NINA Report 692

Collision risk in white-tailed eagles

Modelling kernel-based collision risk using satellite telemetry data in Smøla wind-power plant

Roel May
Torgeir Nygård
Espen Lie Dahl
Ole Reitan
Kjetil Bevanger

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CONTACT DETAILS

NINA head office
Postboks 5685 Sluppen
NO-7485 Trondheim
Norway
Phone: +47 73 80 14 00
Fax: +47 73 80 14 01

NINA Oslo
Gaustadalléen 21
NO-0349 Oslo
Norway
Phone: +47 73 80 14 00
Fax: +47 22 60 04 24

NINA Tromsø
Framsenteret
NO-9296 Tromsø
Norway
Phone: +47 77 75 04 00
Fax: +47 77 75 04 01

NINA Lillehammer
Fakkelgården
NO-2624 Lillehammer
Norway
Phone: +47 73 80 14 00
Fax: +47 61 22 22 15

www.nina.no

Abstract

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Large soaring birds of prey, such as the white-tailed eagle, are recognized to be perhaps the most vulnerable bird group regarding risk of collisions with turbines in wind-power plants. Their mortalities have called for methods capable of modelling collision risks in connection with the planning of new wind-power developments. The so-called “Band model” estimates collision risk based on the number of birds flying through the rotor swept zone and the probability of being hit by the passing rotor blades. In the calculations for the expected collision mortality a correction factor for avoidance behaviour is included. The overarching objective of this study was to use satellite telemetry data and recorded mortality to back-calculate the correction factor for white-tailed eagles. The Smøla wind-power plant consists of 68 turbines, over an area of approximately 18 km^2. Since autumn 2006 the number of collisions has been recorded on a weekly basis. The analyses were based on satellite telemetry data from 28 white-tailed eagles equipped with backpack transmitters since 2005. The correction factor (i.e. “avoidance rate”) including uncertainty levels used within the Band collision risk model for white-tailed eagles was 99% (94-100%) for spring and 100% for the other seasons. The year-round estimate, irrespective of season, was 98% (95-99%). Although the year-round estimate was similar, the correction factor for spring was higher than the correction factor of 95% derived earlier from vantage point data. The satellite telemetry data may provide an alternative way to provide insight into relative risk among seasons, and help identify periods or areas with increased risk either in a pre- or post construction situation.

Roel May, roel.may@nina.no
Torgeir Nygård, torgeir.nygard@nina.no
Espen Lie Dahl, espenlie.dahl@nina.no
Ole Reitan, ole.reitan@nina.no
Kjetil Bevanger, kjetil.bevanger@nina.no

Sammendrag

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Store rovfugler, som havørn, er kjent for å være sårbare for kollisjoner med turbiner i vindkraftverk. Deres dødelighet er benyttet i modeller for kollisjonsrisiko i forbindelse med planleggingen av ny vindkraftutbygging. Den såkalte "Band-modellen" beregner kollisjonsrisiko basert på antall fugler som flyr gjennom rotorsonen og sannsynligheten for at de blir rammet av de passerende rotorbladene. I beregning av den forventede kollisjonsdødeligheten inngår en korreksjonsfaktor for unnvikelsesatferd. Det overordnede målet for denne studien var å bruke fluktdata og registrert dødelighet til å beregne korreksjonsfaktoren for havørn. Smøla vindkraftverk består av 68 turbiner, over et område på ca 18 km^2. Siden høsten 2006 har en søkt etter kollisjonsdrepte fugler ukentlig. Analysene var basert på satellittelemetridata fra 28 havørn merket med ryggsekksendere siden 2005. Korreksjonsfaktoren for havørn (dvs. "unnvikelsesraten") inklusive usikkerhetsnivåer som brukes i Band kollisjonsrisikomodellering er beregnet til å være 99 % (94-100 %) for våren og 100 % for de andre sesonger. Det årlige estimatet, uavhengig av årstider, var 98 % (95-99 %). Selv om det årlige estimatet var lik, var korreksjonsfaktoren for våren høyere enn korreksjonsfaktoren på 95 % basert tidligere på observasjonspunktdata. Satellittelemetridata kan være en alternativ måte å gi innsikt i den relative risikoen mellom sesongene, og bidra til å identifisere perioder eller områder med økt risiko, enten før eller etter utbygging.

Roel May, roel.may@nina.no
Torgeir Nygård, torgeir.nygard@nina.no
Espen Lie Dahl, espenlie.dahl@nina.no
Ole Reitan, ole.reitan@nina.no
Kjetil Bevanger, kjetil.bevanger@nina.no

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Foreword

In July 2010 NINA was contacted by Chris Marden from SSE Renewables, Scotland. He asked whether we could analyze data collected within the Smøla wind-power plant to derive avoidance rates for white-tailed eagles using the so-called ‘Band’ collision risk model. SSE Renewables wished to receive an increased insight into these avoidance rates for use in a pre-construction collision risk assessment for white-tailed eagles concerning the development of a wind-power plant in Scotland. The analyses of vantage point data was presented in NINA report 639. This report presents the collision risk modelling results based on satellite telemetry of white-tailed eagles. This work was financed by SSE Renewables and NINA.

25.05.2011 Roel May

1 Introduction

The evidence of bird mortality due to large-scale wind energy development is increasing (Hunt et al. 1998; Johnson et al. 2002; Langston & Pullan 2003; Thelander et al. 2003; Barrios & Rodriguez 2004; Smallwood & Thelander 2005; Drewitt & Langston 2006, 2008; Madders & Whitfield 2006; DeLucas et al. 2008, Bevanger et al. 2009), and a particular concern has been raised regarding raptors. Large soaring birds of prey are recognized to be perhaps the most vulnerable regarding risk of collisions with turbines in wind-power plants (Barrios & Rodriguez 2004, Hoover & Morrison 2005, Smallwood & Thelander 2008).

These mortalities have called for methods capable of modelling collision risks in connection with the planning of new wind-power developments both in Norway and in other countries. One model has been developed that has been widely used, the so-called “Band model” (SNH 2000, Band et al. 2007). This method is based on 1) estimating collision risk based on the calculated likelihood of a bird being hit by the rotor blades given that it passes through the rotor-swept zone (RSZ), multiplied by 2) the estimated number of birds flying through the RSZ throughout a given time unit (Band et al. 2007). The first step is based on the technical specifications of the turbines and the morphology (e.g. wing aspect), speed and flight behaviour (flapping or soaring) of the bird, while the second step involves the use of field observations. The model is finally adjusted by multiplying its outcome with a correction factor for taking into account, among others, avoidance.

