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**Habitat Utilization in White-tailed Eagles (*Haliaeetus albicilla*) and the Displacement Impact of the Smøla Wind-power Plant**

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**ABSTRACT** On average, 7.8 white-tailed eagles (*Haliaeetus albicilla*) collide with wind turbines annually at the operating wind-power plant on the island of Smøla off the coast of central Norway. To better understand the impact of this wind-power plant on white-tailed eagles, we investigated how habitat utilization affected displacement effects. We collected data on habitat utilization in non-territorial sub-adult white-tailed eagles using global positioning system satellite telemetry (2004-2009). From these data, we estimated utilization distributions using the Brownian bridge movement model and analyzed them using Resource Utilization Functions. Home ranges were circa 10-30% smaller for sub-adults hatched on skerries and islets farther from the wind-power plant, and tended to be circa 40% larger

during spring. Shallow sea, skerries and islets were utilized extensively, as was marsh, heathland, and forest on the main island of Smøla. We noted lower selectivity for arable land and higher levels of differentiation in utilization among individuals for forest and islets. Females also had a nearly 4 times higher between-individual variation, which was likely due to long-ranging excursions. The within- and between-individual variation among seasons showed an annual pattern, with increasing between-individual variation toward summer. Displacement (indicated by an overall 40% proportional reduction in utilization) was more pronounced in the birds' second and third calendar year compared with their first calendar year, and during autumn–winter. Reduced displacement during spring coincides with the white-tailed eagle pre-breeding period with increased flight activity. This may, in part, explain increased collision risk during spring. Possible displacement effects in white-tailed eagles may be avoided by siting wind-power plants farther inland or offshore.

**KEY WORDS** avoidance, collision risk, displacement, habitat use, habitat utilization, *Haliaeetus albicilla*, Norway, wind turbines.

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Renewable energy is seen as an important measure to reduce the effects of climate change (Pachauri and Reisinger 2007, IPCC 2011). Although Norway has its main energy production from renewable sources such as hydropower, the country has committed itself to follow the European Union Renewable Energy Directive and increase the renewable production to cover 67.5% of the total consumption within 2020. As the majority of the hydropower resources are exhausted, within the coming decade wind resources will be exploited especially in coastal areas, where already several wind-power plants are operational or under construction. However, the long and diverse Norwegian coast, which includes offshore archipelagos and shallow waters, also constitutes important European habitats for migrating and resident sea

and coastal birds (Richardson 2000, Barrett et al. 2006). Large soaring birds of prey and long-lived seabirds are recognized to be especially vulnerable to collisions with turbines (Barrios and Rodriguez 2004; Garthe and Hüppop 2004; Hoover and Morrison 2005; Smallwood and Thelander 2008, Carrete et al. 2009, 2012). In addition to direct collision mortality, raptors and sea birds may also be displaced from their natural habitats due to wind-energy development (Larsen and Madsen 2000, Madsen and Boertmann 2008, Pearce-Higgins et al. 2009, Garvin et al. 2011, Dahl et al. 2012).

In Norway, one of the species that is known to be especially vulnerable to wind-energy development is the white-tailed eagle (*Haliaeetus albicilla*). The conflicts at the Smøla wind-power plant, and the extensive research project (2004–2011) that studied them, have received much media attention internationally as a ‘worst case’ (Bevanger et al. 2010*b*), similar to the Altamont Pass Wind Resource Area (Smallwood and Thelander 2008). On average, 7.8 white-tailed eagles collide with wind turbines at the Smøla wind-power plant annually (approx. 0.1 eagle/2.3-MW turbine/yr; Bevanger et al. 2010*b*). The white-tailed eagle is the largest bird of prey in Europe, and Norway holds nearly half of the European population. Because of this, Norway has a special responsibility to the conservation of this species. In 2000, the Norwegian population was estimated at approximately 1,900–2,200 pairs (Folkestad 2003), and has grown since. Since its protection in 1968, it has reoccupied many of its previous habitats, and is a regular breeder along most of the Norwegian coast, including Smøla. About 45 white-tailed eagle territories (= 90 breeding birds) have been reported in the Smøla archipelago (Bevanger et al. 2010*b*, May et al. 2011, Dahl et al. 2012). Most of its nests on Smøla are on flat ground and in small rocky outcrops, while some are in trees (mainly in planted sitka spruce [*Picea sitchensis*]). Satellite telemetry of sub-adult white-tailed eagles has shown that each summer–autumn they migrate large distances from their natal areas on Smøla mainly northward (Nygård et al. 2010). Thus, the species can be

expected to be especially vulnerable to wind-energy development along the entire Norwegian coast.

