REPORT

Post-fledging movements of white-tailed eagles: Conservation implications for wind-energy development

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Abstract The presence of poorly sited wind farms raises concerns for wildlife, including birds of prey. Therefore, there is a need to extend the knowledge of the potential human–wildlife conflicts associated with wind energy. Here, we report on the movements and habitat use of post-fledging satellite-tagged white-tailed eagles in Finland, where wind-energy development is expected to increase in the near future. In particular, we examine the probability of a fledgling approaching a hypothetical turbine that is placed at different distances from the nest. We found that this probability is high at short distances but considerably decreases with increasing distances to the nest. A utilisation–availability analysis showed that the coast was the preferred habitat. We argue that avoiding construction between active nests and the shoreline, as well as adopting the currently 2-km buffer zone for turbine deployment, can avoid or minimise potential impacts on post-fledging white-tailed eagles.

Keywords Wind energy · Post-fledging · White-tailed eagle · Movements · Habitat use · Conservation

INTRODUCTION

Wind power is a fast-growing renewable energy source in many parts of the world (World Wind Energy Association 2014). Despite its climate change-related benefits, the construction of wind farms is a cause of concerns for wildlife (Kuvlesky et al. 2007), including birds (Drewitt and Langston 2006, 2008; Gove et al. 2013).

With evidence of negative impacts on local bird populations (Barrios and Rodríguez 2004; Smallwood and The-lander 2008; Pearce-Higgins et al. 2009), an understanding

of space-use patterns by vulnerable species may have important implications for environmental assessments and mitigation strategies. There has been an increasing interest in the study of bird movements in relation to wind-power generation on both raptor (Duerr et al. 2012; Katzner et al. 2012; Watson et al. 2014) and non-raptor species (Corman and Garthe 2014).

The white-tailed eagle (*Haliaeetus albicilla*) is an apex predator that has been shown to be affected by collision mortality (Krone and Scharnweber 2003; Bevanger et al. 2010; Ueta et al. 2010) and displacement (in terms of nest desertion due to proximity to turbines; Bevanger et al. 2010). Particularly notable is the case of the Norwegian island of Smøla. On this island, a 68-turbine wind farm has caused a reduction in the breeding success of nearby territories due to both turbine strikes and displacement (Dahl et al. 2012).

The recent use of satellite transmitters has revealed important aspects of movement patterns of the white-tailed eagle, including home range (Krone et al. 2008, 2013), dispersal (Bevanger et al. 2010) and migration (Ueta et al. 2010). Even though some previous studies have focused on juveniles (Shiraki 2002; Whitfield et al. 2009a, b), little attention has been paid to the details of their pre-dispersal movements, that is, the flight activity that occurs between fledging and dispersal. In this regard, the present study makes a contribution to the current knowledge of white-tailed eagle movements.

In Finland, the white-tailed eagle is listed as a vulnerable species in the National Red List (Mikkola-Roos et al. 2010). Given its vulnerability to wind-power generation, the expected expansion of the country's wind-energy production raises concerns for its local populations. The target is to reach an annual production of ca. 9TWh by 2025 (National Energy and Climate Strategy 2013), which

corresponds to an installed capacity of ca. 3750 MW (1200–1500 turbines). It is plausible, however, that a higher number of turbines will be in operation by the end of this period. This is indicated by the large number of projects that have recently been presented for the whole country, proposing the deployment of more than 4000 turbines (mainly along the coast; Finnish Wind Association 2015). It is also along the coast that most white-tailed eagles (80–90 %) breed in Finland (Herrmann et al. 2011).

In the context of wind-power generation, the period between fledging and dispersal may be critical to juvenile white-tailed eagles. It is in this period, particularly during the first calendar year, that they lack flight experience and manoeuvrability, while being also more naïve towards the surrounding environment (Bevanger et al. 2010). First-calendar-year juveniles are also apparently less prone to avoid areas with wind turbines (May et al. 2013), a behavioural feature which presumably makes them more vulnerable to collision mortality.

