

Habitat use of flying subadult White-tailed Eagles (*Haliaeetus albicilla*): implications for land use and wind power plant planning

Hannu Tikkanen*, Fabio Balotari-Chiebao, Toni Laaksonen, Veli-Matti Pakanen & Seppo Rytönen

*H. Tikkanen, V.-M. Pakanen, S. Rytönen, Ecology and Genetics Research unit, P.O. Box 3000, 90014 University of Oulu, Finland. * Corresponding author's e-mail: hannu.tikkanen@hotmail.fi*

F. Balotari-Chiebao, Section of Ecology, Department of Biology, University of Turku, FI-20014, Turku, Finland

T. Laaksonen, LUKE, Natural resources institute Finland, Itäinen pitkäkatu 4 A, 20520 Turku, Finland

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Large-scale construction of wind power plants may threaten large raptors at both individual and population levels. The most efficient way to prevent the negative effects of wind power plants is to avoid building on presumably high-risk sites, which requires an understanding of the movement patterns and habitat use of vulnerable species. The White-tailed Eagle (*Haliaeetus albicilla*) is vulnerable to wind energy in terms of both collision mortality and displacement due to disturbance. We used satellite transmitters to study the movements of juvenile and sub-adult White-tailed Eagles. We developed a Resource Selection Function (RSF) to model their habitat use at the Finnish coast, which holds about 80% of all planned and constructed wind power plants in the country. In addition, we made a collision risk assessment by calculating how likely areas are to be visited by a flying White-tailed Eagle at both planned and existing wind-farm areas. Our resource selection model predicted 83% of the observations correctly. We found that sub-adult White-tailed Eagles preferred areas close to their natal sites, the coastline and archipelagos. They avoided the open sea, urban areas and other constructed areas such as cottages, industrial areas and agricultural fields. The White-tailed Eagles flew lower over the sea (median 20 m) than over land (median 80 m), and time spent flying at risk heights (50–200 meters) was greater over land (28%) than over the sea (19%). Due to preferences for different habitat types and varying flight heights, our estimates of relative collision risks differed up to 1,000-fold at the Finnish coast. This illustrates the power of our resource selection model, which can be used to model White-tailed Eagle flying behaviour and habitat use in any given area and provide useful information for landscape planning when searching for the safest areas for wind-energy development.



1. Introduction

Human activities often lead to conflicts between land-use interests and biodiversity conservation (Young *et al.* 2005). Thus, the ability to anticipate the effects of potentially harmful developments is a desirable goal to prevent or minimise impacts on species of conservation value (López-López *et al.* 2011, Watson *et al.* 2014, Miller *et al.* 2014). This predictive ability, however, requires an understanding of the ecological requirements of a target species, especially in terms of its habitat use.

The need for replacing fossil fuels with renewable energy has seen an increase in the number of wind power plants all over the world, in turn raising concerns about their potential impacts on bird and bat populations (Santangeli *et al.* 2018). Large wind power plants are typically built or proposed in coastal, upland, and offshore areas, where wind conditions are favourable and opposition from residents is minimal. At the same time, these areas are often favoured by animal species that require large, undisturbed and continuous natural habitats. Good examples of such species are large raptors, which are known to be vulnerable to collision with wind turbines (Smith & Dwyer 2016). Some of the current wind-farm developments have proven to be particularly problematic for migrating and/or breeding raptors (Barrios & Rodríguez 2004, Smallwood & Thelander 2008, Bevanger *et al.* 2010, Carrete *et al.* 2012).

The Finnish government aims to increase its installed wind power capacity to 3,000 MW (*ca.* 1,000 turbines) by the year 2025 (Ministry of Employment and the Economy 2013). At the end of 2012, Finland's wind power capacity was 288 MW (163 wind turbines), and at the end of 2017 2,044 MW (*ca.* 700 wind turbines; Finnish Wind Power Association 2018). Because coastal areas have particularly good wind resources (Tammelin *et al.* 2013), most of the planned and constructed wind power plants (*ca.* 80%) are located along the coast (Finnish Wind Power Association 2018).

