NINA Report 639

Collision risk in white-tailed eagles

Modelling collision risk using vantage point observations in Smøla wind-power plant

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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 actual flight data and actual 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 number of collisions has been recorded on a weekly basis. The analyses were based on observational data from 12 vantage points collected in spring 2008; of which six vantage points were placed inside the wind-power plant. The results were verified using observational data from 10 vantage points within the wind-power plant from May 2009. In total, five white-tailed eagles have collided with wind turbines during the vantage point periods, between mid-March and the end of May 2008. In May 2009, only one white-tailed eagle was found dead. Given the vantage point observations data the correction factor (i.e. “avoidance rate”) used within the Band collision risk model for white-tailed eagles was 96.4 and 97.1% for 11 and 16 RPM, respectively. These values, however, assume that the wind turbines operated continuously with the respective RPMs. The correction factor adjusted for the actual wind speed distribution at Smøla WPA was 95.8%. We also derived uncertainty levels in the modelling, which resulted in a mean correction factor of 92.5% ± 9.7 SD. This may be due to the wind speed distribution during the period of interest, affecting both bird speed and flight activity. This would decrease the total period of interest; and lower the expected number of bird transits through the rotor swept zone. Although this modelling took into account variation in wind and bird speed, daylight and flight activity, there may exist possible sources of error, such as observer bias. These have been assessed. The correction factor was slightly lower using an independent vantage point data set from May 2009. The relatively low correction factor including uncertainty levels presented here, compared to that for most other raptor species, probably results from high levels of flight and breeding display activity, as demonstrated at the Smøla wind-power plant, where numerous collisions have occurred.

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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 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 observasjonsdata fra 12 observasjonspunkter samlet våren 2008, hvorav seks ble plassert inne i vindkraftverket. Resultatene ble bekreftet ved hjelp observasjonsdata fra 10 observasjonspunkter innenfor vindkraftverket fra mai 2009. I alt fem havørner kolliderte med vindturbinene i observasjonsperioden mellom midten av mars og slutten av mai 2008. I mai 2009 ble kun en havørn funnet død. Basert på observasjonsdataene ble korreksjonsfaktoren for havørn (dvs. "unnvikelsesraten") som brukes i Band kollisjonsrisikomodellering beregnet til å være 96,4 og 97,1 % for henholdsvis 11 og 16 RPM. Disse verdiene antar allikevel at vindmøllene opererer kontinuerlig med de respektive RPM. Korreksjonsfaktoren justert for den faktiske vindhastighetsfordelingen på Smøla WPA var 95,8 %. Vi har også avledet usikkerhetsnivåer i modelleringen, som resulterte i en gjennomsnittskorreksjonsfaktor av 92,5 % ± 9,7 SD. Lavere verdien kan skyldes vindhastighetsfordelingen i den aktuelle perioden, som påvirker både fuglenes hastighet og fluktaktivitet. Dette vil redusere den totale perioden av interesse, og lavere forventet antall flukt gjennom rotordisken. Selv om denne modelleringen tok hensyn til variasjon i vind- og fuglenes hastighet, dagslys og fluktaktivitet, finnes det flere mulige feilkilder, som for eksempel observatørbias. Disse har blitt vurdert. Den beregnede korreksjonsfaktoren var litt lavere for et uavhengig datasett fra observasjonspunkt fra mai 2009. Den relativ lave korreksjonsfaktor inklusive usikkerhetsnivåer, sammenlignet med de fleste andre rovfuglarter, sannsynligvis skyldes høye nivåer av fluktaktivitet og fluktspill, som påvist i Smøla vindkraftverk, hvor tallrike kollisjoner har skjedd.

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Contents

Foreword

In July 2010 NINA was contacted by Chris Marden from SSE Renewables, Scotland. He asked whether we could analyze the vantage point data from Smøla 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 report presents the results from this modelling exercise.

10.12.2010 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, 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, often referred to as an “avoidance rate”.