White-tailed eagles at Smøla wind-power plant experience increased collision risk especially during spring (May et al. 2010, 2011) and seem to be displaced from the wind-power plant when selecting nest sites (Dahl et al. 2012). However, these impacts were not due to changes in their flight behavior because no significant difference in flight behavior and activity were found within versus outside the wind-power plant (Dahl et al. 2013). With a few notable exceptions, little detailed information currently exists on habitat selection of white-tailed eagles in coastal areas in Norway (Willgohe 1961, Nygård et al. 2010). Generally, white-tailed eagle habitat is usually connected to coastal areas, lakes, rivers, and wetlands (Radovic and Mikuska 2009, Nygård et al. 2010, van Rijn et al. 2010, Radovic and Jelaska 2012). Studies elsewhere have shown that white-tailed eagles may avoid human activity (Lõhmus 2001, Radovic and Mikuska 2009). As yet, little information is known on how habitat utilization affects displacement from wind-power plants, because most studies on raptors have been conducted using direct observations (de Lucas et al. 2004, Farfan et al. 2009, Garvin et al. 2011). Displacement of breeding birds have been documented for waders (Pearce-Higgins et al. 2012), and Dahl et al. (2012) suggested that lowered breeding success in white tailed eagles in the Smøla wind-power plant area were partly due to displacement. Using global positioning system (GPS) satellite transmitters mounted on white-tailed eagles, we were able to analyze their habitat utilization, and investigate possible displacement effects of a wind-power plant.

## **STUDY AREA**

Smøla was an archipelago located off the coast of Møre and Romsdal County, Central Norway (63°24'N, 8°00'E; Fig. 1), and consisted of a large main island together with about 5,500 smaller islands, islets, and small skerries. The terrain was flat and the highest point on the main island was only 64 m above sea level. The habitats were characterized by heather moors with a mix of small and large marshes and low rocky outcrops. The Smøla wind-power plant was situated on the northwesterly side of the main island. It was built in 2 phases by the Norwegian energy company Statkraft: the first phase consisted of 20 2.0-MW turbines and was finished in September 2002; and the second phase, with an additional 48 2.3-MW turbines, became operational in August 2005. The wind-power plant covered an area of 17.83 km<sup>2</sup>, represented by the minimum convex polygon (i.e., envelope) around the outermost turbines, including a 200-m buffer. The wind turbines operated in 2 different gears at 11 revolutions/minute and 16 revolutions/minute, depending on wind speeds: first gear at 11 revolutions/minute ( $\geq 3$  m/sec but  $< 6$  m/sec); second gear at 16 revolutions/minute ( $\geq 6$  m/sec but  $< 25$  m/sec). Below 3 m/sec, the turbines idled, while at wind speeds  $\geq 25$  m/sec they stopped.

## **MATERIAL AND METHODS**

### **GPS Data**

Between summer 2004 and 2009, we equipped 44 individual ready-to-fledge nestling of white-tailed eagles with GPS transmitters in June–July at nest. Nine transmitters were battery-powered Argos/GPS LC4 (105 g), while 35 were solar-powered Argos/GPS (70 g), all from Microwave Telemetry, Inc. (Columbia, MD, USA). All transmitters were fitted as back-packs (Buehler et al. 1995). Positions are normally available a few hours after uploading from transmitter to an Argos satellite. Our data were delivered as monthly CD-ROMs, and location

data were retrieved by using the GPS parser from the transmitter manufacturer. We included only data from September of the first calendar year (when they are leaving the nest area) and onward that fell within the municipality borders of Smøla (Fig. 1) in our analyses. Also consecutive relocations had to be different, so as to avoid an overrepresentation of roosting sites (i.e., pseudo-replication) in the analyses. All included data represented 33,804 positions for 36 individuals (on average, 939 positions/individual; range = 48–3,518). Because most transmitters were solar-powered, fewer positions were recorded for January and December in any given year, due to few hours of daylight leading to insufficient battery charge.