As part of the BirdWind-project (“Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway”) (cf. Bevanger et al. 2010), juvenile white-tailed eagles (*Haliaeetus albicilla*) have been captured and equipped with GPS/satellite transmitter backpacks at the Smøla wind-power plant. The aim of the satellite telemetry studies was to investigate how the construction of Smøla wind-power plant would affect white-tailed eagle flight behaviour (Nygård et al. 2010; Bevanger et al. 2010). In 2008, eagle flight behaviour was observed from 12 vantage points, six inside the wind-power plant area and six in adjacent control areas (Hoel 2009). This data, together with additional vantage point data collected by Rowena Langston (RSPB) in May 2009, formed the basis for the ‘Band’ collision risk modelling presented in NINA report 639 (May et al. 2010).

The objective of this study was to back-calculate the correction factor for white-tailed eagles within the Smøla wind-power plant using satellite telemetry data. These data enables deriving correction factors for different seasons, and may function as an independent validation of the correction factors derived for the vantage point data (May et al. 2010). The approach in principle followed the standard collision risk assessment as promoted by Scottish Natural Heritage (SNH 2000, 2005, 2010; Band et al. 2007). The overarching approach was to use actual flight data and actual mortality to back-calculate the correction factor for white-tailed eagles.

2 Material and methods

2.1 Study area and study species

Smøla is an archipelago located off the coast of Møre & Romsdal County, Central Norway (63°24´N, 8°00´E) (Figure 1), and consists of a large main island together with approximately 5500 smaller islands, islets and small skerries. The terrain is flat and the highest peak on the main island is only 64m. The habitats are characterised by heather moors with a mix of small and large marshes. The Smøla wind-power plant was built in two phases by the Norwegian energy company Statkraft, the first phase being finished in September 2002, while the second became operational in August 2005. Since 2005, the wind-power plant has comprised 68 turbines. The wind-power plant covers an area of 17.83 km^2; represented by the minimum convex polygon (i.e. envelope) around the outermost turbines including a 200-m buffer. The wind turbines operate in two different gears at 11 and 16 rotations per minute (RPM), depending on wind speeds: first gear at 11 RPM (≥3 $^{m}/_{s}$ but <6 $^{m}/_{s}$); second gear at 16 RPM (≥6 $^{m}/_{s}$ but <25 $^{m}/_{s}$). Below 3 $^{m}/_{s}$ the turbines idle, while at wind speeds ≥25 $^{m}/_{s}$ they stop.

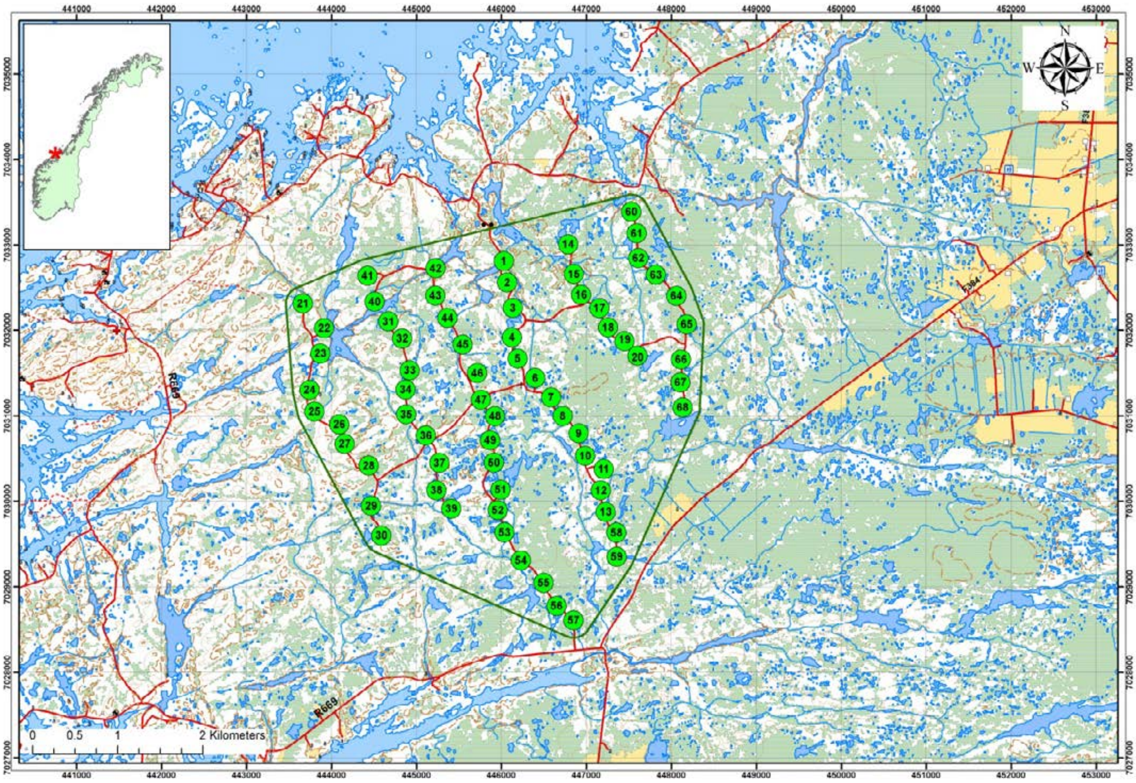

Figure 1. *Smøla wind-power plant, central Norway. The green line indicates minimum convex polygon including a 200-m buffer around the outermost turbines.*

The white-tailed eagle is distributed in parts of northern, eastern and central Europe, across Siberia into China. Its food includes fish, birds, carrion and, occasionally, small mammals. They generally form monogamous pairs for life, although if one dies, replacement can take place rather quickly. The nest is a huge edifice of sticks in a tree, on a coastal cliff, or simply on the flat ground. White-tailed eagles have high territory fidelity. Once they breed, nests are often reused, sometimes for decades by successive generations of birds (Orta 1994). The territory normally covers 30-70km^2 (although smaller on Smøla), usually in sheltered coastal locations (Gjershaug 1994). Approximately 55-60 white-tailed eagle territories have been reported in the Smøla archipelago (Bevanger et al. 2010), but recent data from DNA analyses of feathers indicate that this number is too high (own data, unpublished).