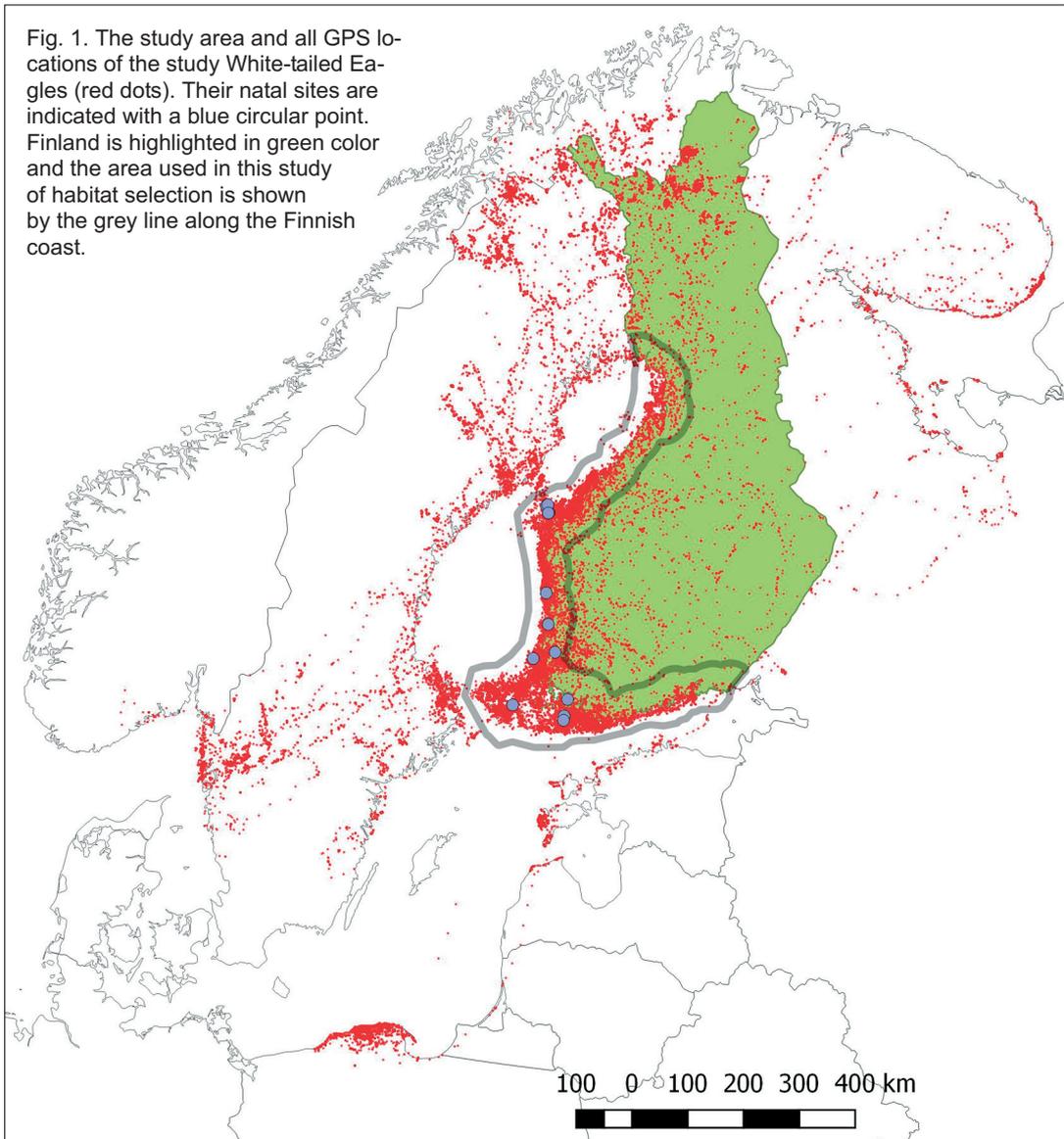
The White-tailed Eagle (*Haliaeetus albicilla*) is a large raptor known to be vulnerable to collision mortality (Bevanger *et al.* 2010, Ueta *et al.* 2010, Krone *et al.* 2017) and displacement (nest desertion due to proximity to turbines; Bevanger *et al.* 2010). Such detrimental interactions have the potential to lead to a reduction of breeding success

(Dahl *et al.* 2012, Balotari-Chiebao *et al.* 2015). The species breeds mostly in areas along the coast (in Finland 80–90% of all pairs; Stjernberg *et al.* 2015), which also serve as main migration routes and harbour individuals during their juvenile and sub-adult phases (Nygård *et al.* 2010, May *et al.* 2013, Toivanen *et al.* 2014). In Finland, construction of large-scale wind power plants started only in the 2010's, and hence there is little information about their potential impacts on large raptors.

Apparently, wind power plants operating in forests pose a greater risk to White-tailed Eagles, game fowl and gulls than other species (FCG 2017). To our knowledge, 18 collisions of White-tailed Eagles have been reported as of September 2018 (T. Stjernberg pers. comm 11.9.2018). In Finland, the White-tailed Eagle is classified as a vulnerable species (Tiainen *et al.* 2016), and is listed in the Annex I of the EU's Birds Directive (European Commission 2009). Following a major decline in the 1960's and 1970's, its population has increased sharply following the implementation of conservation measures (Tiainen *et al.* 2015) and the number of breeding pairs reached 458 in 2014. However, increased mortality due to collisions with wind turbines may well alter the positive development of long-lived species towards local population decline (Sæther & Bakke 2000, Vasilakis *et al.* 2017, Grünkorn *et al.* 2017).

Strategic planning and site selection of wind power plants enable mitigation of wildlife impacts at wind power plants, but this requires identification of areas that host vulnerable species, their priority habitats and major flight routes. This can be achieved by means of Resource Selection Functions (RSFs). These generalizable models can be used for prediction and mapping of areas that are more likely to be selected or avoided by animals within e.g., their home ranges or migration routes (Manly *et al.* 2002, Meyer & Thuiller 2006, Miller *et al.* 2014, Watson *et al.* 2014, May *et al.* 2017). Therefore, RSFs provide useful ecological information for a more environment-friendly land-use planning, including wind power plants (Miller *et al.* 2014, Reid *et al.* 2015, Singh *et al.* 2016, Tikkanen *et al.* 2018).

Here, we study the habitat use of dispersing White-tailed Eagles by using satellite telemetry, a technique that has been successfully applied in other studies on the movements of the White-



tailed Eagle (Bevanger *et al.* 2010, Krone *et al.* 2017, Balotari-Chiebao 2018). Our aim is to develop a general RSF based on the habitat use of dispersing juvenile and subadult (later we only use the word “subadult”) White-tailed Eagles and the use of remote sensing data. We use this approach to assess the relative risks posed by wind-energy development in different parts of the Finnish Baltic Sea coast. In addition, we discuss how the spatial distribution of sensitive areas can be taken into account in future wind power plant and other land

use planning to reduce conflicts between White-tailed Eagle conservation and human interests.