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. 2008, 2009), Pernille Lund Hoel collected vantage point data on white-tailed eagle (*Haliaeetus albicilla*) behaviour at the Smøla wind-power plant as part of her Master thesis at the University of Science and Technology in Trondheim (NTNU). The aim of the study was to test if the construction of this large-scale wind-power plant would affect white-tailed eagle behaviour. This was done by observing eagle flight behaviour from 12 vantage points, six inside the wind-power plant area and six in adjacent control areas. The Master thesis “*Do wind power developments affect the behaviour of White-Tailed Sea Eagles on Smøla?*” was finalized at NTNU in June 2009 (Hoel 2009). This data, together with additional vantage point data collected by Rowena Langston in May 2009, formed the basis for the ‘Band’ collision risk modelling presented in this report.

The objective of this study was to back-calculate the correction factor for white-tailed eagles within the Smøla wind-power plant using the vantage point data. The approach followed as much as possible 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. Similar exercises have been done for other species (e.g. Whitfield & Madders 2006a, 2006b; Whitfield 2009).

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.

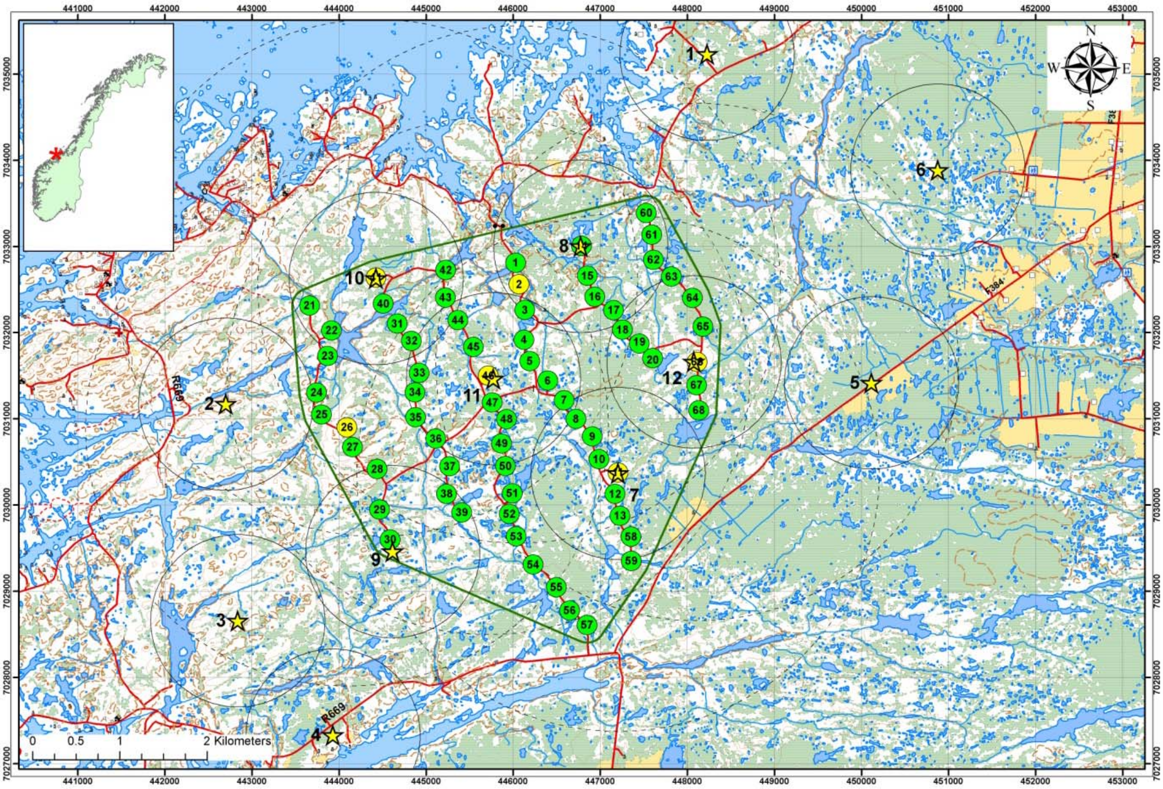


Figure 1. *Smøla wind-power plant, central Norway. The green line indicates a 200-m buffer around the outermost turbines. The yellow stars and circles indicate the locations of the vantage points for 2008 and 2009, respectively. The solid and dotted circles indicate, respectively, the 1-km and 3-km vantage point survey area.*

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). In 2009, approximately 60 white-tailed eagle territories were recorded in the Smøla archipelago (Bevanger et al. 2009).