2.2 Searches for collision victims

Searches for dead birds near turbines have been carried out since 1 August 2006 using two dogs trained to a search image of both feathers and dead birds. A riesenschnauzer was trained to search for feathers before the start of the project in August 2006. In addition, a briard was retrained from a human rescue dog to a dog searching for dead birds by reinforcement when he found dead birds and feathers during the searches. A dog searches mainly by its olfactory sense, and therefore covers an area determined by movements of scent in the air. A dog needs only a few molecules to respond to a scent, and therefore is expected to be more efficient than what is possible with visual searches alone. By making use of this capacity together with wind direction and speed we achieved as efficient searches as possible.

Of the 68 turbines in the Smøla wind-power plant area (WPA), 25 were selected as primary search turbines. These were searched weekly throughout the whole year, i.e. every seven days (variation mainly 6-8 days). Earlier studies in Altamont Pass, California, have found a slightly higher collision rate for golden eagles (*Aquila chrysaetos*) at the end turbines in each string (Smallwood & Thelander 2005, 2008), and the first nine white-tailed eagle victims at Smøla were found in the northern part of the WPA. We therefore selected 17 outermost turbines and eight inner turbines as primary search turbines. The other 43 turbines were searched once each month during periods with expected high activity of birds, mainly March-June, and less intensively during winter (0-2 times depending on snow conditions). Depending on the wind direction each turbine was searched upwind, perpendicular to the wind direction, within a radius of approximately 100 meters from the base of the turbine tower. Objects from dead white-tailed eagles have been found up to about 120 m from the turbines. In addition to the search results, dead white-tailed eagles found by Statkraft personnel and the general public have been immediately reported and collected. All dead white-tailed eagles have been autopsied and X-rayed to verify cause of death.

A possible scavenger removal bias has been investigated. There is an absence of potential mammalian scavengers on the island of Smøla except for mink (*Neovison vison*). The main scavengers on bird carcasses on Smøla seem to be white-tailed eagle, hooded crow (*Corvus cornix*) and raven (*Corvus corax*). Parts of a carcass may be removed, but in general each carcass seems to be present for many months. The main bias at Smøla WPA may therefore be the crippling bias (Bevanger 1999), where birds are injured but survive the collision and die outside the search area.

2.3 Satellite telemetry data

From the entire dataset of all marked fledgling individuals (>50; Nygård et al. 2010), 28 subadult individuals were included in the analyses. They represented the individuals from their first winter and onwards whose transmitters rendered at least 20 relocations per season (n = 22,186). In this analysis we assumed that the flight activity of the subadult eagles was representative for the entire population. We obtained season-specific bird speed and altitude above ground level (agl) from 20 white-tailed eagles equipped with GPS satellite transmitters which rendered 3D location data including information on instantaneous speed (n = 15,716). In order to be able to estimate the flight activity within the rotor swept zone, we calculated the proportion of time the eagles spent in active flight (instantaneous speed > 0) and within the rotor swept zone (altitude agl ≥ 29m and ≤ 111m) for each season. The eagles spent between 2.5% and 5.8% of their time in active flight (0.025, 0.058, 0.026 and 0.047 for winter, spring, summer and autumn, respectively). When in active flight the eagles spent between 17% and 32% of their time within the rotor swept zone (0.320, 0.241, 0.231 and 0.170 for winter, spring, summer and autumn, respectively). Thus, the multiplicative proportion of time spent in active flight within the rotor swept zone for winter, spring, summer and autumn were 0.008, 0.014, 0.006 and 0.008, respectively.

2.4 Collision risk modelling

All programming and statistics were performed in the statistical programme R 2.10.1 (R Development Core Team 2009).

The modelling of collision risk in white-tailed eagles in principle follows the methodology described by the Scottish Natural Heritage (SNH) guidance note (SNH 2000, Band et al. 2007). For calculation of the number of bird transits (per season) through the rotors within the wind-power plant area, we followed SNH' second approach "*Birds using the wind farm airspace*". This approach is most appropriate for birds such as raptors which occupy a recognised territory, and where observations have led to some understanding of the likely distribution of flights within this territory. The standard way of estimating the correction factor does not render any information on the uncertainty involved in the modelling. Here, we have also modelled collision risk incorporating the (observed) variation in flight activity, day length, and wind and bird speed to obtain the correction factor (i.e. "avoidance rate") and associated uncertainty in the Band modelling. Below follows a stepwise explanation of the approach followed.

Number of birds colliding per season

=

Number of birds flying through the rotor swept zone (Stage 1)

x

Probability of one bird being hit when flying through rotor swept zone (Stage 2)

x

Correction factor for taking into account, among others, avoidance (Stage 3)

Stage 1: Number of birds flying through the rotor swept zone

In order to derive the variation in the number of birds flying through the rotor swept zone (RSZ), the following calculations were done including variation in flight activity, day length and bird speed.

1. From the satellite telemetry data, kernel utilization distributions (UD) were calculated separately for each individual and each season (across years). The UD grids were bounded within Smøla municipality with a pixel resolution of 200x200 meters. Each UD was normalized to indicate proportion of time spent within each pixel by dividing each pixel's value with the sum over all pixel values for the entire UD. All individual UDs were thereafter summed for each season separately, divided by the number of individuals and multiplied by the population size of the Smøla archipelago. This population-UD was then multiplied by the proportion of time eagles spent in active flight within the rotor swept zone (see paragraph 2.3) and adjusted for the surface area each pixel represented. This resulted in the estimated total flight activity/hour/km^2 for each season (F).The flight activity within the wind-power plant area (WPA) was obtained by selecting those pixels overlaying the WPA-buffer map (see Figure 1). A control subset was established by randomly selecting equally many pixels outside the WPA-buffer map, but on the main island.
2. Possible effects of season (winter, spring, summer and autumn) and placement (inside WPA versus random control outside WPA), including their interaction, on estimated flight activity were analyzed using linear regression.
3. The wind-power plant area A was defined as the minimum convex polygon (i.e. envelope) around the outermost turbines including a 200-m buffer (17.83 km^2; Figure 1).