Here, we use satellite telemetry to describe the movements of post-fledging white-tailed eagles, and to discuss the threats that birds at this stage may face in cases where turbines are deployed in the vicinity of the nest. Based on their movements, we (1) provide estimates of home range, fledging and dispersal times, (2) calculate the probability of a fledged bird approaching a hypothetical turbine that is placed at different distances from the nest and (3) examine habitat preferences in terms of the use of coastal, inland and aquatic habitats. The primary aim of this study is to provide information that can be used by developers and planning authorities in order to avoid or minimise the

potential risks of wind-power generation to fledgling white-tailed eagles.

MATERIALS AND METHODS

Study species

The white-tailed eagle is a large, diurnal raptor with a widely scattered distribution that ranges from south-western Greenland to Europe and Asia, including India, China and Japan (BirdLife International 2013). It is associated with aquatic habitats such as sea shores and freshwater lakes, nesting preferably on the crown of tall and old-growth trees (Cramp and Simmons 1980).

In Finland, the white-tailed eagle was driven to the brink of extinction in the twentieth century, with numbers increasing over the last decades due to effective conservation measures (Herrmann et al. 2011). In 2014, the known Finnish breeding population had ca. 450 pairs (WWF Finland 2015). Nonetheless, the species is still classified as vulnerable in the Red List of Finnish Species (Mikkola-Roos et al. 2010).

Satellite telemetry and data selection

A total of 14 nestlings were fitted with a 70 g Argos/GPS Solar Powered PTT (Platform Transmitter Terminal), manufactured by Microwave Telemetry, Inc., in June–July 2009–2011 and 2013 (Table 1). Birds hatched in the west and south-west of Finland, the majority of which (12 of 14)

Table 1 General information on the 14 satellite-tagged juvenile white-tailed eagles, including age at the time of fitting, and fledging and dispersal times. Individual age was estimated by back-calculating from wing length measurements, as described in Hardey et al. (2013)

Bird ID	Hatch year	Weight at fitting (kg)	Age at fitting (days)	Age at fledging (days)	Age at onset of dispersal (days)	Days between fledging-dispersal
33207	2010	4.8	57	86	150	64
33210	2011	4.0	47	74	147	73
33211	2013	2.9	57	79	154	75
33212	2013	2.9	57	84	152	68
92632	2009	4.3	58	75	150	75
92633	2009	5.3	63	80	244	164
92634	2009	4.2	60	71	199	128
92635	2009	5.3	59	78	144	66
105680	2011	–	55	83	168	85
105681	2011	–	61	85	184	99
105682	2011	4.0	57	77	168	91
105831	2013	3.3	35	78	177	99
105832	2013	–	57	77	149	72
105833	2013	–	64	78	115	37
Mean ± SD		3.9 ± 0.9	56 ± 7	79 ± 4	164 ± 31	85 ± 31

Fig. 1 Map showing the approximate nest locations of the 14 white-tailed eagles monitored by satellite telemetry during the post-fledging period. The *circular symbols* indicate nine individual nests. The remaining five nests, whose distance to each other is too short to allow proper visualisation at the used scale, are represented with a *dashed circle*

at short distances (<1315 m) to the sea (Fig. 1). The total weight carried by a bird (i.e. the PTT plus the harness and an additional battery for data transmission during the winter) amounted to ca. 100 g, thus representing on average less than 2.6 % (± 0.6 SD) of its mass at the time of fitting. This proportion is in accordance with the recommended loading for birds (Kenward 2001). Permits for ringing and satellite tagging were issued by the local environmental authority, the Centre for Economic Development, Transport and the Environment (ELY).