### **Habitat Covariates**

We assessed habitat utilization for the main habitat types present at the Smøla archipelago. Because the island of Smøla is relatively flat, we did not take into account elevation. The analyses included 3 main categories: mainland, islands, and sea. Mainland habitats were derived from the national 1:50,000 land-cover map with the following categories: arable land, forest, infrastructure (other than inside the wind-power plant), fresh water (lakes–rivers), heathland, and marsh. We further divided islands into islets and skerries based on their surface area, with a division at 4 ha. We divided sea into deep (>190 m), middle, and shallow (<25 m). This was based on a reclassification following the natural breaks in the sea depth distribution within Smøla municipality. We indicated habitat (i.e., lakes, marsh, heathland) falling inside the wind-power plant as a separate covariate. All base maps were made available from the Norwegian State Mapping Authority. We included all habitat categories as separate binary covariates in the analyses.

### **Statistical Modeling**

We estimated utilization distributions for each individual, calendar year, and season separately using the Brownian bridge movement model (hereafter, BBMM; Horne et al. 2007) with the kernelbb function in the adehabitat library (Calenge 2006) of the statistical program R 2.8.1 (R Development Core Team 2008). We classified season as winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and autumn (Sep–Nov). This methodology follows a Brownian bridge approach, which is a continuous-time stochastic model of movement in which the probability of being in an area is conditioned on starting and ending (GPS) relocations, the elapsed time between those relocations, and the mobility or speed of movement (Horne et al. 2007). Only utilization distributions that were based on a minimum of 20 GPS relocations were included in the analyses. Global positioning system relocations >24 hours apart were assessed as separate bursts (i.e., coherent trajectories) in the BBMM. We estimated the diffusion coefficient of the underlying Brownian motion ( $\hat{\sigma}_m^2$ ), which is related to the mobility of the animal, by using the liker function in the adehabitat library (Calenge 2006) for each individual separately, and it ranged between 29.2 m<sup>2</sup> and 3,819.2 m<sup>2</sup> with a mean of 306.3 m<sup>2</sup> (SD = 113.6 m<sup>2</sup>). This approach is based on observed animal trajectories, incorporates temporal autocorrelation between consecutive relocations, and takes into account the measured biotelemetry error. We estimated biotelemetry error (11.3 m;  $N = 5,551$ ) as the standard deviation of 46 transmitters while the birds were still in the nest (before dispersal) from 2004 to 2009. The BBMM gives an estimation of the probability of occurrence in an area based on an animal's movement trajectories separately for each burst. We derived seasonal utilization distributions for each individual by averaging the burst–utilization distributions weighted for the number of relocations they were based on. We normalized these seasonal Brownian bridge utilization distributions by dividing each pixel value with the summed value over all pixels; thus, each pixel represented the proportion of time spent at each location (resolution: 100 × 100 m). We defined the spatial extent of space use by eagles

that are resident at Smøla as the 95% isopleth Brownian bridge utilization distribution boundary. Although a proportion of sub-adult white-tailed eagles are known to migrate northward during summer–autumn (Nygård et al. 2010), our utilization distributions (i.e., home range; Kie et al. 2010) only encompassed space use when eagles were resident at the Smøla archipelago. Thereafter, we compared the 95% Brownian bridge utilization distributions to habitat categories using resource utilization functions (Resource Utilization Function, captured in the `ruf.fit` function in the `ruf` library; Marzluff et al. 2004). Resource Utilization Functions are based on relative space use where the unit of study is the individual utilization distribution (Brownian bridge utilization distribution). A Resource Utilization Function correlates the utilization distribution values, on a continuous rather than a discrete continuum (i.e., used or not used; Manly et al. 2002), to independent spatially defined resources, where the coefficients in the Resource Utilization Function indicate the importance of each resource to variation in the utilization distributions (Marzluff et al. 2004). We only included categorical habitat types; therefore, we excluded the intercept to determine the relative influence of habitat resources on the probability of utilization (Brownian bridge utilization distribution), while incorporating spatial autocorrelation. This approach was warranted because, given the categorical nature of the data, absolute habitat use cannot be estimated (Manly et al. 2002, Johnson et al. 2006). To allow for comparisons among individuals, calendar years, and seasons, we standardized each coefficient outside the wind-power plant by dividing each by the sum over all coefficients outside the wind-power plant (i.e., ‘natural’ habitats unaffected by the wind-power plant), rendering proportional differentiation in use ( $\hat{\beta}_{out} / \sum \hat{\beta}_{out}$ ). The estimates of these standardized coefficients can then be used to rank the relative importance of each habitat (Marzluff et al. 2004).