4. The period of interest T was calculated by multiplying the number of days for each season (90-92 days) by the average day length for each season. Day length was defined as the number of hours between sun rise and sun set for Trondheim, Norway (http://www.timeanddate.com/worldclock/astronomy.html?n=288).
5. The bird occupancy n for each season was estimated within the WPA. This is the number of birds present multiplied by the time spent flying in the WPA for the period of interest for which the collision estimate is being made: $n = F \times A \times T$.
6. The bird occupancy was first calculated for each pixel. From these pixel-based estimates of bird occupancy, we calculated log-transformed mean and standard deviation from the pixel-based estimates of bird occupancy n for the entire wind-power plant. These were used to derive 10,000 randomly created estimates of bird occupancy n assuming a lognormal distribution.
7. Thereafter, a 'flight risk volume' V_w was identified, equalling the area of the wind-power plant multiplied by the rotor diameter (= 82 m).
8. The combined volume swept by the wind-power plant rotors was calculated as $V_r = N \times \pi R^2 \times (d + L)$ where N is the number of wind turbines (= 68), R equals the rotor length (=41 m), d is the depth of the rotor back to front (assumed to be 2 m), and L is the length of the bird (0.8 m; source: http://blx1.bto.org/birdfacts/results/bob2430.htm).
9. The bird occupancy of the volume swept by the rotor blades is then $n \times (V_r / V_w)$ bird-seconds.
10. The time taken for a bird to make a transit through the rotor disk and completely clear the rotors was calculated as $t = (d + L) / v$ where v is the speed in $^{m}/_{s}$ of the bird through the rotor disk. Using the log-transformed mean and standard deviation in bird speed for each season, we derived a random dataset of 10,000 estimates of bird speed which was assumed to follow a lognormal distribution.
11. Finally, the number of bird transits through the rotor swept zone, the total occupancy of the volume swept by the rotors in bird-seconds was divided by the transit time t: Number of birds passing through rotor swept zone = $n \times (V_r / V_w) / t$. Note in this calculation that the factor $(d + L)$ actually cancels itself out, so only assumed values need be used – it is used above to help visualise the calculation.

Stage 2: Probability of one bird being hit when flying through the rotor swept zone

This stage computes the probability of a bird being hit when making a transit through the rotor swept zone. The probability depends on the size of the bird (both length and wingspan), the breadth and pitch of the turbine blades, the rotation speed of the turbine, and of course the flight speed of the bird. In order to derive the hit probability including standard deviation, we obtained the (log-transformed) mean and standard deviation of wind speed and bird speed. Using these estimates, the hit probability was calculated for each record. Finally, the mean and standard deviation were calculated from these 10,000 hit probability estimates. The probability was calculated following the exact formula laid out on an Excel spreadsheet available from the renewable energy pages of the Scottish Natural Heritage web site: http://www.snh.gov.uk/docs/C234672.xls (Band et al. 2007; SNH 2000), using the following input parameters:

- K (3D probability): 1
- Number of rotor blades: 3
- Maximal chord: 3.296 m
- Pitch: 10 degrees
- Bird length: 0.8 m
- Wing span: 2.315 m (average of males and females across age classes; Love 1983)
- Aspect ratio: 0.35 (automatically calculated from the two parameters above)

- Flight type: $(2/\pi)^F$, with F = 1 (flapping (=0) or gliding (=1))
- Average bird speed: mean and standard deviation derived from GPS satellite transmitters for each season separately; using these statistics, we derived a random dataset of 10,000 estimates of bird speed which were both assumed to follow a lognormal distribution
- Rotor diameter: 82 m
- Rotation period: mean and standard deviation of wind speed at nacelle-height (70 m) were calculated from the meteorological station within the WPA. Using these statistics, we derived a random dataset of 10,000 estimates of wind speed which was assumed to follow a lognormal distribution. The estimates were thereafter classified into RPMs as follows: 1 (<3 $^m/_s$; idling); 11 (≥3 $^m/_s$ but <6 $^m/_s$; first gear); 16 (≥6 $^m/_s$ but <25 $^m/_s$; second gear); 0.001 (≥25 $^m/_s$; stopped).

Stage 3: Number of birds colliding per season – derivation of the correction factor

The number of birds colliding per season was estimated by multiplying the 10,000 estimates of bird occupancy with the hit probability estimates. The correction factor was derived as follows: CF = 1 – actual collisions / (number of birds flying through the RSZ x hit probability). From these 10,000 estimates of bird occupancy and hit probability, the mean and standard deviation in the correction factor were calculated.

3 Results

3.1 Background data

3.1.1 Collision victim searches

Altogether, 39 dead or injured white-tailed eagles have been found at Smøla WPA in the period from the beginning of August 2005 until 15 November 2010. During these five years, on average 7.8 dead white-tailed eagles were found per year. This equals on average 0.12 dead white-tailed eagles per turbine per year.

Of the total 39 dead or injured birds, 28 (72%) were found during a period of 2-2.5 months each spring. The period with high level of fatalities varied between years due to prevailing weather conditions. During autumn 6 (15%) dead/injured white-tailed eagles were found (Figure 2).

