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Wind Energy and Wildlife Conservation

White-Tailed Eagles (*Haliaeetus albicilla*) at the Smøla Wind-Power Plant, Central Norway, Lack Behavioral Flight Responses to Wind Turbines

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ABSTRACT Evidence is increasing of bird mortality due to large-scale wind-energy development. Soaring raptors, such as the white-tailed eagle (*Haliaeetus albicilla*), have proven particularly vulnerable to collisions. In this study, we compared white-tailed eagle flight behavior both inside and outside of the Smøla wind-power plant on coastal Central Norway. During the eagle breeding period (mid-Mar–end May 2008), we collected data on flight activity (directional flight, social behavior, and soaring) and flight altitude (below, within, and above the rotor-swept zone [RSZ]) at 12 vantage points; 6 within the wind-power plant and 6 outside (control area). We found that white-tailed eagles did not show any clear avoidance flight responses to the wind turbines. Hence, we found no significant differences in the total amount of flight activity within and outside the power-plant area. However, we found less flight activity among adults than among subadults within the power plant compared with the control area. We also found a slightly increased probability of flight activity in the RSZ within the power plant, which obviously may increase the risk of collision with wind turbines. Our findings may help explain the relatively high mortality rate of white-tailed eagles in the wind-power-plant area and the recorded peak in eagle fatalities during the breeding season. © 2013 The Wildlife Society.

KEY WORDS behavior, collision, flight response, *Haliaeetus albicilla*, mortality, Norway, Smøla, white-tailed eagle, wind turbines.

Global warming and climate change scenarios (e.g., IPCC 2007), have boosted the focus on renewable energy, such as wind power, over the past 2 decades. In coastal Norway, several wind-power plants have already been constructed or are under construction. In 2011, Norway and Sweden established a common green certificate market for the production of renewable energy; thus, several more wind-power plants are likely to be built (Ministry of Petroleum and Energy 2010). The cumulative impact of existing and future wind-energy projects on bird populations is a major concern (Drewitt and Langston 2006). There is increasing evidence of bird mortality due to large-scale wind-energy development (Hunt et al. 1998, Johnson et al. 2002, Langston and Pullan 2003, Barrios and Rodriguez 2004, Drewitt and Langston 2006), especially in regard to raptors (Madders and Whitfield 2006, de Lucas et al. 2008, Smallwood and Thelander 2008, Bevanger et al. 2010).

Although bird mortality due to artificial air obstacles is recognized to be a site- and species-specific problem (Bevanger 1994, Bevanger 1998, Janss 2000, Drewitt and Langston 2008), high-risk factors are still poorly understood, including the impact of species-specific flight behavior. Energy consumption during flapping flight in birds increases with increasing body mass; thus, soaring flight is common for large birds (such as, e.g., eagles [Hedenstrom 1993, Spaar 1997]). Soaring flight requires thermal updraft, and these rising air currents are used by raptors to provide lift and to maintain and gain height with a minimum energy cost. Soaring flight by using rising air currents is highly energy-efficient (Kerlinger 1989), and studies of migrating raptors have shown that eagles spend >95% of their flight-time

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Additional supporting information may be found in the online version of this article.

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either soaring or gliding between thermals (Spaar 1997). Static-soaring birds, such as eagles, typically have long, broad wings, making low flight speed possible without losing too much height. The flight pattern, including flight altitude, is modified by several external factors, such as weather conditions, time of year, and topography. Age and number of individuals flying together may also affect behavioral characteristics over the year (Strickland et al. 2000, Barrios and Rodriguez 2004, Hoover and Morrison 2005, Madders and Whitfield 2006).

Between August 2005 and August 2010, a yearly average of 7.8 white-tailed eagle (*Haliaeetus albicilla*) fatalities resulting from wind-turbine collisions were found in the Smøla wind-power plant in coastal Central Norway (Bevanger et al. 2010). Bevanger et al. (2010) also investigated the spatial distribution of territories on Smøla and found that the breeding density of white-tailed eagles in the pre-construction period was highest in the exact area where the wind-power plant was situated. In addition, Dahl et al. (2012) have shown that the area within the power plant had significantly fewer successful breeding attempts after construction compared with pre-construction, an effect due to both collision mortality and disturbance.

The white-tailed eagle is a species with all the flight characteristics of a soaring raptor. Its social activities, such as chasing or fighting and spiraling–playing, are also important parts of the behavioral pattern when it comes to mating display and territorial defense. As a territorial species, distances to the nest and territorial borders are likely to affect a white-tailed eagle's individual behavior. Territorial flight activities impose energetic costs on the individuals, but they also provide possibilities for increased fitness and are frequently observed in adult individuals during the breeding season. Behavioral changes during the day may also vary because of environmental factors, such as weather conditions and temporal changes in access to food. Their flight behavior and intra-specific interactions may thus result in decreased vigilance in regard to their surroundings and thus increased risk of collisions (May et al. 2010, 2011).