We further investigated possible displacement effects by measuring the proportional reduction in utilization inside relative to outside the wind-power plant. To do this, we



calculated the ratio of unstandardized habitat utilization estimates (i.e., lakes, marsh, and heathland) inside the wind-power plant by the habitat utilization estimates outside the wind-power plant ( $\hat{\beta}_{in} / \hat{\beta}_{out}$ ). Displacement effects may be expected to have a more severe impact on an animal's utilization of habitats that are normally strongly selected. To take into account such possible differential effects in displacement, we calculated the overall impact over all habitats as the weighted average over the habitat-specific utilization ratios inside relative to outside the wind-power plant. This was done by multiplying the utilization ratios for each habitat type used within the wind-power plant by its standardized proportional coefficient used outside the wind-power plant, and dividing by the summed standardized proportional coefficients for all habitat types used within the wind-power plant. Lower utilization ratios signify higher proportional reductions and thereby stronger displacement effects. Although the analyses were based on the utilization ratios, displacement is visualized as one minus the utilization ratios (i.e., proportional reduction in utilization, ranging from 1 [total displacement] to 0 [no displacement] and below, where negative values indicate possible attraction).

We used analysis of variance to explain variation in home range size, standardized Resource Utilization Function coefficients and utilization ratios. We included the following explanatory variables: gender, distance between nest and wind-power plant centroid, calendar year, and season; while controlling for possible individual preferences by including a random intercept. For this, we employed linear mixed-effects models (lme function in the nlme library; Pinheiro et al. 2008). A visual assessment indicated that all response variables approximated a log-normal distribution, and were log-transformed prior to analyses to obtain normality.

Finally, we assessed within- and between-individual variation in proportional utilization among habitat categories, sexes, calendar years, and seasons by calculating coefficients of

variation for each subset. Within-individual variation was estimated as

$$\text{Var}(\hat{\beta}_{i,j})_{\text{within}} = \frac{1}{n^2} \sum \text{SE}_{\hat{\beta}_{i,j}}^2$$

and between-individual variation was estimated as

$$\text{Var}(\hat{\beta}_{i,j})_{\text{between}} = \frac{1}{n-1} \sum (\hat{\beta}_{i,j} - \bar{\hat{\beta}}_j)^2$$

for each habitat category  $j$  over individual  $i$  (per calendar yr and season). The within- and

between-individual coefficients of variation were thereafter calculated as  $\sqrt{\text{Var}} / \bar{\hat{\beta}}_j$ .

## RESULTS

### Home Range Size

The log-transformed home range size (i.e., as delineated by the 95% isopleth utilization distribution boundary) was unaffected by sex ( $F=1.293$ ,  $df=1,33$ ,  $P=0.264$ ) and calendar year ( $F=1.860$ ,  $df=4,108$ ,  $P=0.123$ ). However, home range sizes were smaller when the nest where the eagles were hatched was farther from the wind-power plant centroid ( $F=4.538$ ,  $df=1,33$ ,  $P=0.041$ ;  $-0.23$  [95% CI =  $-0.44$ – $-0.02$ ] (effect indicated in 10km units)). On average, home range size decreased by 2.5% per km from the wind-power plant centroid. Home range sizes tended to vary among seasons ( $F=2.292$ ,  $df=3,108$ ,  $P=0.082$ ); home ranges were circa 40% larger during spring (winter: 130 km<sup>2</sup> [95% CI = 31–542]; spring: 181 km<sup>2</sup> [95% CI = 46–721]; summer: 131 km<sup>2</sup> [95% CI = 29–598]; autumn: 123 km<sup>2</sup> [95% CI = 21–726]).

### Habitat Utilization

The variation in the log-transformed individual seasonal resource-utilization functions (Fig. 1) was analyzed to assess the effects of habitat, sex, calendar year, season, and distance between nest and wind-power plant centroid. Habitat significantly affected utilization distributions