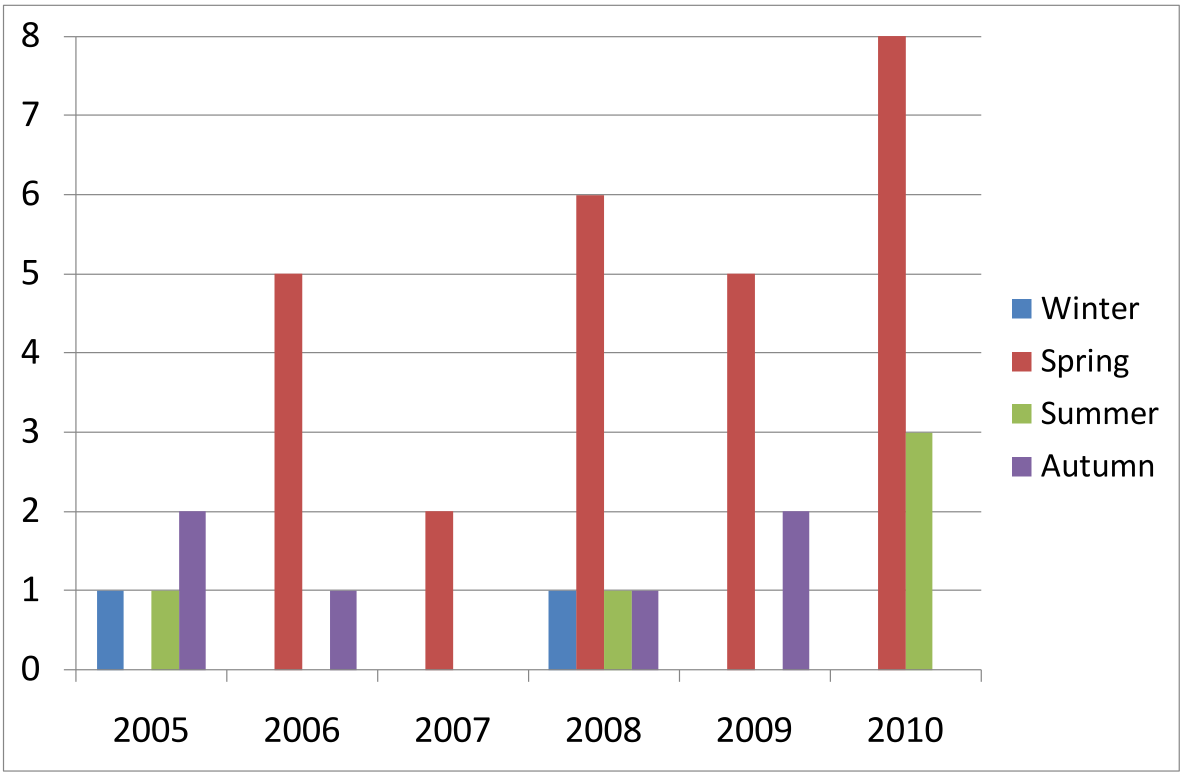

Figure 2. *Number of white-tailed eagles found dead or injured at the Smøla turbines until 15 November 2010. The first was found in August 2005, and regular searches were initiated in 2006. Winter = December-February; Spring = March-May; Summer = June-August; Autumn = September-November.*

The age distribution of the 39 birds found was 21 (54%) adults, 11 (28%) subadult birds and 7 (18%) juveniles. The adults were mainly found in the spring or autumn, the subadult birds, mainly in spring, and the juveniles in the autumn and their first spring (Figure 3).

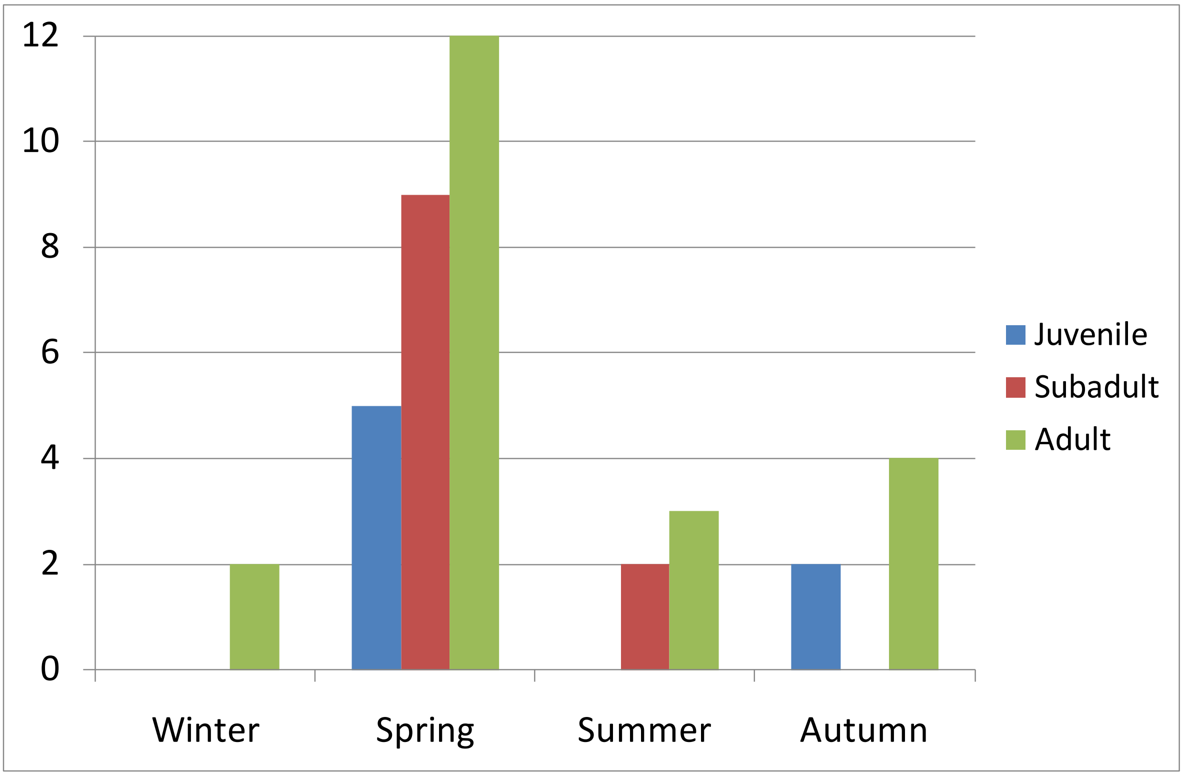

Figure 3. *Age distribution of white-tailed eagles found dead or injured at the Smøla turbines until 15 November 2010. Juveniles represent birds in their first calendar year; subadults calendar year 2-5, and adults calendar year ≥6. See also legend in Figure 2.*

3.1.2 Estimation of population size

The number of eagle chicks produced on Smøla during 2006-2010 varied between 21 and 36 (average 27.4, SD = 5.9). At the same time, the average number of breeding pairs was estimated at 45 (90 adults). Based on DNA analyses of feathers found at and around nests, the number of non-breeding individuals during the same time interval (i.e. “floaters”) was estimated at ca 30% (circa 27 individuals), resulting in an adult population size of circa 117 adult birds (in their 6th calendar year or older). Based on recorded deaths from dog searches and satellite tagging, we estimated the yearly mortality rate of juveniles and subadult to be circa 14% per year, resulting in 76 subadults (calendar year 2-5) present at any one time.

From the extensive satellite telemetry database, most juveniles and subadults have shown to migrate away from their natal areas on Smøla during summer/autumn. They may then move large distances, and have mainly moved north (Nygård et al. 2010). This means that the total population at Smøla shrinks during summer/autumn. We took this into account in the analyses by calculating the proportion of juveniles/subadults present at Smøla for each season. Based on the telemetry data, these proportions were 0.64, 0.90, 0.50 and 0.38 for winter, spring, summer and autumn, respectively.

3.2 Collision risk modelling

3.2.1 Seasonal flight activity

Flight activity (step 1) was calculated for each season. Thereafter we tested for possible effects of season and placement (inside or outside the wind-power plant) using a linear model (step 2; Table 3, Figures 4 – 6). The data indicated both significant differences in flight activity outside versus inside the wind-power plant, an effect that varied over the seasons. Flight activity in white-tailed eagles also showed a significant variation between seasons. Bird occupancy (step 6) was estimated at 30.30, 148.86, 26.79 and 23.56 hours for winter, spring, summer and autumn, respectively (median values). For each of these seasons, the median number of bird transits through the rotor swept zone (step 11) was 304, 1172, 208 and 184.