2. Materials and methods

2.1. The study area and land cover data

We modelled White-tailed Eagle space use within an area that covered the whole Finnish coastline, extending 40 km towards the mainland and 5 km

towards the sea (Fig. 1). We chose the 40-km distance because this is the maximum distance that is visible by a White-tailed eagle at an average flight height (i.e., 127 m). This distance included ca. 83% of all observations made in Finland. The 5-km distance was chosen because it contained around 99% of all observations made at the sea.

Spatial data handling and analysis were carried out in QGIS (version 2.14.11) and MapInfo by using the following open access data sets: Corine Land Cover data from 2012, provided by the Finnish Environment Institute, topographic database and elevation model (10 m × 10 m) provided by National Land Survey of Finland, and water depth data and human population data provided by Finnish Environment Institute. White-tailed Eagle nest locations were provided by the WWF Finland White-tailed Eagle working group and Metsähallitus, which have a conclusive database of known nest locations in Finland in each year.

2.2. Satellite telemetry data

During June–July in 2009–2011 and 2013, we fitted solar powered Argos/GPS PTTs (Platform Transmitter Terminal; Microwave Telemetry, Inc.) on 14 White-tailed Eagle nestlings in the west and south-west of Finland (Fig. 1). One of the individuals provided insufficient data (spanning less than one year) and was therefore excluded. Most of the nests (12 of 13) were located close to the sea (< 1,315 m). We programmed the satellite transmitters to transmit data on location (± 18 m), elevation above sea level (± 22 m), speed (± 1.85 km/h) and flight direction ($\pm 1^\circ$) on an hourly basis during daylight hours. See Balotari-Chiebao *et al.* (2016) for more detailed information on sampling. We only included the data collected after the individuals departed from their natal areas. We considered this to be the case when they spent more than 10 consecutive days farther than 5 km from their natal nest.

As we were interested in the juvenile and sub-adult period before first breeding, the data received afterwards were not considered. The number of observations totalled 113,039. Individual transmitters sent data on average 3.7 years (range 1.0–6.0 years). For modelling purposes (see below), we used only locations where the birds were

flying (speed value $\geq ca.$ 4 km/h, 2 kn/h), which corresponded to 11% of all locations. Most of the flight locations (71%) were positioned in Finland, and 83% of these were in our study area (see Fig. 1).

2.3. Resource Selection Functions (RSFs)

We developed RSFs to identify a number of landscape and environmental variables that are presumably relevant for flying White-tailed Eagles. We used a total of 12 explanatory variables which were assigned to two categories: a) Distance variables and b) continuous variables describing average values from different-sized buffers:

The variables were the following:

1. distance to natal nest (km),
2. distance to main road (paved roads; km),
3. distance to closest land (km)
4. distance to the sea (km).
5. elevation above sea level (within a 50-m buffer),
6. sea water depth (26 classes, 0–510 m, 50-m buffer),
7. amount of agricultural field area (ha, 1-km buffer),
8. wetland area (open bog ha, 1-km buffer),
9. cottage (leisure house) area (ha, 1-km buffer),
10. industrial area (ha, 1-km buffer),
11. number of residents (2.5-km buffer),
12. index of archipelago fragmentation (shoreline amount, 5-km buffer),

In addition, we tested whether the presence or absence (1/0) of agricultural fields, open bogs, urban areas (at observed and random points) would better fit the models. However, these were not used in the final analyses because their performance (as measured by AUC and AIC values) was not as good as that of the corresponding continuous variables (above).

We assigned random points individually into the same area where an individual's GPS-points were located (*ca.* 1.5 × observation points). We removed the outliers following a visual inspection, which represented less than 1% of observations of probably long-distance moving birds. The maxi-

imum distances of both random and observed GPS locations varied between 111–492 km from the nest.

We modelled the RSFs by applying binary logistic regression models in R (R Core Team 2017). We used Generalized Linear Mixed Effects (GLMM) models with function “glmer” in package “lme4” to analyse all data together including individual and year as random intercept effects and random slope effects (Manly *et al.* 2002, Quinn & Keough 2002, Tabachnick & Fidell 2006).

We present the most relevant RSF (“best model”) graphically using the raster calculator in QGIS by multiplying each environmental variable of each pixel in the map with the coefficients and by summing them.

2.4. Preliminary steps for analysis and model validation

We examined collinearity between explanatory variables with the Variance Inflation Factor (VIF) applying a threshold of 3 (Zuur *et al.* 2010). The collinearity issues were avoided by excluding the variables “elevation” and “distance to main road”. GPS-based resource selection studies are subject to both temporal and spatial autocorrelation (Dormann *et al.* 2007, Boyce *et al.* 2010). Distance to shoreline and distance to natal nest site can explain a considerable amount of variation in White-tailed Eagle space use (May *et al.* 2013, Balotari-Chiebao *et al.* 2018).

A large study area can lead to spatial correlation in the data, which can bias the impact of variables that are not evenly distributed across the landscape. We reduced the risk of temporal autocorrelation by selecting only one observation per day, thus reducing our dataset of in-flight positions to about 11%. The final number of observations used in the analyses was 3,712 (93–716/eagle). The proportion of observations decreased with age class (1–7 calendar years) from 32% to 4%. We examined the role of spatial autocorrelation, i.e., the degree to which one object is similar to other nearby objects (Boyce 2006), by using the Moran’s I index. This index measures whether the predicted values of the model are independent of the geographical distance between locations (Dormann *et al.* 2007, Griffith & Peres-Neto 2006). We calculated the Moran’s I for the full

model with function “moran.test” in package “spdep” in R.