2.2 Searches for collision victims

Searches for dead birds near turbines have been carried out since 1 August 2006 using specially trained dogs. Two dogs were trained to a search image of both feathers and dead birds. A riesenschnauzer (Luna) was specially trained to search for dead birds before the start of the project in August 2006. In addition, a briard (Solan) was converted from a human rescue dog to a dog searching for dead birds by reinforcing 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 is possible with visual searches alone. By making use of this phenomenon together with wind direction and velocity 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 downwind 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 large 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 Vantage point data collection

The methodology mostly followed the vantage point based survey method proposed by SNH (2005). The analyses were based on vantage point data collected in spring 2008, and verified using an independent vantage point data set from May 2009.

In 2008, the data were recorded from 12 vantage points (VP), of which six were selected within the WPA and six in an area with similar topography outside the wind farm as a control area (CA) (Figure 1). Each VP had an observation-radius of 1 km, and VPs were located as far as possible away from each other in order to minimize the risk of observation overlap. The data were collected from mid-March to the end of May 2008 and included 136 observation hours (12 vantage points at 5-6 hours each). The observation sessions were done every second week, and were divided into four observation periods during the daytime (Table 1). Starting with a random VP sequence over the observation periods, the observation sessions at each VP were thereafter rotated over the observation periods to ensure an even distribution of the data over the day. Two persons were simultaneously collecting data in the field to increase the probability of detecting the flying individuals in the area, and to increase the accuracy of the observations. With the use of two persons observing in each direction in flat terrain, almost complete 360 degrees observations were accomplished and possible detection limitations were decreased. The distance to the individual under observation was estimated using a binocular rangefinder (Leica Geovid 10x42 HD), taking known distances between structures in the terrain as a reference when the distance to the individual was difficult to estimate.

Table 1. *Overview of the distribution of the two-hour vantage point observation sessions from mid-March to the end of May 2008. Each cell contains the identification number of vantage points; numbers 1 through 6 were placed inside the WPA.*

Week	Time-of-day			
	0800-1000	1100-1300	1400-1600	1700-1900
13	1, 5, 10	2, 4, 11	6, 8, 9	5, 7, 12
15	3, 6, 7, 12	1, 5, 10, 12	2, 4, 10,11	3, 6, 8, 9
17	4, 8, 9, 11	3, 6, 7	1, 5, 12	2, 10, 11
19	1, 2, 10	4, 8, 9,11	3, 6, 7, 9	1, 3, 4, 5
21	3, 5, 12	1, 2, 10	4, 8, 11	6, 7, 9

For verification purposes, we also modelled collision risk using VP data collected in May 2009 which included 58 observation hours with varying observation periods (range: 40 minutes to 2.5 hours). These observations were only conducted from six different VPs located at wind turbines within the WPA, to focus on behavioural responses to turbines (Table 2). Each VP had an observation-radius of circa 3 km (R. Langston pers. comm.). The fieldwork was conducted by one person, undertaken only in May, so these data were only used for verification purposes.