Table 3. *Analysis-of-variance results from the linear model.*

Covariate	df	F-value	P-value
(Intercept)	1,3552	10626.20	<0.001
Inside/Outside	1,3552	101.61	<0.001
Season	3,3552	1932.45	<0.001
Interaction	3,3552	129.73	<0.001

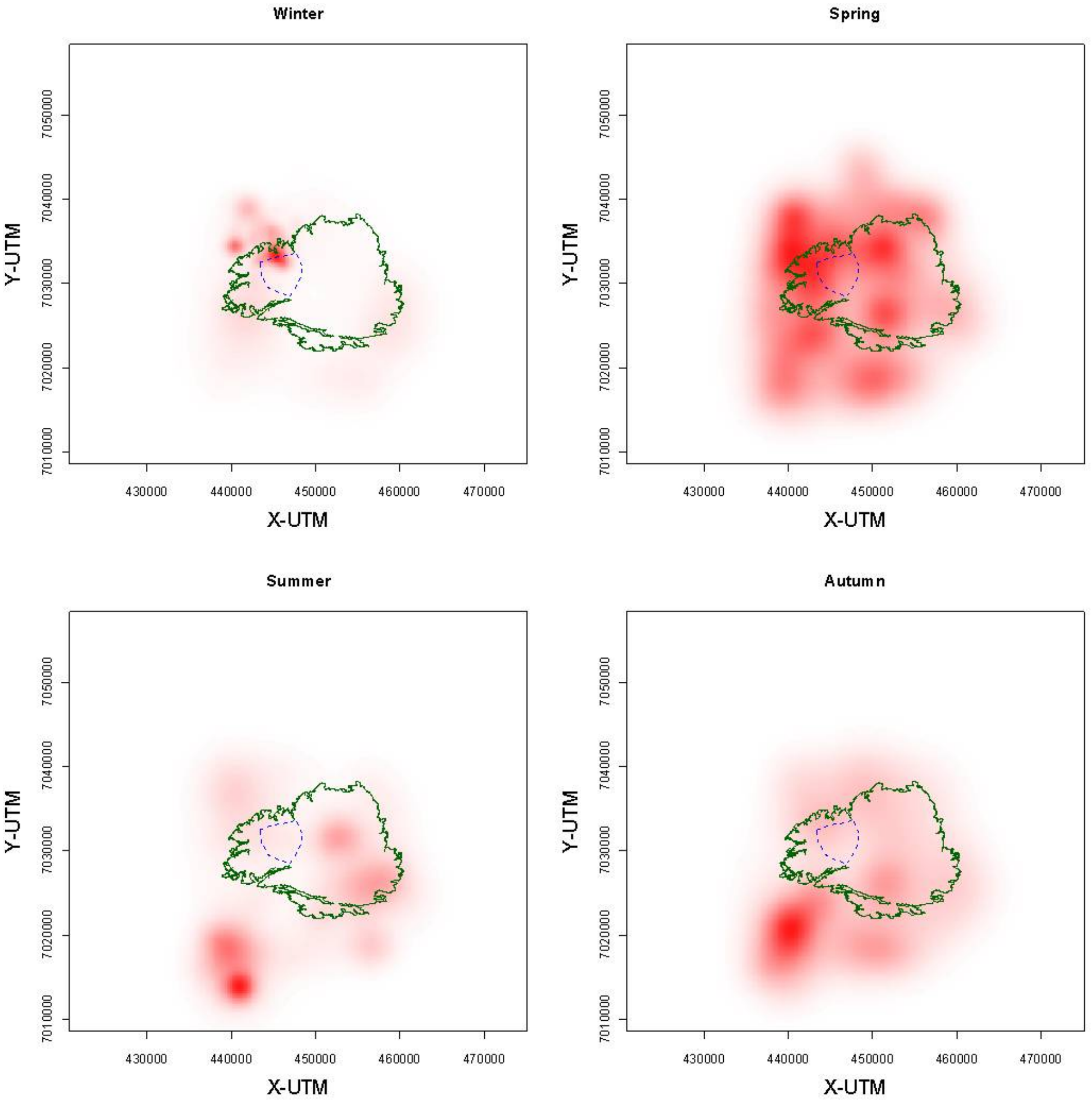

Figure 4. *Maps showing the estimated distribution of the total flight activity within the rotor swept zone per season for the subadult population at Smøla; more intense red indicates increased activity. The placement of the wind-power plant is indicated with the blue broken-line polygon.*

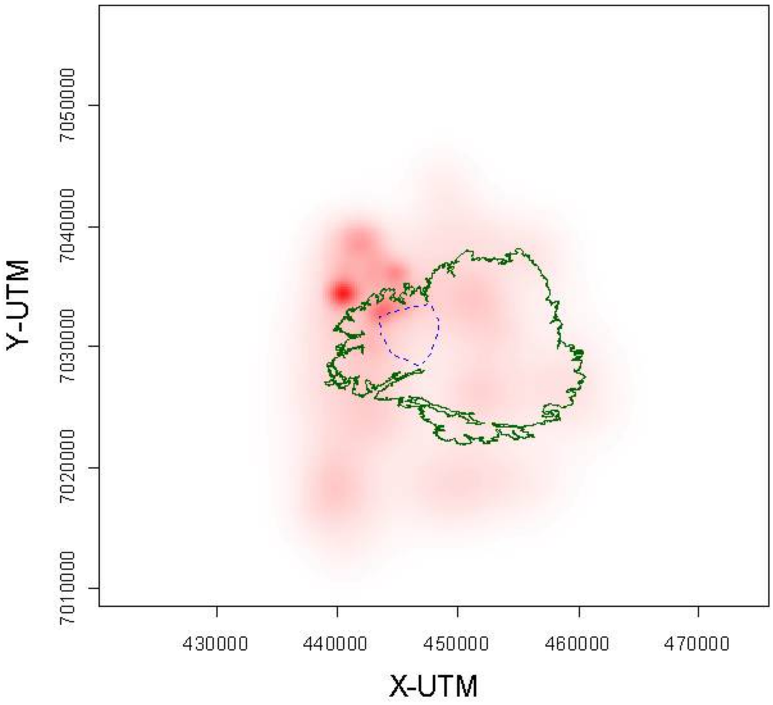

Figure 5. *Map showing the estimated distribution of the total flight activity within the rotor swept zone year-round for the subadult population at Smøla; more intense red indicates increased activity. The placement of the wind-power plant is indicated with the blue broken-line polygon.*