We found significant spatial autocorrelation in the data, especially for locations within 3 km from each other. We thus incorporated a correction variable (autocovariate, “ac”) using the R-function “autocov_dist” in package “spdep” (R Core Team 2017) in order to reduce bias from spatial autocorrelation. Because the correction variable “ac” cannot be applied in predictive models, we handled spatial autocorrelation using a two-step approach as suggested by Boyce 2006 (see also Tikkanen *et al.* 2018). We first fitted the full model including the correction variable “ac” to establish a set of the most important variables explaining habitat use. Subsequently, we fitted the best model containing these important variables without the correction variable “ac”, which could be used as a predictive model. We also centered and standardized the explanatory variables to enable the comparison of their regression coefficients in the models (Schielzeth 2010).

We used the Akaike Information Criteria (AIC) for model selection. Because there was model selection uncertainty within $\Delta AIC < 2$, we applied model averaging to obtain the most important (relative importance > 0.7) variables explaining habitat use. The relevance of these selected explanatory variables was also tested by including individual and year as random slope effects, i.e., we allowed each group line to have a different slope across environmental gradients, so that the uncertainty is not underestimated (Gillies *et al.* 2006). In the second step we ran a model including the above selected variables using data that comprised random resamples (repeated 100 times) of 25% of the original data. Using this subset effectively reduced bias caused by spatial autocorrelation (Heckmann *et al.* 2014) and enabled the use of the whole dataset.

We used k-fold cross-validation to test for model performance (Kohavi 1995, Picard & Cook 1984) with the package “cvAUC” in R (R Core Team 2017). We partitioned the data, which included 60 year-individual-specific datasets, into five random groups of roughly equal size. We used four groups for predicting habitat use in the fifth group. This takes into account the factors that we assigned as random effects in the RSF-model (Tikkanen *et al.* 2018). We calculated confidence

Table 1. The results of the full RSF-model which included all predictor variables and the autocovariate (ac3000). z denotes to standardization of variables (mean = 0, sd = 1), and 0/1 to absence/presence. Random variables accounted for the following amounts of variance; Year: 0.004, Eagle: 0.012.

Explanatory variables	Full Model (FM)		Model averaging		Relative importance	FM with random slope	
	Coef. (se)	<i>p</i>	Coef. (se)	<i>p</i>		Coef. (se)	<i>p</i>
(Intercept)	-0.883(0.114)	< 0.001	-0.883(0.114)	<0.001	1	-1.687(0.419)	< 0.001
cac3000	-0.31(0.09)	< 0.001	-0.31(0.090)	<0.001	0.99	-0.256(0.157)	0.102
zDistance to birth site	-0.692(0.033)	< 0.001	-0.692(0.033)	<0.001	1	-1.259(0.458)	0.006
zDistance to land	-0.524(0.061)	< 0.001	-0.524(0.061)	<0.001	1	-1.209(0.273)	< 0.001
zDistance to sea	-0.811(0.043)	< 0.001	-0.810(0.043)	<0.001	1	-0.792(0.115)	< 0.001
zField	-1.523(0.096)	< 0.001	-1.524(0.096)	<0.001	1	-1.607(0.161)	< 0.001
zInland waters	0.077(0.027)	0.004	0.077(0.027)	0.004	0.95	0.074(0.058)	0.203
zOpen bogs	0.125(0.028)	< 0.001	0.125(0.028)	<0.001	1	0.162(0.048)	< 0.001
zSummer cottages	-0.267(0.029)	< 0.001	-0.266(0.029)	<0.001	1	-0.280(0.051)	< 0.001
zShoreline density	0.384(0.036)	< 0.001	0.384(0.036)	<0.001	1	0.355(0.086)	< 0.001
zDepth	-0.677(0.053)	< 0.001	-0.677(0.053)	<0.001	1	-0.495(0.134)	< 0.001
zPopulation	-0.251(0.069)	< 0.001	-0.251(0.069)	<0.001	1	-0.599(0.238)	0.011
zIndustry	-0.15(0.036)	< 0.001	-0.15(0.036)	<0.001	1	-0.155(0.061)	0.011

limits for AUC-values by repeating each analysis 100 times. We classified the variables into artificial environments (variables 2, 7, 9, 10 and 11), topography (variables 5, 6 and 12), waters and wetlands (variables 3, 4 and 8).

2.5. Relative risks of wind power plants for the White-tailed Eagles

We performed a risk assessment by presenting the relative probability (odds value) to identify which wind-farm areas are more likely to conflict with the space use of flying White-tailed Eagles. We calculated the probabilities for each wind-farm area by considering a surface area (10 km²) large enough to contain 10 to 15 turbines. Wind power plant locations were retrieved from a database upheld by the Finnish Wind Power Association (FWPA; updated information in April 2016). Information on proposed wind data included the number of projects, energy capacity and the estimated locations.

We also calculated the percentage of flight heights that occurred within 50–200 meters above ground level, which encompass the diameter of modern blades. Calculations were conducted separately for inland and at-sea locations. We estimated flight heights by subtracting ground eleva-

tion (18 m mean buffer) from the height indicated by the transmitter. A bird was considered to be flying above the sea when the ground elevation of the location point was less than 1 m. To reduce bias from tag altitude inaccuracy (Poessel *et al.* 2018), we considered birds to be flying when their speed was ≥ 2 kn (*ca.* 4 km/h). We tested whether White-tailed Eagles flew at risk heights (binary variable: 1 = 50–200 m, 0 = other heights) more often above land than above the sea using generalized linear mixed models with function *glmer*. Individual eagles were included as a random effect.