( $F=14.895$ ;  $df=10,1311$ ;  $P<0.001$ ; Fig. 2). While deep sea and middle sea were utilized less (deep sea:  $-0.98$  [95% CI =  $-1.21$ – $-0.76$ ]; middle sea:  $-0.30$  [95% CI =  $-0.40$ – $-0.20$ ]), shallow sea, skerries and islets along the coast were utilized equal to the reference category heathland (shallow sea:  $0.03$  [95% CI =  $-0.07$ – $0.13$ ]; skerries:  $-0.03$  [95% CI =  $-0.13$ – $0.07$ ]; islets:  $-0.07$  [95% CI =  $-0.17$ – $0.03$ ]). Marsh and forest were utilized equal to the reference category heathland on the mainland (marsh:  $-0.06$  [95% CI =  $-0.16$ – $0.04$ ]; forest:  $-0.07$  [95% CI =  $-0.17$ – $0.03$ ]), while water and arable land were utilized less (water:  $-0.28$  [95% CI =  $-0.38$ – $-0.18$ ]; arable land:  $-0.19$  [95% CI =  $-0.29$ – $-0.09$ ]). Also, utilization of infrastructure did not significantly differ from utilization of the reference category heathland ( $-0.08$  [95% CI =  $-0.21$ – $0.04$ ]). We noted higher levels of both within- and between-individual variation in, especially, arable land, forest, and islets (Fig. 3). This indicates lower selectivity for arable land and higher levels of differentiation in utilization among individuals for the latter 2 habitats. Deep sea was not important for habitat utilization, which can also be seen by the low levels of within- and between-individual variation (Fig. 3). Sex ( $F=1.647$ ;  $df=1,33$ ;  $P=0.208$ ), calendar year ( $F=0.738$ ;  $df=4,1311$ ;  $P=0.566$ ) and distance from the nest to the wind-power plant centroid ( $F=2.637$ ;  $df=1,33$ ;  $P=0.114$ ) did not significantly affect utilization distributions. Utilization tended to differ among seasons ( $F=2.456$ ;  $df=3,1311$ ;  $P=0.062$ ), with stronger habitat selection during autumn and winter relative to the reference category spring (winter:  $0.09$  [95% CI =  $0.01$ – $0.16$ ]; summer:  $0.03$  [95% CI =  $-0.04$ – $0.10$ ]; autumn:  $0.08$  [95% CI =  $0.00$ – $0.16$ ]). The within- and between-individual variation among seasons showed a clear annual pattern, with increasing between-individual variation toward summer (Fig. 3). Within-individual variation decreased toward summer, and autumn had the lowest levels of both within- and between-individual variation. Females had nearly 4 times higher between-individual variation in utilization than males. The between-individual

variation decreased over the years, coinciding with increased establishment of their own territories.

### **Displacement Effects**

The variation in displacement, as measured by the log-transformed in utilization ratios of habitats within the wind-power plant, was analyzed to assess the effects of sex, season, and distance between nest and wind-power plant centroid. Utilization ratios were unaffected by both sex ( $F=0.119$ ;  $df=1,33$ ;  $P=0.732$ ) and calendar year ( $F=1.610$ ;  $df=4,108$ ;  $P=0.177$ ). However, in second calendar year and third calendar year, utilization ratios were lower—and displacement was more pronounced—compared with first calendar year (2cy:  $-1.72$  [95% CI =  $-3.35$ – $-0.09$ ]; 3cy:  $-2.10$  [95% CI =  $-3.81$ – $-0.38$ ]; 4cy:  $-1.16$  [95% CI =  $-3.17$ – $-0.86$ ]; 5cy:  $-1.21$  [95% CI =  $-3.66$ – $-1.24$ ]). Utilization ratios decreased with distance from the nest to the wind-power plant centroid ( $F=5.111$ ;  $df=1,33$ ;  $P=0.031$ ;  $-0.08$  [95% CI =  $-0.15$ – $-0.01$ ] (effect indicated in 10km units)). Utilization ratios also varied significantly by season ( $F=4.865$ ;  $df=3,108$ ;  $P=0.003$ ; Fig. 4). During winter and autumn, utilization ratios were lower relative to spring (winter:  $-2.28$  [95% CI =  $-3.63$ – $-0.92$ ]; summer:  $-0.74$  [95% CI =  $-1.98$ – $-0.49$ ]; autumn:  $-1.87$  [95% CI =  $-3.27$ – $-0.47$ ]). During spring, the within- and between-individual variation was similar to habitats inside the wind-power plant (heathland, marsh, and water indicated with an asterisk; Fig. 3). Although selection among the habitat categories present inside the wind-power plant differed (Fig. 2), their utilization ratios were similar ( $F=0.252$ ;  $df=2,169$ ;  $P=0.778$ ; heathland:  $0.61$  [95% CI =  $0.52$ – $0.72$ ]; marsh:  $0.59$  [95% CI =  $0.52$ – $0.67$ ]; water =  $0.59$  [95% CI =  $0.48$ – $0.72$ ]).