We calculated an average GPS location error to increase data accuracy for analyses. This was achieved by first estimating all nest locations based on the positions received during the first 2 days of data collection. From their standard deviation we then computed the average location error, which equalled to 10.29 m ($n = 474$). Data were transmitted on an hourly basis during daytime, and we only retained GPS positions that were obtained during the period between fledging and dispersal from the natal area (see below). An individual was considered to have fledged when the distance from the nest was at least twice as long as the average location error for five consecutive locations. Similarly, an individual was considered to have dispersed

when being for more than 10 consecutive days farther than 5 km from the nest. The fledging time of one individual, which apparently fell out of the nest, was determined by its altitudinal profile as this indicated when it became able to fly.

Home range analyses

To obtain an estimation of home range, we computed utilisation distributions (UDs)—a method that estimates the probability density of an individual being located at a given location (Worton 1989, 1995)—with a bivariate normal density kernel. To this end, we first centred all individual nests, along with the bird positions, on coordinates (0, 0). Given the large heterogeneity in the number of locations per bird, we used a bootstrap approach, sampling for each individual 332 locations (the lowest individual sample size). This procedure was repeated 100 times. From the resulting 100 home ranges, an average home range was obtained. We specified home ranges for two different percentages, which represented the smallest area within which the probability to relocate an individual corresponded to 50 or 95 %. Given the behaviour of the

monitored juvenile white-tailed eagles, which covered short distances from the nest and spent most of the time at rest, we assumed autocorrelation to be of negligible influence.

In addition, we calculated the maximum daily distance from the nest after fledging, both at the individual level and as an average over all individuals.

Probability of a bird visiting the vicinity of a hypothetical turbine

Our aim was to compute the probability $P(d)$ by which a fledged bird will ever visit the vicinity of a single hypothetical turbine that is installed at a distance d from the nest. Here, we defined vicinity as the area (hereafter vicinity area) within 150 m from the turbine, assuming that such proximity entails a substantial degree of individual risk.

We computed $P(d)$ for all birds separately. To this end, we partitioned the area around each nest into concentric circles, with the distance between the nest and the circle perimeter (denoted by d) ranging from 100 to 5000 m with an increment of 100 m. Based on the observed movement tracks (assuming that the birds moved from one recorded position to the next in a straight line), we then asked by which probability a bird will ever reach the vicinity of a turbine that is placed at a distance d from the nest in a random direction. Using movement tracks, rather than positions alone, we were able to account for the space used between consecutive positions (despite being unable to know the real trajectory between them).

As a computational tool, instead of randomising the location of the nest, we selected 100 uniformly distributed positions along each circle perimeter. We discretised the tracks on a grid with cell size 100×100 m. We then computed the probability in question as $P(d) = \frac{\sum_{i=1}^{100} W_i}{100}$, where $W_i = 1$ for grid cells with the presence of a track, and $W_i = 0$ for grid cells with the absence of a track.

We note that we intentionally opted for a relatively simple scenario that included a one at a time single turbine deployment across a distance range, as opposed to a complex scenario with multiple turbines and different configurations, given the large number of possibilities and arbitrariness of the latter. Furthermore, we did not perform the calculation including only in-flight positions (i.e. instantaneous speed $>5 \text{ km h}^{-1}$) because such positions amounted to only ca. 4 % of all observations, and thus the data would have been insufficient.

In addition, we estimated the height above ground level (AGL) for in-flight positions with the aid of a digital elevation model (ASTER GDEM; 30 m resolution). This was achieved by subtracting the topographic height from the

height above sea level (ASL) of each recorded in-flight position. Negative values, which resulted from inaccuracies associated with the satellite transmitter, were not considered. Following Reid et al. (2015), we considered flights up to 200 m AGL as a meaningful range for the threat of a turbine strike.

Habitat preferences

The surrounding landscape was classified into three habitat categories: coastal (coastline extending 100 m towards both land and sea), inland (land > 100 m from seashore) and aquatic (water > 100 m from seashore or lakeshore). The latter was included to account for the importance of distant islets and skerries as movement habitats.