Given the high white-tailed eagle mortality at the Smøla wind-power plant, it is critical to understand the species-specific behavioral characteristics that make this species vulnerable to collisions with wind turbines (May et al. 2010, 2011). Thus, our goal was to investigate how the presence of a large-scale wind-power plant in an area with a high density of white-tailed eagles affects the species' behavior.

STUDY AREA

Smøla was an island 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 skerries. The terrain was flat and the highest peak on the main island was only 64 m above sea level. Vegetation cover included heather

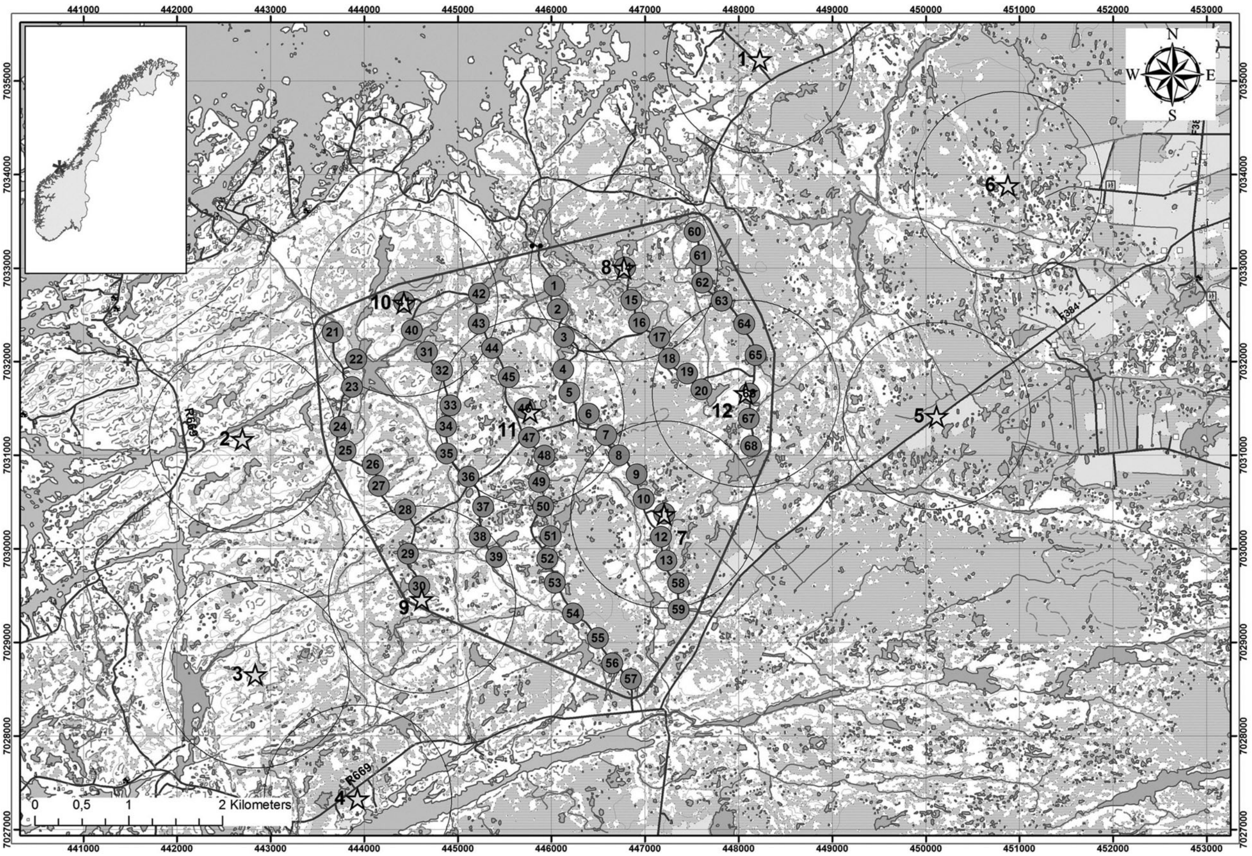

Figure 1. Smøla wind-power plant, Central Norway; with each wind turbine indicated with a small circle including its identification number. The bold line indicates a 200-m buffer around the outermost turbines. The stars indicate the locations of the vantage points during spring 2008; the surrounding circles represent the 1-km vantage-point survey area.