3. Results

3.1. Flying habitat use from the full model

The flying White-tailed Eagles selected the vicinity of their natal sites, the coastline, fragmented archipelago and open bogs. They avoided human settlements, cottages, agricultural areas, and deep sea water (Table 1). The number of observations decreased sharply when moving from the coast towards the open sea (Tables 1 & 2). The median distance between the shoreline and at-sea observations was only about 100 m and less than 1% of observations extended further than 5 km from the closest land area.

Table 2. Coefficients and their 95% Confidence Intervals from the predictive RSF-model in explaining White-tailed Eagle flying behaviour when 25% of data were randomly resampled 100 times. For comparison, coefficients derived from all data are shown (All).

Explanatory variables	Coefficient	95% LCI	95% HCI	Coefficient (All)
Intercept	0.827	0.63	1.050	0.833
Distance to birth site	-0.030	-0.048	-0.013	-0.030
Depth	-0.483	-0.581	-0.39	-0.482
Distance to land	-0.532	-0.8	-0.27	-0.496
Field areas	-0.033	-0.041	-0.028	-0.033
Open bog	0.007	0.001	0.013	0.007
Distance to sea	-0.056	-0.076	-0.041	-0.056
Cottage areas	-0.007	-0.01	-0.004	-0.008
Industry areas	-0.016	-0.033	-0.003	-0.014
Population	-0.001	-0.003	-0.001	-0.001
Shoreline density	0.003	0.002	0.003	0.003