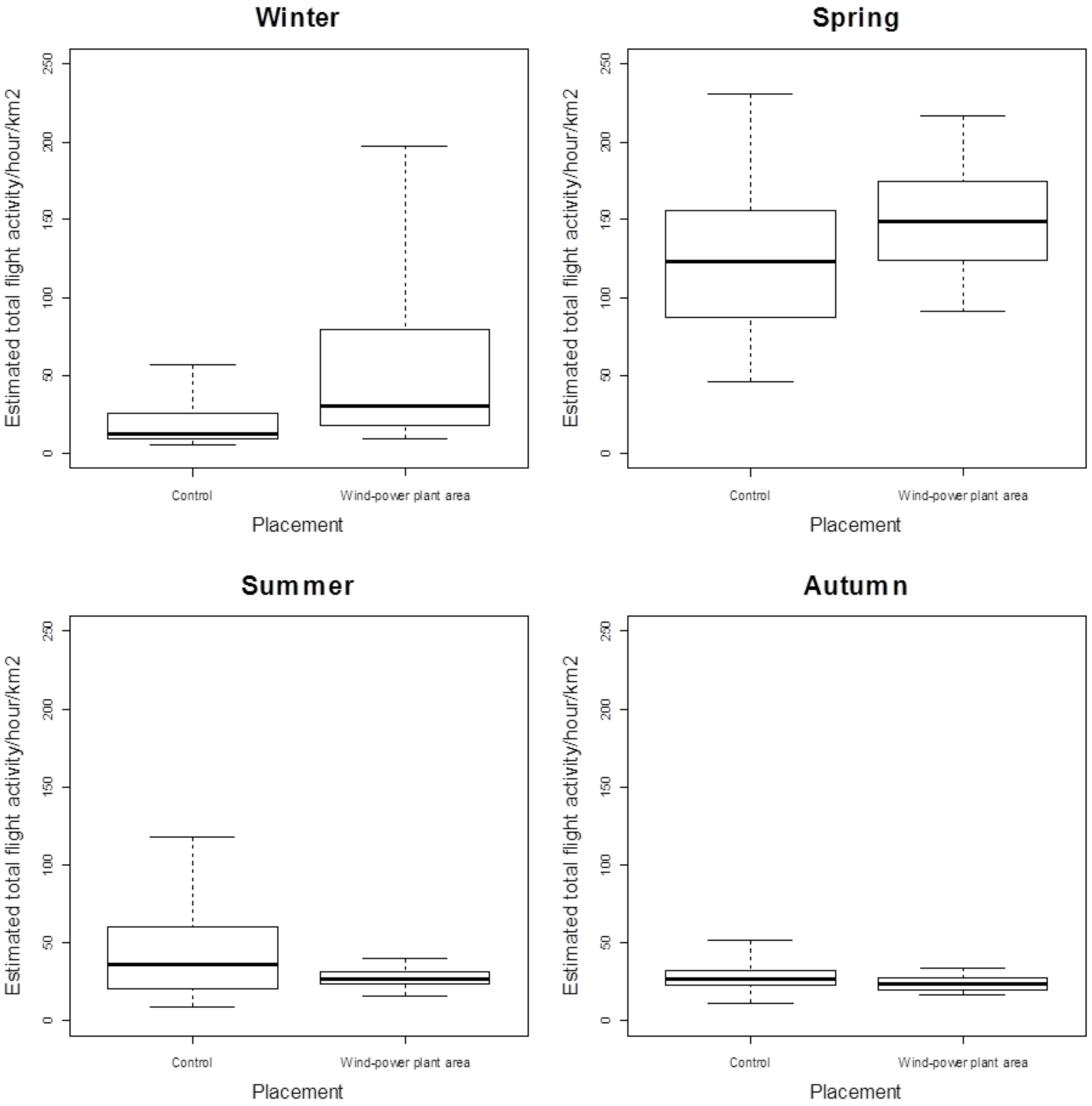

Figure 6. *Box plots showing the estimated total flight activity within the rotor swept zone per season and placement for the entire white-tailed eagle population at Smøla. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile).*

3.2.2 Collision risk including uncertainty levels

The correction factor was estimated including variance in wind speed and bird speed (which were assumed to follow a lognormal distribution). Median wind speeds at nacelle-height (70 m) were 6.59 $^{m}/_{s}$, 5.70 $^{m}/_{s}$, 4.53 $^{m}/_{s}$ and 6.60 $^{m}/_{s}$ for winter, spring, summer and autumn, respectively (median RPMs: 16, 16, 11, 16). Median bird speeds for these seasons were estimated from the telemetry data at 12 $^{m}/_{s}$, 20 $^{m}/_{s}$, 19 $^{m}/_{s}$ and 23 $^{m}/_{s}$. Using these estimates, we iterated the Band-model calculations 10,000 times to produce robust estimates of the correction factor. Given the variation in wind and bird speed for each season, the median hit probability was 0.193, 0.115, 0.108 and 0.118 for winter, spring, summer and autumn, respectively (stage 2, Figure 7). The year-round median hit probability was estimated at 0.121. From the number of recorded collision (paragraph 3.1), the estimated flight activity/occupancy (stage 1) and the hit probability (stage 2) the median correction factors for the Band-model (i.e. “avoidance rate”, stage 3) were estimated at 1.000 for winter, summer and autumn and 0.991 for spring (Table 4, Figure 8). The year-round median correction factor was estimated at 0.975 (interquartile range: 0.946 – 0.989; 5th percentile: 0.864). In this analysis we assumed that the flight activity of the subadult eagles was representative for the entire population. When only taking into account the juvenile/subadult collisions, the correction factor could only be derived for spring: 0.989 (interquartile range: 0.933 – 1.000). The correction factors for the other seasons were estimated at 1.000 (interquartile range: 1.000 – 1.000).

Table 4. *Uncertainty statistics for the modelled correction factors using the Band collision risk model on satellite telemetry data from Smøla.*

Season	**Median**	**5th percentile**	**Interquartile range**
winter	1.000	1.000	1.000 – 1.000
spring	0.991	0.831	0.942 – 1.000
summer	1.000	0.933	0.977 – 1.000
autumn	1.000	0.800	0.931 – 1.000

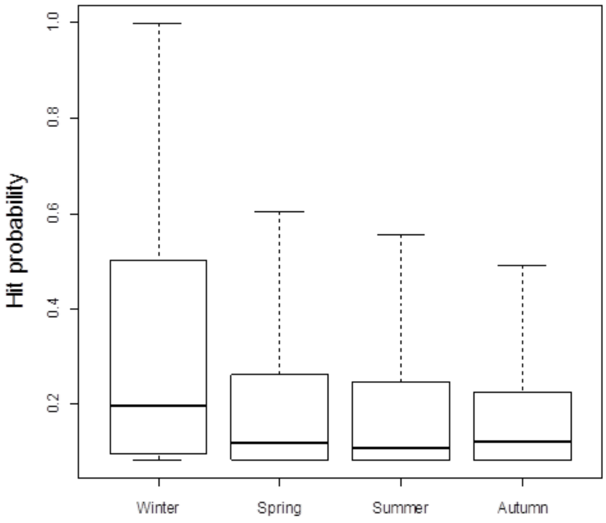

Figure 7. *Box plot showing the hit probability per season. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile).*