(*Calluna vulgaris*) moors with a mix of small and large marshes (Dahl et al. 2012). The Norwegian energy company Statkraft built the Smøla wind-power plant in 2 phases. The first phase was finished in September 2002, and consisted of 20 2.0-MW turbines with a 70-m hub height and 76-m rotor diameter. The second phase became operational in August 2005, and consisted of 48 2.3-MW turbines with a 70-m hub height and 82.4-m rotor diameter. The 68 turbines totaled 150 MW of capacity, covering an area of 18.1 km^2. Average yearly energy production was 356 GigaWatt-hour (Statkraft 2008). Smøla held a large, dense breeding population of white-tailed eagles, and 45 active territories were recorded in the Smola archipelago in 2010 (E. L. Dahl et al., unpublished data).

METHODS

Data Collection

We recorded data from 12 vantage points, 6 from within the wind-power-plant area and 6 in a control area with similar topography and habitats to those inside the wind-power plant (Fig. 1). The vantage points were carefully chosen to prevent disturbances around active nest sites. Each vantage point had a pre-defined observation radius of 1 km, and was located spaced to minimize the risk of observation overlap. Vantage-point areas overlapped 1% in the control area, and 4% in the power-plant area. Observation areas overlapped 0.04% between the power plant and the control areas (Fig. 1). We collected data every other week from mid-March to end May 2008 (International Organization for Standardization [ISO] weeks 13, 15, 17, 19, and 21); totaling 144 observation-hours. The observations were distributed in 4 2-hour daytime observation periods (0800–1000 hr, 1100–1300 hr, 1400–1600 hr, and 1700–1900 hr local time), see Appendix 1, available online at www.onlinelibrary.wiley.com.

We measured distance to the observed individual with a binocular rangefinder (Leica Geovid 10 × 42 HD; Solms, Germany), using known distances to points in the terrain or structures as a reference when the distance to the observed individual was difficult to measure directly. Two observers (PLH and ELD) simultaneously collected data in the field to increase the probability of detecting eagles in the observation area and the accuracy of the observations that we recorded. With 2 persons observing in opposite directions in a flat terrain, close to optimal sight in 360° was achieved, and possible vision limitations were decreased.

Our sampling method was based on the "Focal-Animal Sampling" method (Lehner 1979), where one individual is the focus of observations during a particular sampling period. That is, a particular individual receives highest priority when observers are recording its behavior, but this does not necessarily restrict observations to only that specific individual. Where social behavior was recorded, a focal animal sample on an individual provides a record of all acts in which that animal is either the actor or receiver (Lehner 1979). In this study, the first individual that entered within the observation radius of 1 km was chosen as the focal animal. When several individuals (performing social behavior) entered the observation radius together, all the individuals were followed until one left the social grouping. Each time the observed individual changed behavior or flight altitude-zone, we recorded this as a new event. Throughout the sampling period, we recorded 1–12 events/individual/observation. In the field, we recorded the following information for each event: 1) date and time at the start of the observation, 2) vantage-point identification, 3) distance and azimuth to the observed bird(s) from the observer, 4) flight direction, 5) flight altitude <29 m, 29–111 m, or >111 m (below, within, or above the rotor-swept zone [RSZ]), 6) whether directional flight (including flapping and gliding), social behavior (including chasing–fighting or spiraling–playing), or soaring, 7) whether adult, subadult, or unknown age, 8) duration of each behavior (s), and 9) number of individuals observed together and performing the same behavior. We also recorded the number of individuals observed within 1 km during each 2-hour period. From these data, we calculated the Universal Transverse Mercator coordinates using the distance and azimuth of each observation from the vantage point. Thereafter, we used Environmental Sciences Research Institute ArcMap Geographic Information Systems to calculate 10) distance from the vantage point to the nearest wind turbine (m); and 11) distance from the vantage point to the nearest active white-tailed eagle nest.

We used only observed aerial activities in the analyses, and excluded data on perched birds, because flight activity alone may pose collision risk. Because of a small sample size in ISO week 11 and ISO week 20, we excluded the data collected during these 2 weeks from the analyses. Due to small sample sizes, we pooled the categories chasing–fighting and spiraling–playing. We summed observed flight time per observation session for the observed individuals at each vantage point. When we observed >1 individual simultaneously, we multiplied the observation time by the number of simultaneously observed individuals. The summed observed flight times per observation session were then divided by the number of observed individuals and multiplied by the total number of individuals seen during the entire observation session. This number was thereafter divided by 2 hours (the duration of the observation session) and the visible survey area for each vantage point (i.e., $\pi \times 1$ km^2). In this way, we estimated the total flight activity in seconds per km^2 for all birds during an observation session. We obtained weather data during the observation sessions from a weather station monitored by Statkraft, situated about 10 km away from the study area and thus representative of the weather conditions in the power-plant area. From these weather data, we used temperature (° C), wind speed (m/sec), and precipitation (mm) in the analyses as possible explanatory environmental variables to changes in flight activity per 2-hour observation session.