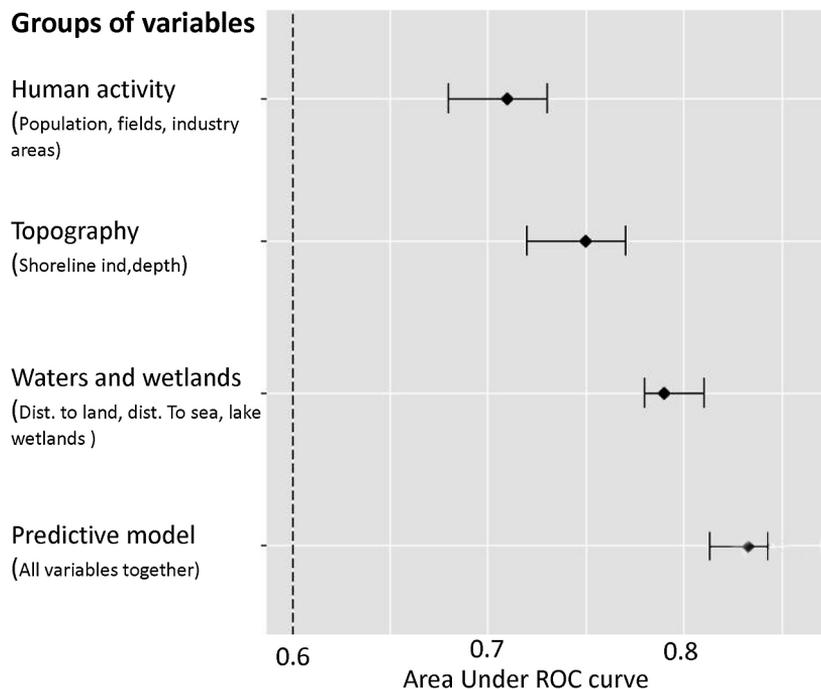


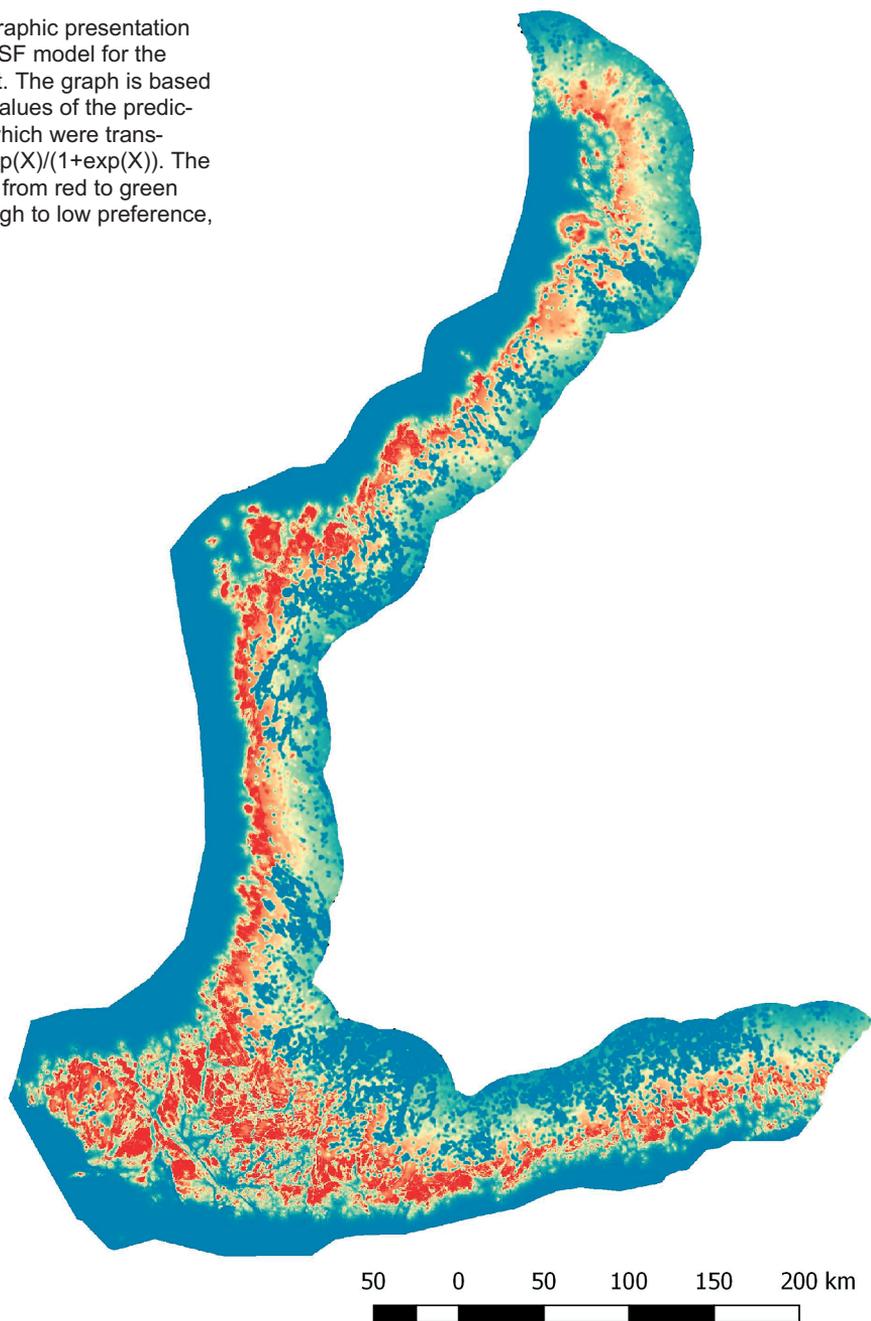
Fig. 2. The cross-validation performance of different variable groups (mean AUC value with 95% CI).

3.2. Predictive model

We calculated the final RSFs and their predictive ability without the autocovariate. The variables included in the final RSF ("best model") were selected from those having relative importance over 0.75 in the analysis presented in Table 1. There were three different models within $\Delta AIC < 2$, including variables that all were shown to be important in the full model analysis. In the random slope

model, one explanatory variable (proximity to inland water) did not reach significance. To avoid underestimating uncertainty, we did not include this variable to our predictive model (Table 2). Although the coefficients for the predictive model were estimated using 25% resamples of the original data (to avoid spatial autocorrelation), the coefficients were highly similar to those estimated by the full model (Table 2), indicating the preference for coastal areas and archipelagos, and the avoid-

Fig. 3. The graphic presentation of the best RSF model for the Finnish coast. The graph is based on the logit-values of the predictive model, which were transformed as $\exp(X)/(1+\exp(X))$. The colour-range from red to green represents high to low preference, respectively.