The observed habitat use was obtained in the following way: we counted for each bird the number of positions that fell in each habitat category within the limits of concentric circles (centred on the nest) with radius 500–5000 m with a 250 m increment. To obtain a measure of the expected habitat use, we randomly sampled for each bird twice the number of positions obtained per concentric circle before randomising their directions within each circle, thereby ensuring a representative sample for each distance range. We used the Chi-square technique to test whether the birds used each habitat category in proportion to its availability as estimated by the random sampling. If observed and expected habitat uses differ significantly (i.e. if the null hypothesis is rejected), it is possible to determine preference or avoidance of individual habitats based on confidence intervals (p_i) calculated with a Bonferroni z statistic (Neu et al. 1974). Two birds (the ones which hatched far from the sea; Fig. 1) were excluded from this analysis, given that the coastal habitat was unavailable to them.

All analyses and graphic displays (except for Fig. 1, which was produced with MapInfo Professional 12.0) were performed in R 3.0.1, including the following packages: adehabitatHR (Calenge 2006), raster (Hijmans and Etten 2013), rgeos (Bivand and Rundel 2013), ggplot2 (Wickham 2009) and maptools (Bivand and Lewin-Koh 2013).

RESULTS

We monitored the movements of 14 white-tailed eagles from fledging until the onset of dispersal from the natal area. All satellite transmitters were functioning at the end of the study period. Our data ranged from late June to late December and amounted to 11 171 positions ($\bar{x} = 798 \pm 308$ SD; range = 412–1541), which indicate a relatively high success rate of transmission (ca. 80 %).

Nestlings fledged at 71–86 days old, and fledglings dispersed at the age of 115–244 days (Table 1). For most

Table 2 Individual and average home ranges for two different percentages (50 and 95 %) estimated by the kernel method. The last column provides a comparison between the 50 % and the 95 % home ranges, reporting the proportion of the former in relation to the latter

Bird ID	50 % Isopleth (km ²)	95 % Isopleth (km ²)	Proportion between 50 and 95 % isopleths (%)
33207	0.46	2.98	15
33210	0.71	7.46	10
33211	0.19	3.53	5
33212	0.51	4.76	11
92632	0.77	7.86	10
92633	1.39	22.66	6
92634	0.34	10.72	3
92635	0.33	3.85	9
105680	0.12	1.3	9
105681	2.73	20.95	13
105682	0.58	11.27	5
105831	0.52	6.62	8
105832	0.61	3.99	15
105833	0.15	1.71	9
Mean $\pm$ SD	0.67 $\pm$ 0.67	7.83 $\pm$ 6.66	11 $\pm$ 4

individuals ($n = 8$) dispersal took place between two and 3 months after fledging, and there was no overlap between the two biological events (i.e. when the first bird dispersed all the others had already fledged; Table 1).

Home range analyses

Home ranges varied considerably among individuals in the 50 % isopleth as well as in the 95 % isopleth (Table 2). The 95 % average home range had a much (ca. 11 times) larger area than that of the 50 % average home range (Table 2; Fig. 2).

After fledging, there was a general gradual increase in the maximum daily distance from the nest over time (Fig. 3). On average, the distance increased sharply within approximately the first 75 days, nearly reaching 4 km, and levelled off over the following 2 months (for the six individuals which remained in the natal territory; Table 1).

Visiting the vicinity of a hypothetical turbine

As expected, the probability of a fledged bird ever visiting the vicinity of a single hypothetical turbine decreases with increasing distances from the nest (Fig. 4). In other words,

Fig. 2 Diagram showing the average home ranges of the 14 satellite-tracked individuals, with individual nests and positions centred on coordinates (0, 0). The *dark*, central patch corresponds to the contour of the 50 % home range (i.e. the core area), while the patch in *lighter grey* corresponds to the 95 % home range area

Fig. 3 Individual maximum daily distance from the nest covered by post-fledging white-tailed eagles, with the average shown by the *bold line* together with the standard error interval. The *arrows* indicate the onset of individual dispersal; the *arrows in bold* indicate when two individuals dispersed in the same day