Statistical Treatment

We used the statistical program R 2.10.1 (R Development Core Team 2009) to investigate differences between the control area and the wind-power-plant area with regard to flight activity per km^2 for each 2-hour observation session, flight behavior, and flight altitude. We tested how environmental factors influenced (log-transformed) flight activity using a linear mixed-effects model, while controlling for a random grouping over vantage points.

Possible explanatory variables for variation in general flight activity were week, number, time of day, temperature, wind speed, precipitation, location inside or outside the wind-power plant, distance from the vantage point to the nearest turbine, and distance to nearest active nest. We assessed variation among flight behaviors and flight altitudes using multinomial logistic regression models. To explain variation in flight behavior with regard to collision risk, we included location, age, and flight altitude. We also assessed variation in flight altitude with regard to location, age, and flight behavior. Flight behavior and flight altitude are likely inter-dependent. Also, it is difficult to disentangle whether behavior explains flight altitude or vice versa. To avoid the "chicken and the egg" problem, we present both approaches building separate models, using either variable as a response variable.

RESULTS

We recorded 244 observations, representing 554 events. Of these events, 281 were of single birds in directional flight, 134 were of soaring birds, 62 were of birds sitting on the ground, 54 were of birds spiraling–playing, and 23 were of birds chasing–fighting. Of the 554 events, 255 were recorded to be above the RSZ, of which 68 were very high; 156 events were within RSZ; 72 events were below RSZ; and 71 events were in the ground-level category. In 98% of the cases, we could assess the age of the observed birds (subad vs. ad). Overall, we observed nearly twice as many adults as subadults (312 vs. 172 observations, respectively); this significantly deviated from an expected equal age distribution ($\chi^2 = 40.5$, df $= 1$, $P < 0.001$). This difference was apparent during all 5 weeks of observation ($\chi^2 = 47.0$, df $= 4$, $P < 0.001$; subad-to-ad ratio range $= 0.0$–0.9, median $= 0.5$). There was a significant difference in age distribution outside versus inside the wind-power plant relative to an expected equal distribution (subad-to-ad ratio of 0.4 vs. 0.7; $\chi^2 = 10.3$, df $= 1$, $P < 0.001$). Although we observed significantly more adults inside the wind-power plant compared with the control area (181 vs. 131; $\chi^2 = 8.0$, df $= 1$, $P < 0.001$), no such difference was found for subadults (76 vs. 96; $\chi^2 = 2.3$, df $= 1$, $P = 0.127$).

There was a slight effect of temperature on flight activity within 29–111 m above ground level, and above the RSZ. Apart from this, none of the environmental covariates affected flight activity significantly (Table 1). Flight activity varied significantly over weeks for all altitude classes and during daytime within and above RSZ (Table 1; Figs. 2 and 3); with the highest flight activity in week 17 (22–25 Apr; i.e., during the early breeding period) and during early afternoon (1400–1600 hr). Distance from the vantage point to the nearest active nest did not affect flight activity (Table 1). The location of the vantage point—whether outside versus inside the wind-power plant—did not significantly alter flight activity levels (Fig. 4). The same was true for behavior; no differences in behavior were found outside versus inside the wind-power-plant area (Table 2). The multinomial logistic regression analyses indicated that directional flight was more commonly observed than other behaviors, these behaviors (social, soaring) were more likely to be performed above the RSZ (Table 2; Fig. 5). Subadults were less likely than adults to be observed in social behavior, and were more often observed above the RSZ (Table 2). Moreover, the probability for observations within the RSZ increased by 6% inside the wind-power-plant area, relative to observations both below and above the RSZ (Fig. 6).

DISCUSSION

General Activity

Adult white-tailed eagles at Smøla are resident birds, while Global Positioning System (GPS)-tagging of juveniles has

Table 1. Analysis of variance (ANOVA) from a linear mixed-effects model regressing log-transformed flight activity of white-tailed eagles, measured as seconds/hour/km^2, to environmental covariates, while controlling for a random grouping over vantage points. Data sampled inside and outside the Smøla wind-power plant, Central Norway, during mid-March to end May 2008. The results show the marginal sum of squares obtained by deleting each term from the model one at a time. *F*-values represent the strength of the effects, and signs show direction of the effects.