Table 2. *Overview of the distribution of the vantage point observation sessions in May 2009. Each cell contains the number of the vantage points; the numbers indicate the wind turbine numbers where the VP was located.*

Week	Time-of-day			
	0800-1000	1100-1300	1400-1600	1700-1900
18			11, 46	
19	11, 41	11, 26, 41	26 (2x)	2, 46
20	26, 46	46, 66 (2x)	41, 46, 66	11, 26, 41
21	46	26, 41	11	11, 46

The sampling method used during both years was based on the method Focal-Animal Sampling (Lehner 1979); where one individual is the focus of observations during a particular sample period. That is, a particular individual receives highest priority for recording its behaviour, but it does not necessarily restrict observations to only that specific individual. Where social behaviour 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 2008, altogether 244 observations were recorded, with a total of 581 events. In 2009, in total 242 events were recorded over 143 observations. Each time an observed individual changed behaviour or flight height, this was recorded as a new event. In this way each individual had from one up to 12 recorded events, during an observation period.

At each observation point (i.e. location of each event) the following data were recorded: (i) date and time; (ii) UTM coordinates (using GPS positions for the VPs, distance to the observation UTM was calculated and plotted on a map); (iii) flying direction and angle for the observation (with zero degrees in north, 180 degrees in south etc.); (iv) flight height above ground level relative to the rotor swept zone (RSZ) (below = 0-39m; within = 39-111m; above = >111m); (v) type of activity; (vi) age of the observed individuals (juvenile: birds up to one and a half year old (1K-2K), in their 1st -2nd calendar years; subadult: 3K-5K birds, in their 3rd-5th calendar years; adult: 6K+ birds, in their 6th calendar year or older; unknown age) and (vii) the duration of each behaviour (in seconds). In addition, the number of individuals observed together (defined as flying close together and performing the same behaviour) and the total number of individuals observed during each two-hour observation period was recorded.

Only observed aerial activities (i.e. moving flight; soaring; chasing/fighting; spiralling/playing) within the rotor swept zone were used in the analyses because it is the flight activity within this zone that imposes a collision risk. Ground activities were excluded from the analysis. Wind speed data at nacelle-height (70 m) during the observation periods were received from the meteorological station within the WPA. We obtained the bird speed from 26 white-tailed eagles equipped with GPS satellite transmitters which rendered information on instantaneous speed ($n = 3{,}646$).

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 was done for VP data from mid-March to the end of May 2008, and verified using VP data from May 2009.

The wind turbines at the Smøla wind-power plant 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. The modelling was done for these two gears (11 and 16 RPM).

The modelling of collision risk in white-tailed eagles follows, as best as possible, 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. 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 (observed) variation in flight activity, day length and bird speed.

1. From the VP data collection observed flight time within the rotor swept zone per observation session was summed for the observed individuals. When more than one individual was observed simultaneously, the observation time was multiplied by the number of simultaneously observed individuals, and summed for each observation session. These sums were then divided by the number of observed individuals and multiplied by the total number of individuals seen during the entire observation session. Thus the total flight time was estimated (in bird-seconds). This number was thereafter divided by the session duration (2 hours) and the visible survey area for each VP (i.e. π x 1 km^2 for the 2008 data and π x

3 km^2 for the 2009 data). This resulted in the estimated total flight activity/hour/km^2 for each observation session (*F*).

2. Possible effects of time-of-day, week and placement (inside versus outside WPA) on estimated flight activity, were analyzed using a mixed-effects linear model, while controlling for possible grouping effects on VP. This was done using the `lmer` function of the `lme4` library. Possible sources of error in the data are assessed separately.
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).
4. The period of interest *T* was calculated by multiplying the number of days (75 days for the 2008 data, and 31 for the 2009 data) by the day length for each observation session. 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 observation session 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 average bird occupancy for each VP was calculated. From these 12 VP-based estimates of bird occupancy, we calculated the average bird occupancy *n* for the entire wind-power plant.
7. Thereafter, a 'flight risk volume' V_w was identified, equalling the area of the wind-power plant multiplied by the rotor diameter (= 82m).
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 (=41m), *d* is the depth of the rotor back to front (assumed to be 2m), and *l* is the length of the bird (0.8m; source: BTO bird facts 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.
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. 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: 10.2 $^{m}/_{s}$ (derived from GPS satellite transmitters)
- Rotor diameter: 82 m
- Rotation period: 5.45 and 3.75 seconds for 11 and 16 RPM, respectively

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 average bird occupancy with the hit probability. The correction factor for the two gears (hereafter CF1) was derived as follows: CF1 = 1 – actual collisions / (number of birds flying through the RSZ x hit probability).