Fig. 4 Probability of a fledging white-tailed eagle ever visiting the vicinity of a single turbine located at different distances from the nest. The probability is shown at both the individual level and as an average over all individuals, represented by the *bold line* with the standard error interval

a turbine that is closer to the nest will be approached by a bird with a greater probability. This pattern primarily reflects the way in which our satellite-tagged individuals used the space around the nest, namely that the closest vicinity areas were visited at a larger proportion. In fact, most of the recorded movements were restricted to short distances from the nest, resulting in the steep decline of the probability that is seen in the first half of the distance range (Fig. 4). For instance, 83 and 91 % of all observations occurred within less than 2000 and 3000 m. At these distances, the probability declines to 0.5 and 0.3, respectively (Fig. 4).

When considering only in-flight positions ($n = 464$, $\bar{x} = 33 \pm 19$ SD; range = 8–76), the average flight height was 75 m AGL (± 93 SD; range = 1–543). Most of the flight heights (422 of 464) occurred within 200 m AGL ($\bar{x} = 50 \text{ m} \pm 43$ SD), indicating that the birds showed preference for a vertical range which is encompassed by the height of modern turbines.

Habitat preferences

The monitored birds used coastal, inland and aquatic habitats in a proportion that was significantly different from their availability within the study area ($\chi^2 = 1916.4$, $df = 2$, $p < 0.001$). We therefore rejected the null hypothesis and proceeded to detect preference or avoidance of individual habitats. According to the individual confidence intervals on the observed habitat use, coastal areas were used considerably more than expected (i.e. were preferred) while inland and aquatic areas were used considerably less than expected (i.e. were avoided; Table 3).

DISCUSSION

The general pattern of movements of the studied pre-dispersal juvenile white-tailed eagles clearly suggests that the closer to the nest a turbine is deployed, the higher the risk of an individual at this stage visiting its vicinity. This spatial behaviour, together with the pattern of habitat selection reported here, provides valuable information for

the avoidance or minimisation of undesirable effects associated with wind-power generation.

Bird movements were predominantly concentrated within short distances from the nest. In the average core area (i.e. the 50 % average home range), positions were rather regularly distributed, whereas in the 95 % average home range they were considerably spread and formed a few scattered concentrations. These features made the latter irregular in shape and much (ca. 11 times) larger than the former. The difference in magnitude between these two home ranges is partly explained by the fact that juvenile white-tailed eagles tend to initially spend time in a restricted area around the nest, being fed by their parents, and only exploring farther areas as they become more independent in later stages (Cramp and Simmons 1980).

The studied birds showed much greater variation in the dispersal time than in the fledging time. More than 4 months separated the first from the last individual to disperse, while only 15 days elapsed between the fledging time of the first and the last individual. The greater variation of the former may reflect the assertion that, after fledging, the quality of the surrounding habitats (e.g. in terms of feeding opportunities) influences individual decision on how much time to spend in the natal area (Clobert et al. 2012). Presumably, the longer an individual remains in the natal area, the higher the risk of being affected by wind turbines and associated infrastructure; our data indicated that the majority of individuals started dispersing between two and 3 months after fledging. In addition, their flight heights tended to fall within a range that overlaps not only with the height of older turbines, but also with the higher turbines that are currently being deployed (International Energy Agency 2013). However, it is important to note that the birds spent little time in actual flight (ca. 4 % of the observations). This suggests that, if turbine deployment is done sufficiently far from the nest, the risk of collision, which is dependent on an apparently high avoidance rate (May et al. 2011), may be greatly reduced.

