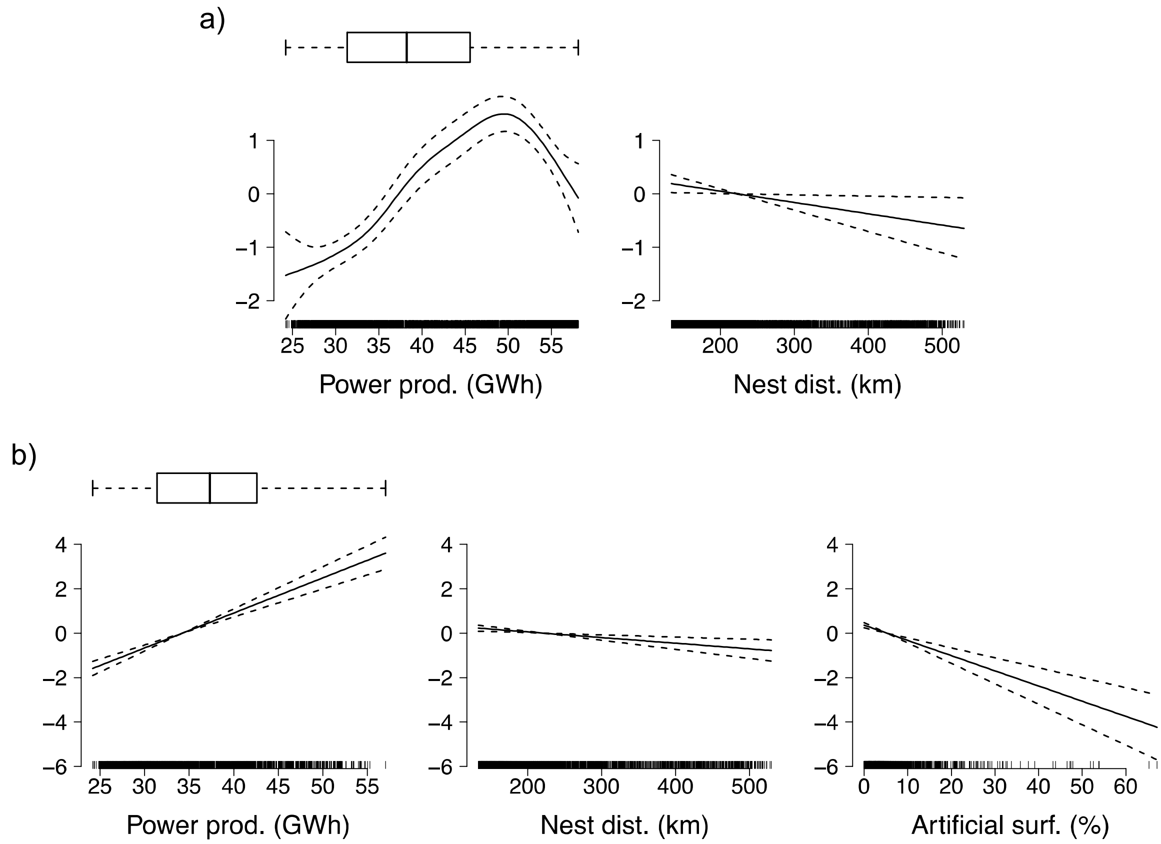
a)
1
0
−1
−2
25 30 35 40 45 50 55
Power prod. (GWh)
1
0
−1
−2
200 300 400 500
Nest dist. (km)
b)
4
2
0
−2
−4
−6
25 30 35 40 45 50 55
Power prod. (GWh)
4
2
0
−2
−4
−6
200 300 400 500
Nest dist. (km)
4
2
0
−2
−4
−6
0 10 20 30 40 50 60
Artificial surf. (%)