2.5 Deriving uncertainty levels

The standard way of estimating the correction factor, as done above, 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 (hereafter CF2).

Instead of using the average bird occupancy (step 6), we calculated the log-transformed mean and standard deviation from the 12 VP-based estimates of bird occupancy. These were used to derive 10,000 randomly created estimates of bird occupancy n assuming a lognormal distribution. Using the log-transformed mean and standard deviation in bird speed, we derived a random dataset of 10,000 estimates of bird speed which was assumed to follow a lognormal distribution (step 10). These two estimates were used within the modelling exercise instead of the mean values used above.

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 statistics, we derived a random dataset of 10,000 estimates of wind and bird speed which were both assumed to follow a lognormal distribution. Wind speed was 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). 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.

From these 10,000 estimates in bird occupancy and hit probability, the mean and standard deviation in the correction factor were calculated.

3 Results

3.1 Collision victim searches

Altogether, 38 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 7.6 dead white-tailed eagles were found per year. This equals on average 0.11 dead white-tailed eagles per turbine per year.

Of the total 38 dead or injured birds, 27 (71%) 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 (16%) dead/injured white-tailed eagles were found (Figure 2).

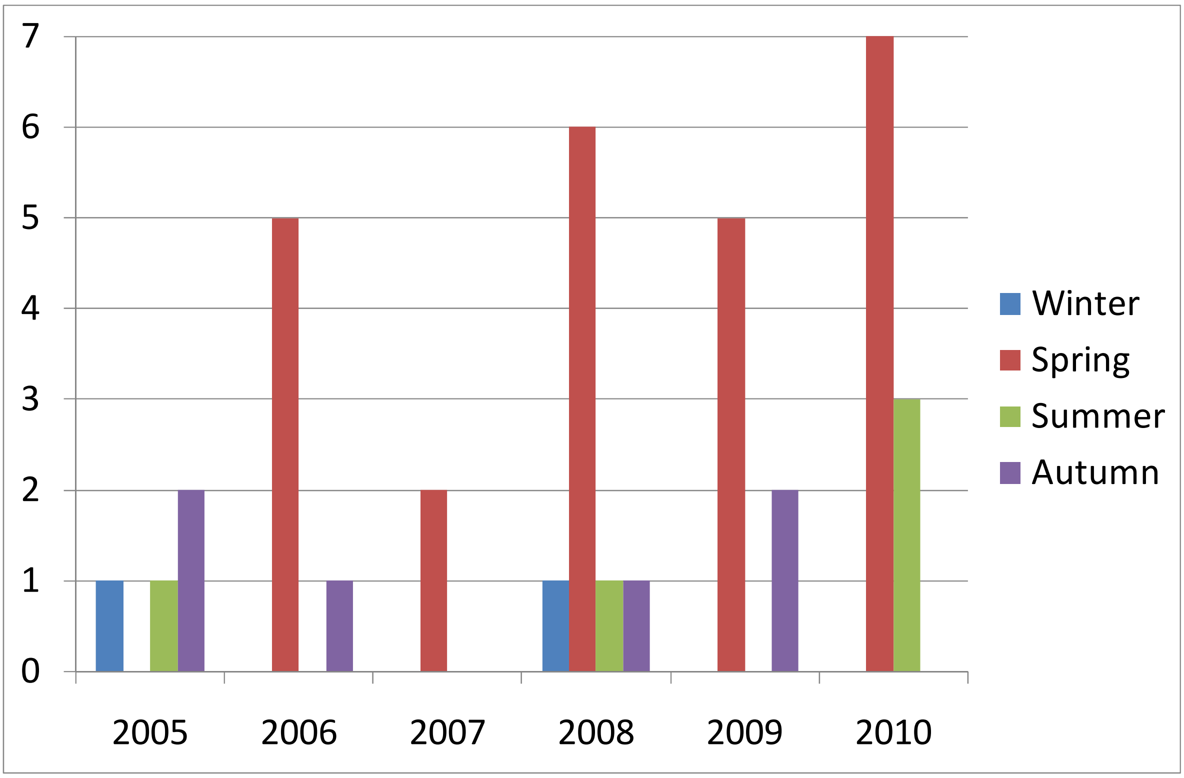


Figure 2. *Number of white-tailed eagles found dead or injured at the Smøla turbines until 15 November 2010. The first was found in August 2005, and regular searches were initiated in 2006. Winter = December-February; Spring = March-May; Summer = June-August; Autumn = September-November.*

The age distribution of the 38 birds found was 20 (53%) 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).

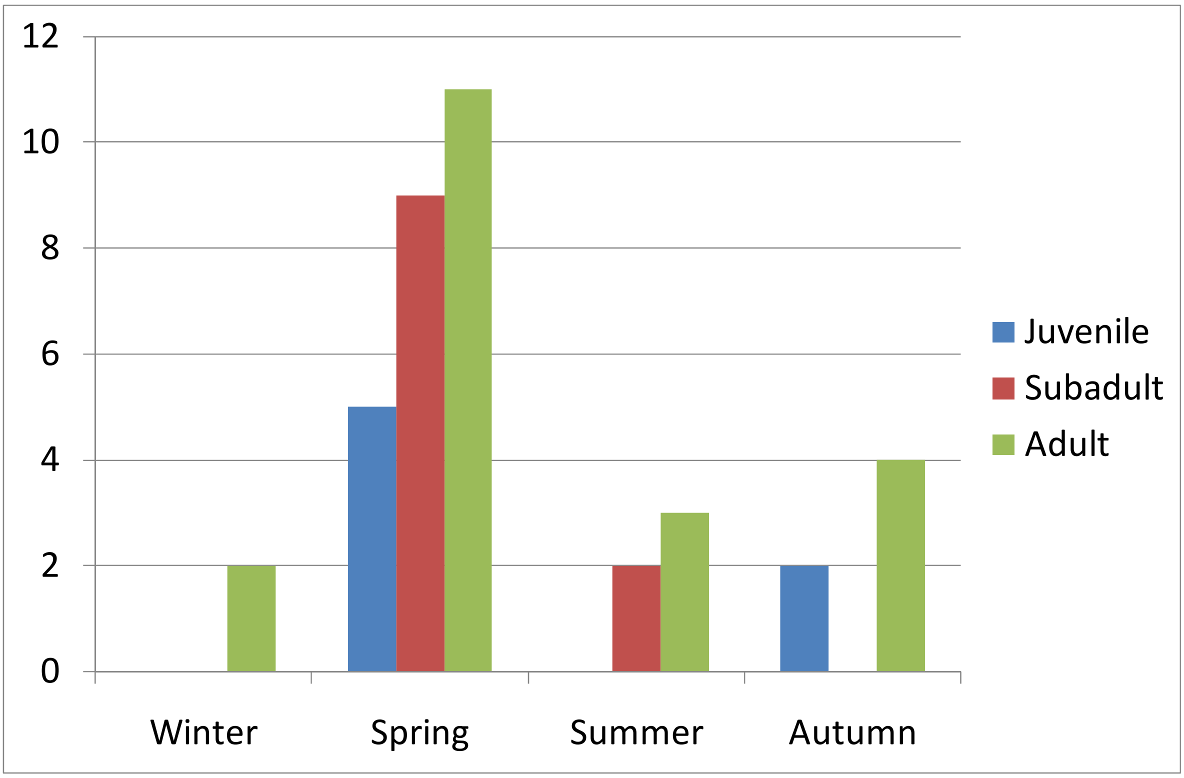


Figure 3. *Age distribution of white-tailed eagles found dead or injured at the Smøla turbines until 15 November 2010. See also legend in Figure 2.*

In total, five white-tailed eagles collided with wind turbines during the first vantage point sampling period (mid-March – end of May 2008). In May 2009, only one white-tailed eagle was found dead. These numbers were used in the further analyses in Stage 3.