As regards habitat selection, coastal areas were shown to be preferred while inland and aquatic areas were shown to be avoided. A coastal strip as narrow as 200 m (i.e. the width used in this study to define the coastal and adjacent

Table 3 Observed and expected proportions for the coastal, inland and aquatic habitats within the study area along with their corresponding confidence intervals. Preference (+) is indicated by a confidence interval that exceeds the expected proportion; avoidance (–) is indicated by an interval whose values remain below the expected proportion

Habitat	Observed proportion	Expected proportion	Confidence interval on the observed proportion (p_i) ^a	Preference (+) or avoidance (–)
Coastal	0.466	0.226	$0.447 \leq p_1 \leq 0.485$	+
Inland	0.458	0.561	$0.439 \leq p_2 \leq 0.477$	–
Aquatic	0.076	0.213	$0.066 \leq p_3 \leq 0.086$	–

^a Confidence intervals were computed with the z statistic at the 0.05 level of significance

habitats) undoubtedly attests the great importance of the coast for those juveniles that hatched close to the sea. Given their strong pattern of movements towards the sea after fledging, we recommend the avoidance of turbine deployment between a white-tailed eagle nest and the coastline. Following May et al. (2013), we stress that attention should also be given to coastal areas where nearby shallow waters, islets and skerries are foraging habitats.

In Finland, the WWF White-Tailed Eagle Working Group has proposed a 2-km buffer zone around active nests as a reference for the deployment of onshore turbines (WWF Finland 2011). A 2-km radius centred on the nest corresponds to an area of ca. 12.6 km². Here, it is important to highlight that nearly all (12 of 14) individuals had a 95% home range that remained within the limits of this area. If we assume our results to be representative, a 2-km buffer has therefore the potential to safeguard pre-dispersal juvenile white-tailed eagles. We note, however, that the probability of a bird at this stage approaching a turbine placed at this distance is still 0.5, which is a relatively high figure. Whether this probability implies an actual high threat of collision mortality, we cannot say. We cannot make quantitative predictions on collision risk (which is likely the greatest threat for it increases juvenile mortality; Bevanger et al. 2009) because our analysis did not include influencing factors such as flight heights (Corman and Garthe 2014), avoidance rate (May et al. 2011), and topography (de Lucas et al. 2012; Katzner et al. 2012).

In this study, the probability of a bird approaching a potential turbine was estimated by actual bird visits to the vicinity of 100 positions distributed equidistantly over the perimeter of each circle around the nest (as described in “Probability of a bird visiting the vicinity of a hypothetical turbine” section). It should be noted that, based on our study design, it is inevitable for certain movement patterns that the resulting probabilities are higher for areas that are closer to the nest. Consider, for instance, a bird that upon leaving the nest flies along a straight line, crossing the whole study area. In this case, the probability in question would be greater for a turbine located close to the nest than for a turbine located far from the nest, because the bird’s flight path crosses more vicinity areas at closer distances (due to overlapping) than at longer distances. This pattern reflects the reality that the area of a turbine corresponds to a larger proportion of a circle perimeter when installed at closer distances than at longer distances.

Lastly, we would like to reiterate that the approach we used to define the study scenario is not equivalent to placing 100 hypothetical turbines at different distances from the nest. Such a scenario would be inappropriate as the turbines would be unrealistically close to each other on the closest

perimeters. As explained above (“Probability of a bird visiting the vicinity of a hypothetical turbine” section), our aim was to provide instead the probability of a bird approaching a turbine (i.e. a single turbine) that is installed in any of the 100 positions available at any of the distances considered. The probabilities obtained across the distance range may nevertheless be combined to account for multiple turbines (i.e. a wind farm) at different distances from the nest.

CONCLUSIONS

Based on our results and the vulnerability of the species, we argue that a conservation conflict may be avoided or minimised if turbine deployment is done sufficiently far from the nest. Ideally, areas already environmentally disturbed should serve as an alternative (Drewitt and Langston 2008). Also, the aggregation of turbines into as few as possible wind farms, rather than the installation of single turbines resulting in the same power production, may reduce the effects on local populations, as shown by Schaub (2012) in a simulation study on a large raptor species. Detailed pre- and post-construction monitoring as well as further research, particularly on spatial and demographic models, are needed to complement our findings. In view of this growing human–wildlife conflict, a most conservative approach to wind farm construction, with the avoidance of priority habitats, is highly desirable.

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