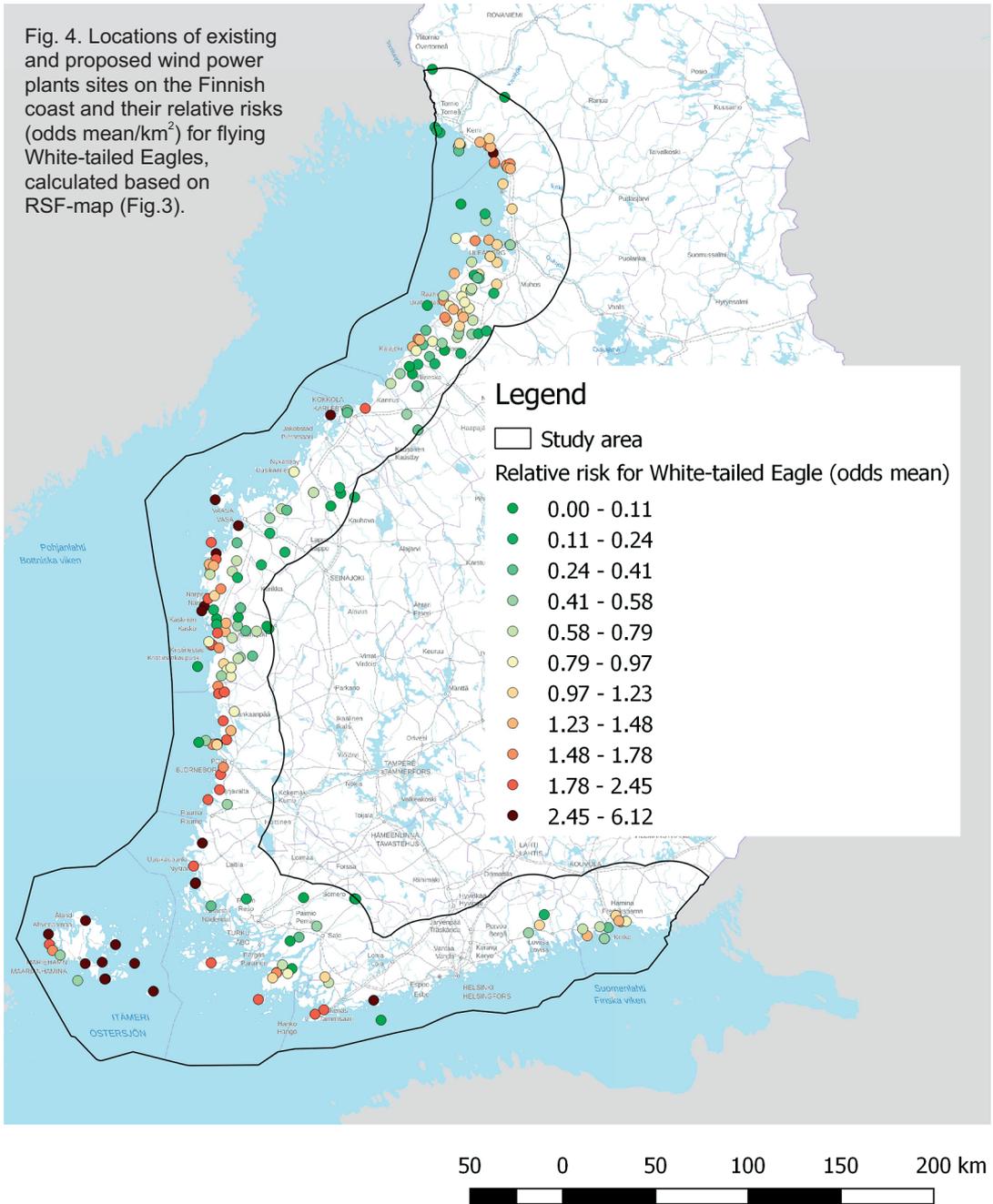


ance of open sea, agricultural areas and housing areas (Fig. 3).

3.3. Cross validation

Our predictive model determined the distribution of 0/1-points with high accuracy (AUC = 0.83,

Fig. 2). Distance to shoreline and wetlands (encompassing distance to land, distance to sea and open bog and other inland waters) performed slightly better (AUC = 0.80) than topography variables (shore line index and depth together; AUC = 0.78) and human infrastructure and agriculture areas (AUC = 0.71).



3.4. Flight heights

White-tailed Eagles flew more often at risk heights (50–200m) above land (29%) than above the sea (18%; GLMM: $\beta = 0.2776$, $SE = 0.0582$, $z = 4.77$, $p < 0.001$). The mean and median flight heights

were more than twice higher above land (mean 160 m; median 81 m) than above the sea (mean 78 m; median 20 m).

An altitude of 200 meters is considered an upper limit of the risk height at wind power plants (e.g., Vestas 2016). About 72% of flights occurred

under 200 meters above land and 87% above the sea, correspondingly.

3.5. Relative risks posed by proposed and constructed wind power plants

There was large spatial variation in the observations of White-tailed Eagles. On the basis of our space use model, the relative probabilities of occurring at different wind-farm areas can differ by more than 1,000 times. If we assume that the probability of occurrence directly reflects collision risk, we can predict relative risks using our model. The wind power plants that pose the greatest risk are located in the Kvarken Archipelago and the Åland Islands, whereas the lowest risks are located inland, far away from the coast and large waterbodies, agricultural areas or out in the open sea (Fig. 4). Importantly, there can be a tenfold difference in the risk even between areas within close proximity (less than 10 km) as seen between the industrial area in Kokkola (lower risk) and a close by archipelago (higher risk; Fig. 4).

4. Discussion

We developed a resource selection model that accurately predicted habitat use of flying sub-adult White-tailed Eagles, a species vulnerable to wind turbine collisions. We used this powerful tool for giving general guidelines on wind power plant planning in relation to the most important environmental variables. Furthermore, we produced a spatially explicit map predicting space use across the landscape and estimate risks associated with existing and planned wind power plants with the aim of minimizing future negative impacts caused by wind power plants (Harju *et al.* 2011).

4.1. Environment use and preference of White-tailed Eagles

The White-tailed Eagles in our study area flew most often on the coastline and islands, which is common among breeding and subadult individuals (Radović & Mikuska 2009, Bevanger *et al.* 2010, May *et al.* 2013, Balotari-Chiebao *et al.*

2018). Within the Baltic Sea coast, White-tailed Eagles preferred areas with a fragmented shoreline and shallow waters. Both variables most likely reflect food availability such as fish and aquatic birds (Sulkava *et al.* 1997, Ekblad *et al.* 2016). Dependence on these coastal habitats was further supported by strong avoidance of open sea areas.

In addition to prey availability, the avoidance of open sea habitats may be linked to the “sit-and-wait” hunting mode used by most raptors including the White-tailed Eagle (Nadjafzadeh *et al.* 2016), and a lack of uplifts that may prevent soaring (Bohrer *et al.* 2012, Miller *et al.* 2014, May 2013). Accordingly, the probabilities of use declined faster when moving towards the sea from the shoreline than when moving inland, where uplifts occur more frequently. Land areas also offer water bodies and bogs as potential foraging areas.

White-tailed Eagles avoided human settlements, concentrations of cottages, agricultural and industrial areas, which is consistent with previous studies on the avoidance of human activity (May 2013, Radović & Mikuska 2009, Scholz 2010, Balotari-Chiebao *et al.* 2018). This enhances a growing conservation concern as the encroachment of human infrastructure increases, including wind power plants. May *et al.* found that non-territorial subadult White-tailed Eagles were partially displaced from habitats encompassed by a wind-power plant.

However, the eagles still failed to show any sign of behavioural in-flight changes (Dahl *et al.* 2013), making them more vulnerable to collision mortality. The distance to the natal nest was an important factor affecting the distribution of the observations from the flying eagles. Although White-tailed Eagles move over vast areas, and they can make prospecting movements of up to several hundreds of kilometres (Stjernberg *et al.* 2015), the observations were concentrated around their natal areas.