### **DISCUSSION**

Habitats selected by sub-adult white-tailed eagles studied here are comparable to results found in other studies. Eagles utilized coastal areas (shallow sea, skerries, and islets) where they find most of their prey. The importance of water for hunting is a recurring observation with white-tailed eagle presence at skerries and tidal mudflats (bald eagle [*H. leucocephalus*]: Garrett et al. 1993, Thompson and McGarigal 2002; white-tailed eagle: Evans et al. 2010), and coastal and alluvial wetlands (Radovic and Mikuska 2009, Krüger et al. 2010, van Rijn et al. 2010). White-tailed eagles feed mainly on fish taken from shallow waters, but also feed and scavenge on seabirds, land-birds, and occasional mammals (hares [*Lepus timidus*], dead sheep [*Ovis aries*], etc., and stranded whales [Cetacea] and seals [Pinnapedia]; Willgohs 1961, Helander and Stjernberg 2003). Although freshwater lakes on Smøla contain fish (mainly trout [Salmoninae]), the waters are generally turbid and likely do not represent preferred foraging habitat. However, they do delineate landscape structures with respect to possible transportation corridors along valley bottoms. On the main island, eagles disproportionately utilized natural habitats (heathland and marshes) more than arable land with human activity. The lack of significant differences in utilization between heathland (as reference category) and infrastructure may be due to distribution of human settlements and roads along the coast and distribution of perching opportunities in open terrain on electricity transmission poles (Bevanger 1998, Bevanger et al. 2010a). The finding that males had less between-individual variation in utilization than did females may be caused by the very long excursions that many (not all, but in greater numbers than males) young females set out on (mainly northward in their second and third calendar year; Nygård et al. 2010). Home-ranges were enlarged during spring, which may be attributed to breeding-season activity, when these sub-adult birds move around to prospect for a vacant territory or a potential mate. Also, individuals captured away from the wind-power plant were often hatched on skerries–islets, which may explain the observed effect of distance between nest and wind-power plant centroid on home range size.

We found that non-territorial sub-adult white-tailed eagles were displaced from habitats encompassed by the wind-power plant. Displacement varied by season, and was less pronounced during spring. The unweighted proportional reduction in utilization was approximately 40%, without any significant differences among habitat types. When weighing for habitat quality, displacement effects reached 75%. Garvin et al. (2011) also did not find any significant differentiation due to amount of natural habitat within a 3-km radius. Still, in our study, only natural habitats, excluding linear infrastructure, were present within the wind-power plant. Garvin et al. (2011) found an overall reduction in raptor abundance post-construction by 47% compared with pre-construction levels, which was comparable to our estimates. Farfan et al. (2009) found even higher levels of displacement in raptors in southern Spain (38–72%). Bevanger et al. (2010b) found that white-tailed eagle territory density within the Smøla wind-power plant decreased post-construction compared with pre-construction. In addition, Dahl et al. (2012) found a 54% reduction in breeding success of occupied territories within 500 m of the Smøla wind-power plant. The reduced displacement during spring coincides with a period of increased flight activity at the onset of the breeding season (Dahl et al. 2013). During this period, white-tailed eagles are also most susceptible to collide with wind turbines (May et al. 2010, 2011). The proposition made by de Lucas et al. (2008) that collision mortality not only depends on raptor abundance but also topography is confirmed by our study. We found a proportional reduction in utilization inside the wind-power plant as a behavioral response of the satellite-tagged individuals in their space use (i.e., irrespective of abundance).

We have only assessed resource utilization of non-territorial sub-adult birds using the different habitat categories present in the Smøla archipelago. We did not account for other factors that may possibly affect habitat utilization and displacement, such as distance to coast and topography (Barrios and Rodriguez 2004, de Lucas et al. 2008). Although white-tailed

eagles are attracted to coastal habitats for foraging (Evans et al. 2010), on the island of Smøla white-tailed eagles are in fact always in the vicinity of the coast. The island of Smøla is relatively flat, with the highest point at 64 m above sea level. However, in regions with more pronounced topography, such as the neighboring island of Hitra (which also houses a wind-power plant; Bevanger et al. 2010c), localized updrafts and thermal convection columns may be generated, which in turn enhance thermal soaring and thus affected habitat utilization (Barrios and Rodriguez 2004, Bohrer et al. 2012). Although thermal soaring occurs on Smøla, this may more likely be the result of solar reflectivity of different vegetation types rather than topography. Only satellite data from sub-adult birds were available for this study, but the area also supports a dense population of adult birds. Dahl et al. (2013) found that, relative to sub-adult birds, adult birds had less flight activity in the Smøla wind-power plant compared with a control area. This, together with the findings showing reduced territory density (Bevanger et al. 2010b) and reduced breeding success (Dahl et al. 2012), indicates that adults are also likely displaced from the wind-power plant.