Fig. 4

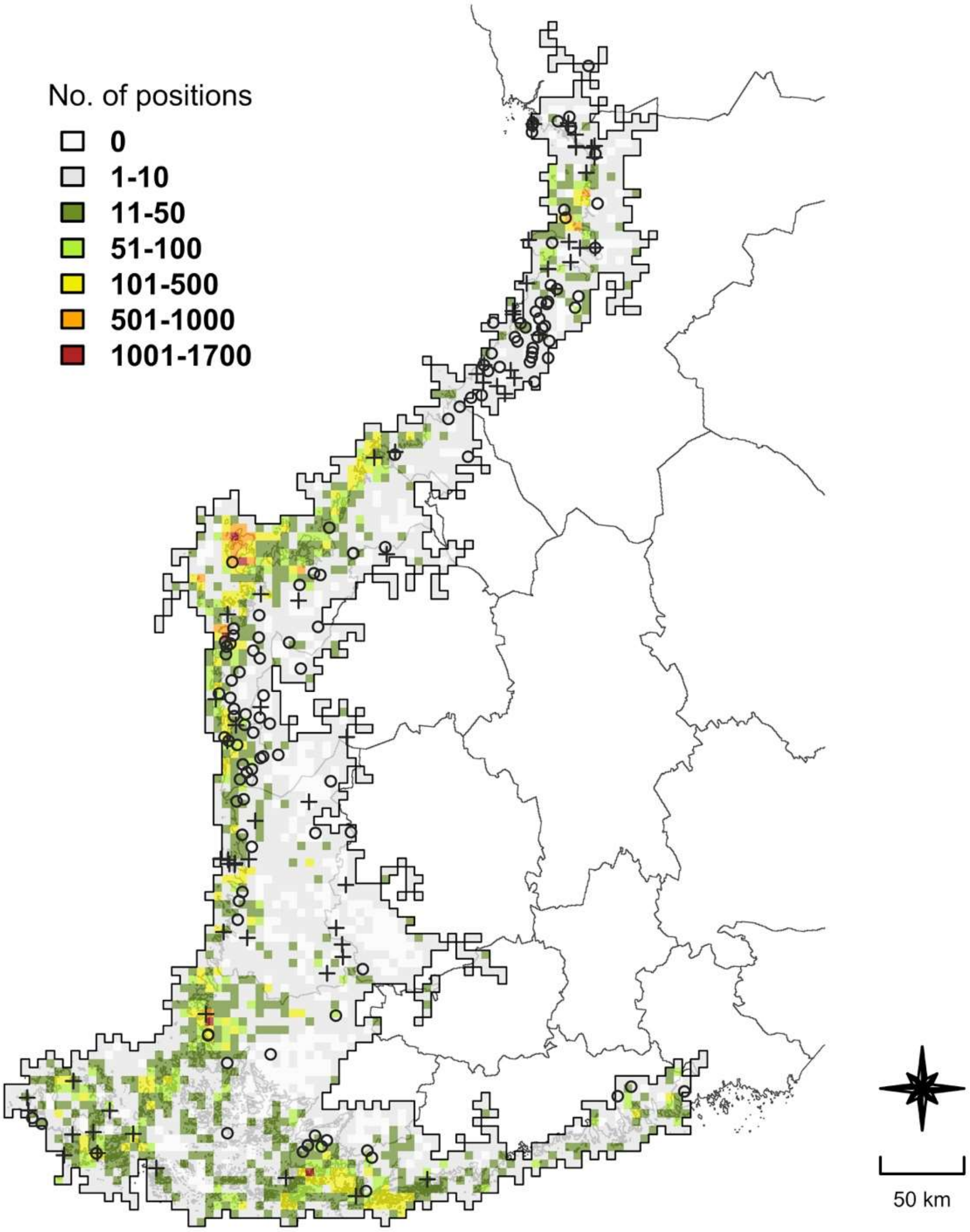
No. of positions
0
1-10
11-50
51-100
101-500
501-1000
1001-1700
50 km

Fig. 5

Tables

Table 1 Details of the long-term telemetry data collected within Finland from 14 satellite-tagged white-tailed eagles during dispersal. Positions from other Baltic Sea countries were excluded.

Bird ID	Hatch year	All positions	In-flight positions (≥ 5m/s)
92632	2009	4093	976
92633	2009	9851	259
92634	2009	15196	70
92635	2009	11399	552
33207	2010	11785	638
33210	2011	2316	917
105680	2011	6790	1286
105681	2011	2548	1151
105682	2011	2901	801
33211	2013	508	292
33212	2013	4781	176
105831	2013	2010	210
105832	2013	4401	512
105833	2013	4810	558
Mean ± SD		5956 ± 4410	600 ± 382

Table 2 Proposed wind farms for the whole of Finland summarised according to project phase. Proposals refer to the period 2016-2020. It should not be assumed that all projects will be granted approval.

Project phase	Projects	Minimum turbine number	Capacity (MW)
3 - EIA under process	27	602	1809
4 - EIA approved/Spatial planning under process	105	1427	4315
5 - Applying for permits	50	693	2172
6 - Preparing for construction	26	247	777
7 - Under construction	21	226	670
Total	229	3195	9743
Mean ± SD	46 ± 35	639 ± 487	1949 ± 1473

Table 3 Results of a Generalised Additive Mixed Model (GAMM) examining the space use of dispersing white-tailed eagles in their largest area of occurrence (see Fig. 3). A distinction based on the proportion of land surface is made to evaluate all cells and cells with $\geq$ 50% of land surface, with only the latter used to test the influence of artificial surfaces and forests.

Dataset	Variables	Estimate	t-value	Significance of smooth terms		
				edf	F-value	P-value
All cells	Power production	-	-	4.790	31.216	< 0.001
	Nest distance	-	-	1.000	5.095	0.0241
	Wind-farm presence	0.073	0.379	-	-	0.705
Cells ≥ 50 % land use	Power production	-	-	1.000	99.403	< 0.001
	Nest distance	-	-	1.000	10.776	0.001
	Artificial surfaces (%)	-	-	1.000	33.620	< 0.001
	Forests (%)	-	-	1.000	0.224	0.636
	Wind-farm presence	-0.003	-0.018	-	-	0.986