Covariate	df	All flight altitudes	Below RSZ[a]	Within RSZ	Above RSZ
Intercept	1,46	-13.70^{**}	8.95^{**}	-24.09^{**}	24.98^{***}
Temp	1,46	2.09	1.17	5.01^{*}	4.42^{*}
Wind speed	1,46	−0.06	0.03	0.01	0.07
Precipitation	1,46	0.51	0.23	0.63	0.08
Week	4,46	-4.42^{**}	2.96^{*}	-8.27^{***}	6.16^{***}
Time-of-day	3,46	6.35^{**}	0.71	3.73^{*}	3.34^{*}
Distance to nest	1,9	−0.00	1.01	0.21	0.17
Inside WPA[b]	1,9	−2.36	1.69	−0.17	0.18

[a] RSZ—rotor-swept zone.

[b] WPA—wind-power-plant area.

* P-value < 0.05.

** P-value < 0.01.

*** P-value < 0.001.

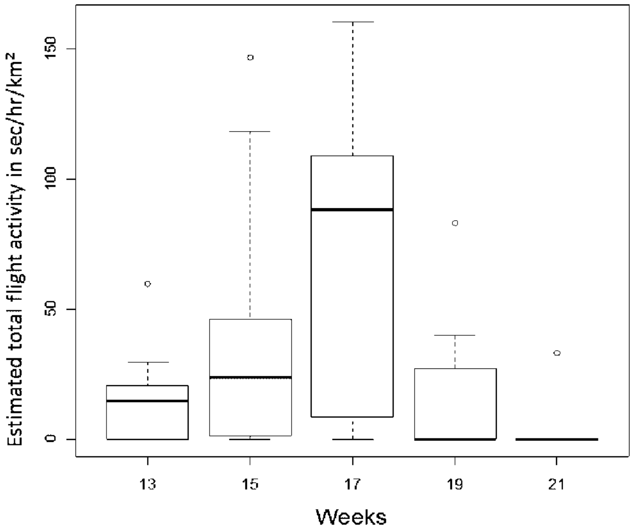

Figure 2. Estimated total white-tailed eagle flight activity (in sec) per hour and km^2 over weeks during mid-March until end of May 2008 at the Smøla wind-power plant, Central Norway. Weeks in International Organization for Standardization (ISO) week numbers.

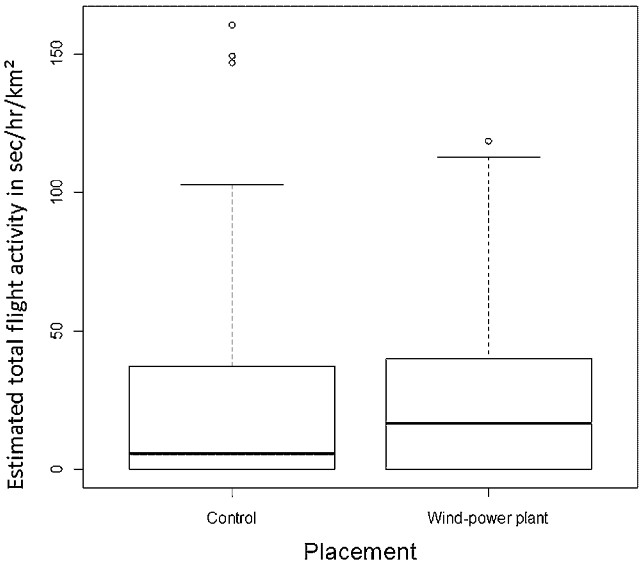

Figure 4. Estimated total white-tailed eagle flight activity (in sec) per hour and km^2 during mid-March until end of May 2008 outside (control) and inside the Smøla wind-power plant, Central Norway.

shown that most birds in younger age classes move away from Smøla during summer and autumn, mainly to the north (Nygård et al. 2010). In the power-plant area, eagle activity peaks in spring during the early breeding season, which is also reflected in the collision mortality pattern in the power plant (Bevanger et al. 2010). Although more adult birds (≥5 yr) than subadults (1–5 yr) were observed over the entire study, we observed a significant difference in age distribution when comparing inside and outside the wind-power plant, with more subadults than adults inside the power-plant area compared with outside. This may indicate that territorial adults have been displaced from the wind-power-plant area (Dahl et al. 2012), while subadults perceive this area as potential habitat. Before construction of the wind-power plant, the area had a high density of breeding white-tailed eagles relative to surrounding areas, while the breeding density was lower in the power plant area relative to the surrounding areas after construction (Bevanger et al. 2010, Dahl et al. 2012). Several vacant territories leading to reduced density of territorial eagles could explain why we observed a higher percentage of subadult birds in the power-plant area compared with outside, because there were fewer territorial birds to chase subadult birds away compared with the surrounding areas with higher density of territorial birds. If this was the case, the area has become an ecological trap (Battin 2004) for the subadults, attracting them into an area that increases their mortality risk due to turbine collisions.