## MANAGEMENT IMPLICATIONS

The non-territorial sub-adult white-tailed eagles whose habitat utilization was assessed indicate that, given their selection for coastal habitats (shallow seas, islets, and skerries), and heathland and forest on the main island, possible displacement effects may be avoided by not siting wind-power plants in such habitats (Kiesecker et al. 2011). From the perspective of white-tailed eagle conservation and consequent reduced social (media) acceptance, it may be preferred to construct wind-power plants away from such habitats (e.g., in arable lands). Although our study did not allow for studying possible effects of distance to coast on the island of Smøla, placement of wind-power plants farther inland from the coast, and therefore

away from white-tailed eagle foraging habitat, may be considered on the Norwegian mainland. Also, development of offshore wind-power plants in deep sea and at a distance from the shallow seas and skerries–islets will likely reduce collision risks and displacement effects.

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**Figure 1.** Study area showing the distribution of white-tailed eagle habitats falling within the Smøla municipality borders, Central Norway. The proportional distribution of each habitat is indicated in the legend; the latter values indicate the percentage of the total land mass (12.6% of the total surface area within Smøla municipality). The black border indicates the location of the wind-power plant on Smøla, central Norway.

**Figure 2.** Box-plots indicating the relative importance of different habitats on utilization of radio-tracked white-tailed eagles (2004–2009) at Smøla, Central Norway. Thick lines indicate the median, the boxes indicate the 50% range, and the whiskers indicate the 95% range.

**Figure 3.** Representation of the within- and between-individual coefficients variation (CV) for different habitats used by radio-tracked white-tailed eagles (2004–2009) (Ds = deep sea; Ms = middle sea; Ss = shallow sea; Sk = skerry; Is = islet; Wa = water; Ma = marsh; He = heathland; Fo = forest; Ar = arable land; In = infrastructure; habitats indicated with an asterisk were within the wind-power plant), calendar years (1cy–5cy), seasons (Wi = winter; Sp = spring; Su = summer; Au = autumn), and sex (M = males; F = females) at Smøla, Central

Norway. The latter 3 categories are given in bold and are connected by solid, striped, and dotted grey lines, respectively.

**Figure 4.** Seasonal variation in displacement of radio-tracked white-tailed eagles (2004-2009) from the Smøla wind-power plant, Central Norway. Displacement was defined as one minus the proportional reduction in utilization compared with similar habitats outside the wind-power plant. Negative values indicate possible attraction effects. Thick lines indicate the median, the boxes indicate the 50% range, and the whiskers indicate the 95% range





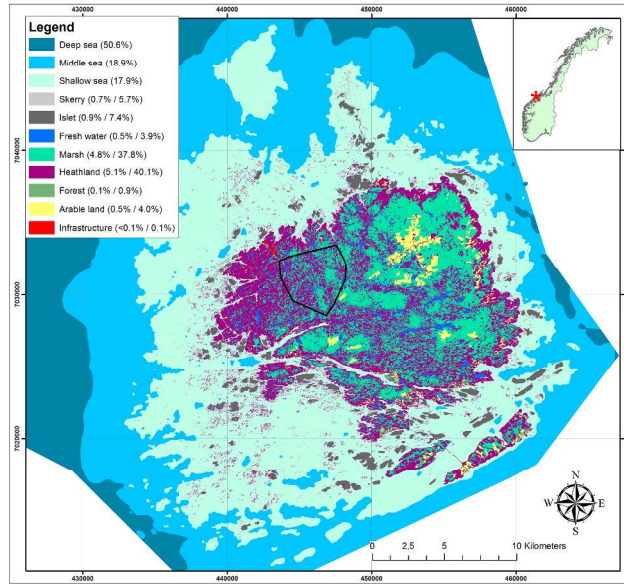


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