3.2 Collision risk using VP data collected March-May 2008

3.2.1 Collision risk for 11 and 16 RPM

Flight activity (step 1) was calculated for each observation session at each VP separately (*n*=68). Thereafter we tested for possible effects of time-of-day, week and placement (inside or outside the wind-power plant) using a mixed-effects linear model; controlling for possible grouping effects on VP (step 2; Table 3, Figure 4). The data indicated no significant difference in flight activity between VPs placed outside the wind-power plant versus those placed inside. In other words, white-tailed eagles did not show different flight activity between the two areas. Because of the lack of effect inside/outside of the wind-power plant, all data were pooled in the further analyses. The data did, however, show a significant variation in flight activity through the day and over weeks.

Table 3. *Results from the mixed-effects linear model.*

Covariate	df	F-value	P-value
(Intercept)	1,49	25.487	<0.001
Inside/Outside	1,10	0.086	0.775
Week	4,49	11.057	<0.001
Time-of-day	3,49	6.927	0.006

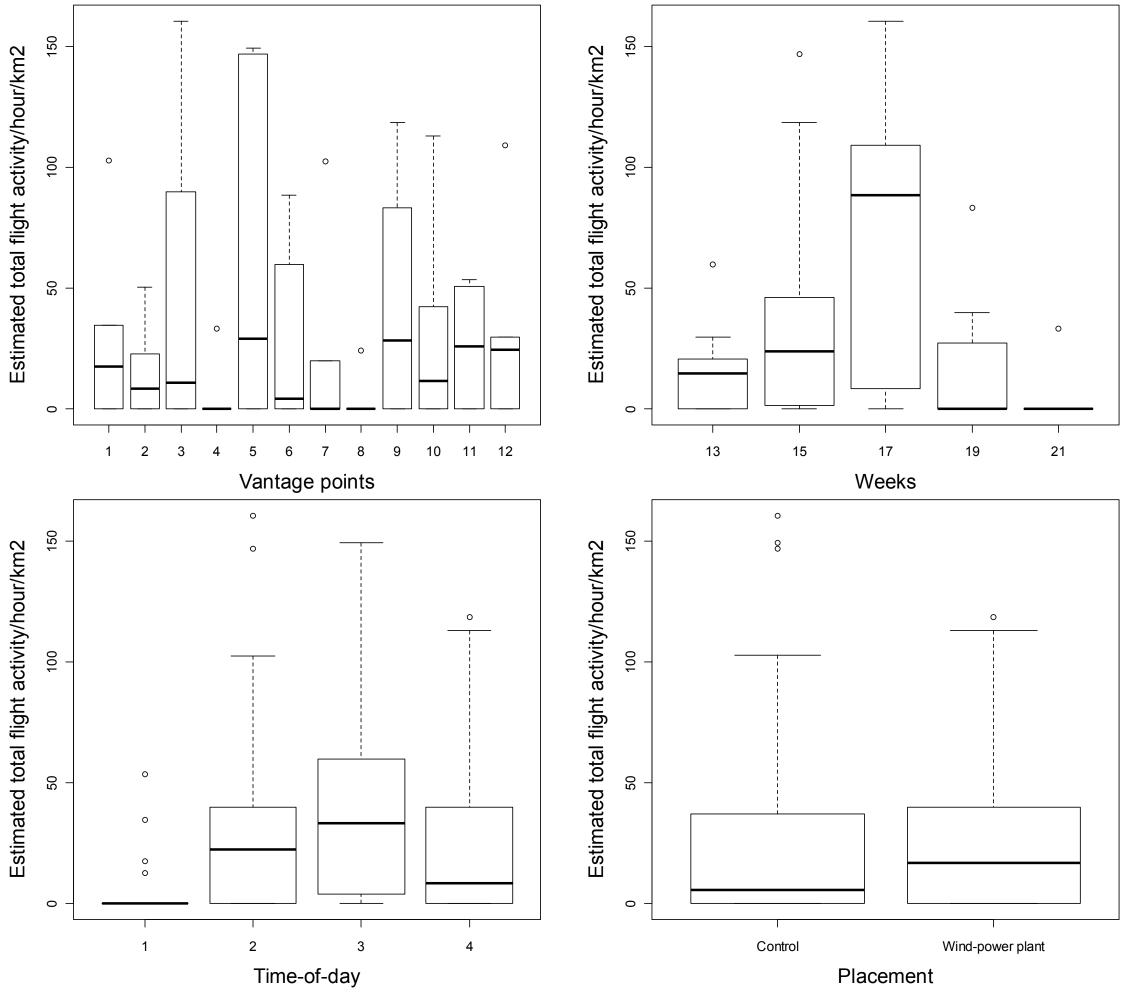


Figure 4. *Box plots showing the estimated total flight activity (bird- seconds) per vantage point and placement; over weeks and time-of-day. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile), whereas the dots indicate outliers. VP's 1-6 were placed inside the wind-power plant, whereas 7-12 were placed outside (control). Time-of-day was defined as 2-hour periods over the day (0800-1900, see Table 1).*

The white-tailed eagle occupancy of the wind-power plant area (step 6) was 162 hours for the entire observation period (15.3.08 – 31.5.08). The bird occupancy of the volume swept by the rotors (step 9) was 401 bird-seconds. From this, and a transit time of 0.274 seconds, the number of bird transits through the rotors (step 11) was 1462 for the entire observation period. The likelihood of collision (stage 2) was calculated for the two gears with which the wind turbines at the Smøla wind-power plant operate: 11 and 16 RPM. The probabilities were respectively 0.094 and 0.118. The correction factors (CF1; stage 3) resulting from the outcome of stage 1 and 2, and the actual collisions (5), were 96.4% and 97.1% for 11 and 16 RPM, respectively.