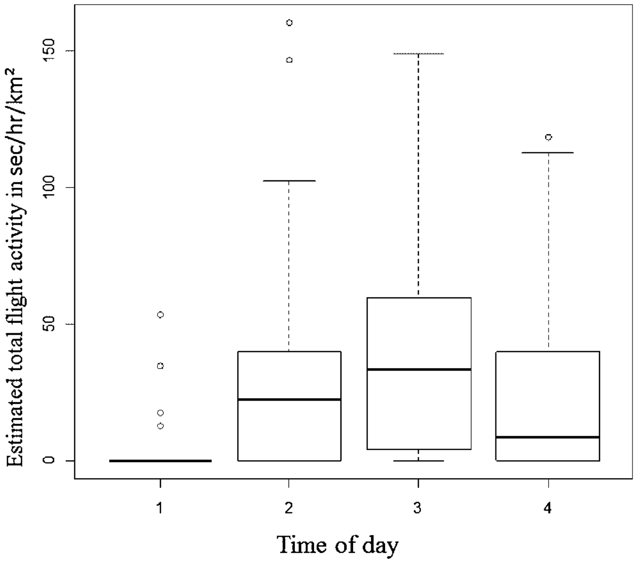

Figure 3. Estimated total white-tailed eagle flight activity (in sec) per hour and km^2 over 4 2-hour daytime observation periods (1 = 0800–1000 hr, 2 = 1100–1300 hr, 3 = 1400–1600 hr, and 4 = 1700–1900 hr; local time) during mid-March until end of May 2008 at the Smøla wind-power plant, Central Norway.

We found no effect on the amount of flight activity in relation to distances from vantage points to nearest active nest, so we are confident that the difference in age distribution between the power-plant and the control area was not an effect of locations of active nest sites. The activity level peaked in ISO week 17 (22 Apr–25 Apr), which was toward the end of the incubation period for the species in the study area.

Flight Behavior

We found no significant differences in flight activity levels when comparing the power plant area with the control area (i.e., eagles did not seem to actively avoid using the power-plant area during flight activity). This finding could explain why that there were relatively high numbers of white-tailed eagle collision victims found within the power plant. Although there were no significant differences between

Table 2. Results of the multinomial logistic regression explaining, respectively, flight behavior and flight altitude of white-tailed eagles inside and outside the Smøla wind-power plant, Central Norway, in the period mid-March to end May 2008. The intercept represents the (reference) probability of observing an adult outside the wind-power-plant area, within the rotor-swept zone and in directional flight. Given are the Wald statistics representing the strength of the effects; the signs show the direction of the effects.

	Flight behavior		Flight altitude	
Covariates	**Directional vs. social**	**Directional vs. soaring**	**RSZ[a] vs. below**	**RSZ vs. above**
Intercept	−14.99***	−13.64***	1.80	7.08**
Subad	−8.24**	1.51	−0.06	6.74**
Inside WPA[b]	−1.72	0.53	−8.08**	−6.00*
Below RSZ	−1.91	−0.04		
Above RSZ	8.86**	6.44*		
Social behavior			−1.95	8.94**
Soaring			0.00	6.43*

[a] RSZ—rotor-swept zone.
[b] WPA—wind-power-plant area.
* P-value < 0.05.
** P-value < 0.01.
*** P-value < 0.001.

the activity levels related to location of vantage point, there was a smaller percentage of adults than subadults observed in the wind-power-plant area than in the control area.

Comparing flight behavior between age classes, we found that adults spent more time engaged in social behavior than did subadults. Social behavior may impose a greater risk to collision with wind turbines due to decreased awareness of surroundings (Smallwood et al. 2009; May et al. 2010, 2011). These differences may also be associated with increased flight activity during the period when social behavior is most important for pair-bonding; the activity level during our study period peaked in ISO week 17 (Fig. 2). To test the assumption that social behavior increases collision risk, long-term studies with sample sizes that provide the opportunity to separate between seasons and even more types of flight behavior are needed.