4.1. Recommendations for wind power plant locations

Careful site selection is crucial to reduce the risk of collision, especially in species such as the White-tailed Eagle which does not seem to actively avoid wind turbines (Dahl *et al.* 2013, Krone *et al.* 2017,

FCG 2018). Given the uneven space use caused by the strong habitat preferences, and different flight heights above land and sea, we found large differences in the risks that different wind power plants pose to sub-adult White-tailed Eagles. Differences in relative risks can be up to 1,000 times. Our results conform with the suggestion that the safest sites for wind power plants are situated away from coastal foraging and breeding habitats (Balotari-Chiebao *et al.* 2018, May 2013), either clearly inland or in deep sea areas at a distance from shallow seas and skerries—islets, i.e., > 3–5 km from the shoreline.

As White-tailed Eagles flew clearly lower above the sea and less often at the risk height (50–200 m) than on land (see also Nygård *et al.* 2010, Balotari-Chiebao *et al.* 2018), the collision risk may be further reduced at sea but further research is needed to ascertain behaviour of White-tailed Eagles that encounter a wind turbine. It must be noted, however, that wind power plants and risk height at rotors are often larger at sea (Kurian 2010). Inland, the proximity to wetlands increases collision risks, but suitable options for onshore wind turbines include large agricultural, forest and industrial (also near the coastline) areas.

4.2. Recommendations for future studies

Our study illustrates the potential of combining telemetry data with information on environmental and landscape variables in order to assess avian space use in relation to wind-energy development. A limitation to our study is that our data did not include breeding adult eagles or individuals from areas further inland or from Lapland, a region that comprises 20% of the current Finnish population (Stjernberg *et al.* 2015). Individuals from other areas can behave differently from those hatched in coastal areas. GPS data provide reliable information about flight activity (daily and annual), which, taken together with our flying resource selection model, can be used for estimating flying times, as has been done for breeding Golden Eagles (*Aquila chrysaetos*; Tikkanen *et al.* 2018).

This makes it possible to estimate collision risk at wind power plants or single turbines. Risk models for White-tailed Eagles can be further developed for estimating collision risks in a more pre-

cise manner. Habitat use, and flight activity coupled with collision risk (Masden & Cook 2016, Péron *et al.* 2017) and demographic models (Hunt *et al.* 2017, Wiens *et al.* 2017) are important tools in predicting anthropogenic and cumulative (Masden *et al.* 2010) impacts and in assessing allowable levels of environmental change caused by renewable energy sources (Tikkanen *et al.* 2018).

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Lentävien esi aikuisten merikotkien habitaa tin valinnan mallintaminen tuulivoimala-alueiden ja muun maankäytön suunnittelun avuksi

Laajamittainen tuulivoimaloiden rakentaminen saattaa muodostaa uhan kookkaille petolinnuille sekä populaatio- että yksilötasailla. Tehokkain tapa ehkäistä tuulivoiman haitallisia vaikutuksia uhanalaisille lajeille on välttää rakentamista riskialttiimmille paikoille. Merikotka (*Haliaeetus albicilla*) on tuulivoimaloille erityisen riskialtis laji. Etenkin laajojen maankäyttösuunnitelmien ongelmana on se, ettei kotkien liikkeitä ja käyttäytymisestä ole riittävän tarkkoja ja kattavia tietoja suunnitteluvaiheessa.

Ratkaisuksi tähän ongelmaan kehitimme satelliittipaikannuksiin perustuvan elinympäristömallin (RSF), jonka avulla voidaan ennustaa esi aikuisten lentävien merikotkien liikkeitä Suomen rannikolle (maks. 40 km rantaviivasta). Tälle alueelle keskittyy noin 80 % sekä Suomeen suunnitelluista tuulivoimapaustoista että pesivistä merikotkista. Lisäksi laskimme aineiston ja mallin avulla esiintymistodennäköisyyksiä, mikä kuvastaa myös törmäysriskejä, Suomen rannikolle suunnitelluille ja jo rakennetuille tuulivoima-alueille. Paras malli ennusti lentohabitaa tin valinnan 83 % luotettavuudella (perustuen ristiinvaldointiin).

Kotkat suosivat synnyinpesänsä läheisyyttä,

merenrantoja, rikkonaista saaristoa ja kosteikkoja ja välttävät meren ulappa-alueita, rakennettuja/muutettuja ympäristöjä kuten taajamia, huvilakeskittymiä, teollisuutta ja peltoja. GPS-aineistojen mukaan kotkat lentävät meren yllä selvästi matalammalla kuin maalla (mediaani maalla 80 m ja merellä 20 m). Esiakuiset merikotkat lensivät tuulivoimaloiden muodostamalla riskikorkeudella (50–200 m) maalla noin 28 % ja merellä noin 19 % lentoajasta.

Eri ympäristötyyppien suosimisesta/välittelemisestä sekä lentokorkeuksien eroista johtuen, suunniteltujen/rakennettujen tuulivoima-alueiden suhteelliset riskit eroavat toisistaan jopa yli tuhattaisesti Suomen rannikolla. Esittämällämme menetelmällä voidaan mallintaa merikotkien lentokäyttäytymistä ja elinympäristöjen valintaan ja ennustaa niiden esiintymistä rannikolla. Malli toimii työkaluna maankäytön suunnittelussa ja vaikutusten arvioinneissa esim. etsittäessä tuulivoimapuistoille soveltuvia ja merikotkille haitattomia alueita.

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