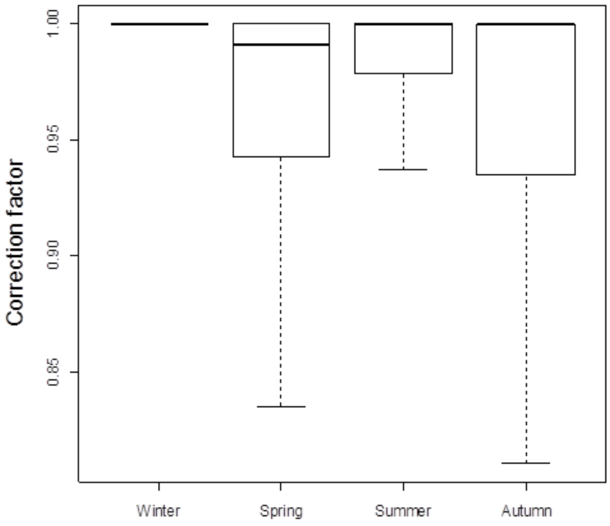

Figure 8. *Box plot showing the correction factor for the Band collision risk model. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile).*

4 Discussion

Given our satellite telemetry data the median correction factor (i.e. “avoidance rate”) derived from the Band collision risk model for white-tailed eagles was estimated at 100% for winter, summer and autumn and 99.1% for spring. The year-round estimate based on the satellite telemetry data was 97.5%. The SNH guidance note has set the correction factor to 95% based on flight behaviour and collision monitoring studies. The reason given for this is “*because there is sufficient evidence for their vulnerability to collisions: white-tailed eagle (evidence of a disproportionate number of collisions at Smøla, than might be expected)*”. Here they refer to the annual report from the BirdWind-studies at the Smøla wind-power plant (Bevanger et al. 2008). The median correction factor based on vantage points was earlier estimated at 95.4% (interquartile range: 0.907 – 0.976) (May et al. 2010). The year-round correction factor derived from the satellite telemetry data was similar to vantage point-based factors (95-99%; SNH 2010). However, the correction factor for spring, the season with most collisions, was estimated higher than the vantage point-based factor. Hopefully, this report can be used to increase our understanding on how the correction factor may affect the results from collision risk modelling. It may provide an alternative method for estimating correction factors, unaffected by observer biases, terrain conditions, and seasonal and daily variation. Also the satellite telemetry data may provide an alternative way to provide insight into relative risk among seasons, and help identify periods or areas with increased risk either in a pre- or post construction situation. The correction factors presented here also illustrate when white-tailed eagles may experience the greatest collision risk due to their flight activity patterns.

Although the correction factor often is thought to be related to avoidance, we did not find strong differences in flight activity inside/outside the wind-power plant (Figure 6; May et al. 2010). The estimated correction factor therefore may not represent displacement (i.e. not using the WPA as habitat anymore) or large-scale avoidance (i.e. active behavioural response). It may however, include fine-scale avoidance, such as flying round the actual physical turbine structures or last-minute evasion of the rotor blades. It is important to realize that the correction factor may in fact encompass different sources of error in the model (i.e. stage 1 and 2). The correction factor likely represents the total effect resulting from many unknown factors:

- *‘Observer’ biases*: The kernel utilization distributions (UD) may possibly be affected by the recording schedule the transmitters were programmed. In the analyses the UDs were normalized by dividing each pixel’s value with the sum over all pixel values for the entire UD, to take this into account. The transmitters were either battery- or solar-powered; the latter generally rendered less relocations during the winter half year. For the year-round estimates this means that the UDs overestimate summer activity and underestimate winter activity.
- Seasonal and daily variation: natural variation in the onset of seasons, daily fluctuations and weather conditions may affect flight activity differently over the seasons. In the analyses we have pooled the data over the years, and used set seasonal three-month intervals. This may somewhat affect the *true* variation in the correction factors.
- Species- and site-specific bird density, behaviour and flight activity: the high local density at the Smøla wind-power plant and resulting high levels of social and/or territorial flight activity resulting in a disproportionate number of collisions; thus affecting the correction factor.
- *Model assumptions:* the analyses done here assume that the flight activity of the subadult eagles is representative for the entire population; which is not necessarily the case. Juvenile and subadult eagles migrate northwards during summer/autumn; a pattern which becomes less and less pronounced over the years. The effect this may have on the population size has been taken into account in the analyses. Also, May et al. (2010) noted that the hit probability (stage 2) never reaches zero; even when the rotor blades are barely moving.

Given the nature of the data, and the possible sources of error involved one rarely has control over, it is important to visualize the uncertainties to the model outcomes. Although often the uncertainty connected to this type of modelling is rarely given, we have incorporated the uncertainty of the calculated estimates in our analyses. This should, ideally, become common practice. Chamberlain et al. (2006) also point out that relatively small changes in the correction factor can lead to large proportional changes in mortality rates. The Band model allows for calculating separate correction values for different seasons and/or geographic regions when such, and enough, data is available. Splitting the year into seasons may, however, hamper robust estimates because of lack of enough actual recorded collisions (e.g. the effect of 0 versus 1 collisions is relatively large), and the natural variation in the timing of seasons. Also, the calculation of the hit probability (stage 2) assumes that all birds approach a turbine up- or downwind (50-50%). This is not really realistic; birds may also approach the turbine crosswind for example. In the original calculations derived by Tucker (1996); he presented two models: one for up/downwind and one for crosswind. Based on these formulae a stochastic model for estimating the hit probability more realistically is possible. This model would then include information not only on average wind and bird speed (as is required now) but also on wind directions and bird headings, and variations in both speeds and directions. Data on these should be fairly easy to obtain from weather stations and direct observations, respectively.

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Norwegian Institute for Nature Research
NINA head office
Postal address: P.O.Box 5685, NO-7485 Trondheim, NORWAY
Visiting address: Tungasletta 2, NO-7047 Trondheim, NORWAY
Phone: + 47 73 80 14 00
Fax: + 47 73 80 14 01
Organisation number: NO 950 037 687 MVA

www.nina.no

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