Garvin et al. (2011) found that raptor abundance in a United States wind-power plant was reduced after construction of the power plant due to displacement. They also found high levels of avoidance and they found collision victims only within one raptor species. However, red-tailed hawks (*Buteo jamaicensis*), the only raptor species that was recorded as a collision victim, also displayed high-risk flight behavior, defined as no flight response and lack of avoidance close

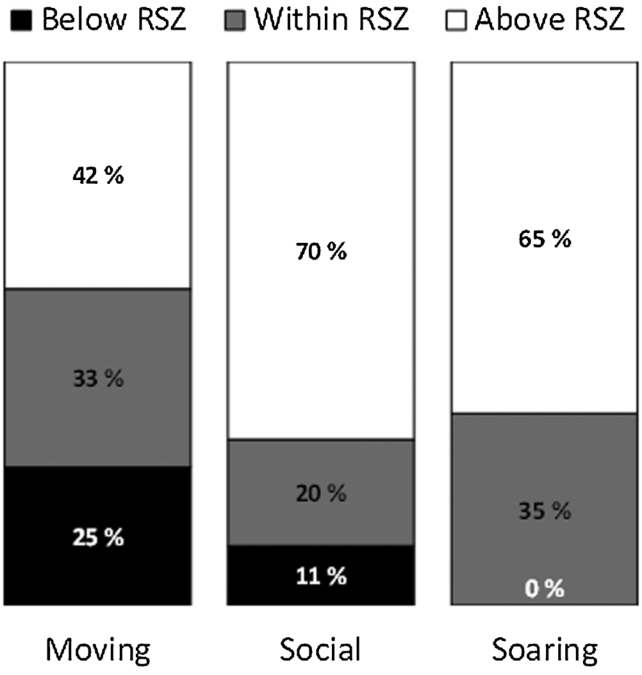

Figure 5. Proportional distribution of number of behavioral events below, within, and above the rotor-swept zone (RSZ) for different white-tailed eagle flight behaviors (directional flight [Moving], social behavior [Social] and soaring) during mid-March until end of May 2008 at the Smøla wind-power plant, Central Norway.

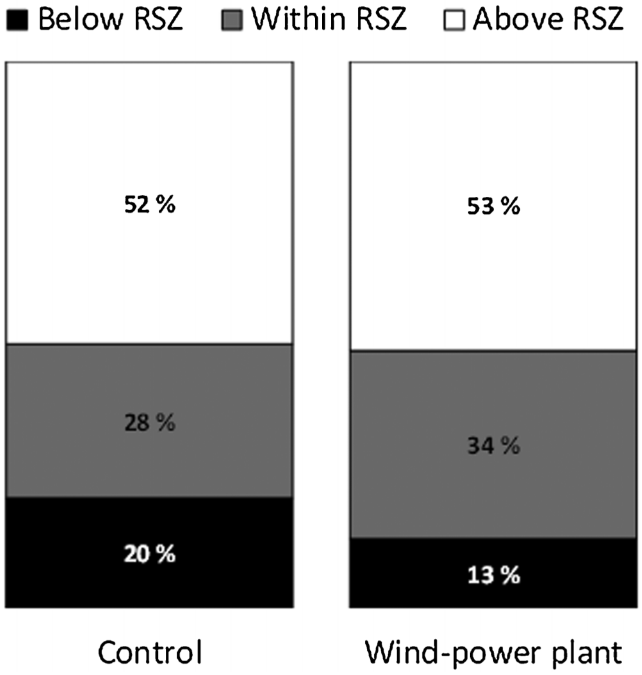

Figure 6. Proportional distribution of number of behavioral events below, within, and above the rotor-swept zone (RSZ) for different white-tailed eagle flight behaviors, during mid-March until end of May 2008, both outside (Control) and inside the Smøla wind-power plant, Central Norway.

to turbines, more often than did other raptor species. The white-tailed eagles in our study clearly displayed high-risk flight behavior and lack of avoidance behavior and were also frequently recorded as collision victims.

Flight Altitude

When assessing risk of bird collision with wind turbines, the frequency of flights in the RSZ is clearly relevant to most studies, either for estimating activity within a "risk volume" for a collision risk model (Band et al. 2007, May et al. 2010) or for computing indices of risk exposure (Erickson et al. 2002). Activity within the RSZ is usually estimated by eye at the point of detection and can then be recorded subsequently at regular intervals. Flight altitude was considered an important explanatory variable for possible differences in flight behavior in our study, because it would be reasonable to expect behavioral changes in the RSZ (or change of altitude), when eagles approached the turbines. Flight altitude can, however, also be viewed as a response variable influenced by many of the same variables suggested as possible explanatory variables for differences in flight activity. Daily and seasonal behavioral patterns (such as courtship flight, foraging, or migration) likely play an important role in influencing flight altitudes (Kerlinger 1989). To model and improve our understanding of the daily dynamics of flight altitudes, knowledge of the potential influential factors is important.

Few studies have so far analyzed the direct influence of weather on flight altitudes, but some studies have shown a strong relationship between thermal convection and flight altitudes (e.g., Shamoun-Baranes et al. [2006] and Bohrer et al. [2012]). We could not find any effect of environmental covariates on the amount of flight activity, except a slight effect of temperature within and above RSZ, with increased amount of activity at these altitudes during higher temperatures. This is expected, because broad-winged raptors use rising air currents (thermals) as uplift to gain altitude when temperatures rise and warm up the ground (Pennycuick 1998). The proportion of flight activity above the RSZ is constant when comparing inside and outside the power plant, while the proportion of activity below the RSZ decreases inside the power-plant area. This could be due to observer bias. Flight altitude of observations inside the wind-power plant are relatively straightforward to assess as being below, within, or above the RSZ using nearby turbines as a reference. However, it could be more challenging to assess flight altitude outside the power plant where there were no nearby turbines to use as references. Even though we only did observations within 1 km of the observer and where other structures were available for comparison (trees, power lines, hills, etc.), it may still be difficult to estimate the height of the eagles above ground level, which would bias our result outside the power plant. An alternative explanation for the increased probability of observations within the RSZ inside the wind-power plant could be that the air currents (turbulence vortices) created by the rotating wind turbines are attractive to eagles in some way; if this is the case, it could contribute to explain the number of collisions taking place.

Bias Considerations

A random grouping factor on vantage point was not included in the multinomial analysis because a distribution map from "ground-truthed" data from a bird radar placed inside the wind-power plant shows that individual white-tailed eagles move large distances throughout the day, and are likely to visit several of the vantage points within a short period of time (Bevanger et al. 2010). Moreover, data collected from both visual observations and by radar confirm a large number of individuals in this area. Despite the relatively high mortality, data from an ongoing population monitoring at Smøla show that ≥ 12 breeding pairs of eagles can potentially be recorded from within our vantage points (Dahl et al. 2012). In addition, estimates based on data from 59 GPS-tagged juvenile eagles at Smøla suggest that these non-territorial eagles move between different ground positions, on average, 15 times/day (E. L. Dahl et al. unpublished data). Observing only a few individuals repeatedly throughout the data-sampling period could cause biases in the data. However, the fact that up to 60 observations were collected from one vantage point during a 2-hour observation period suggest that a high number of individuals are involved in the observations from the vantage points, which decreases the possibility for pseudo-replication. Data from the 59 GPS-tagged birds and from the population monitoring also support the premise that there are a high number of individuals in the study area. Because the data have been collected from a relatively high number of vantage points over a large area (Fig. 1), this also contributes to reduce the possibility for pseudo-replication in the data. Even if each observation were treated as a new observation (rather than a new individual with a series of new events), there would still be a possibility for pseudo-replications through some unknown degree of inter-dependent observations. Overlap in visibility from the vantage points may violate the statistical assumption that the visible areas from each vantage point are effectively independent. Provided that observations are not collected from different vantage points simultaneously, together with the limited amount of overlapping areas (see the Methods Section), this violation should not be serious (Madders and Whitfield 2006).

It is not possible to detect all activity and behavioral aspects within a 1-km radius, which results in an observer bias (May et al. 2010). Decreased detection may occur due to visibility limitations in range, in altitude, and in their interaction (i.e., decreased detection of low-flying birds at farther distances). However, given the use of 2 observers observing in separate directions and a flat terrain with good sight in 360°, this visibility limitation has been reduced. The unknown degree of activity not detected by observers is likely to be equal both inside and outside the power plant because the terrain and visibility is very similar around the vantage points. Flight activity may also be affected by weather conditions (May et al. 2010), the field design should therefore encompass all environmental and species-specific variation as much as possible. The ideal situation, however, would have been a Before–After-Control–Impact study, but because this was not possible, a control area with a similar terrain was carefully selected.

MANAGEMENT IMPLICATIONS

White-tailed eagles apparently show no significant behavioral flight responses involving avoidance of the wind-power plant. While adults were more often observed engaging in social behavior, subadults frequented the wind-power plant more often than adult birds. Thus, distracted flight behavior and increased frequency of use are 2 factors that increase risk of collisions with wind turbines and may explain the high number of eagle fatalities across both age classes in the Smøla wind-power plant. In addition, there was an increased probability of observing birds within the RSZ inside the wind-power plant. These results suggest that it will be difficult to employ mitigation measures to decrease the white-tailed eagle collision hazard. We therefore emphasize the importance of conducting thorough pre-construction studies to identify wind-power plant locations with low densities of species vulnerable to collision. A more accurate prediction of high-hazard collision periods (based on environmental variables such as air temp, wind, and precipitation triggering high flight activity in Mar–May) would make it possible to advise the wind-power plant operators when to shut down the wind-power plant (or selected turbines) during high-hazard conditions to reduce eagle mortality.

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