These values, however, assume that the wind turbines operated continuously with the respective RPMs. During the observation period at Smøla WPA, 42.4% of the time the turbines operated at 11RPM, whereas 35.7% of time they operated at 16 RPM. For the rest of time they were either idling at low wind speeds (21.8%). The expected correction factor for the actual wind speed distribution at a given site (CF1') may be derived by: CF1' = 1- (1-CF1)/*p*, where *p* equals the proportion of time the wind turbines operated (i.e. sum of operation time for both gears). Thereafter the adjusted correction factors for 11 RPM (95.3%) and for 16 RPM (96.3%) can be averaged using a weighted mean (over the proportion of time for each RPM), to derive an overall correction factor; for Smøla, this was 95.8%.

3.2.2 Collision risk including uncertainty levels

The correction factor including uncertainty levels (CF2) was estimated including variance in wind speed and bird speed (which were assumed to follow a lognormal distribution). Average wind speed at nacelle-height (70 m) for the period mid-March to the end of May 2008 (15.3.08 – 31.5.08) was 5.40 $^{m}/_{s}$ ± 2.99 SD (10.15 ± 5.75 RPM). Mean and standard deviation in bird speed 10.2 $^{m}/_{s}$ ± 4.6 SD. The flight activity was averaged over weeks and time-of-day; rendering 12 VP-based estimates. From this the average and standard deviation in flight activity was derived (which was assumed to follow a lognormal distribution). Using these estimates, we iterated the Band-model calculations 10,000 times to produce robust estimates of the correction factor. Given the wind speed during mid-March to the end of May 2008, and the variation in bird speed, the mean hit probability was 0.115 ± 0.052 SD.

The average correction factor for the Band-model (i.e. “avoidance rate”) was 0.925 ± 0.097 SD (95% confidence interval: 0.923 – 0.927; median: 0.954; Figure 5). 95% of the estimated correction factors were found within the range 0.734 – 1.000 (± 1.96 SD).

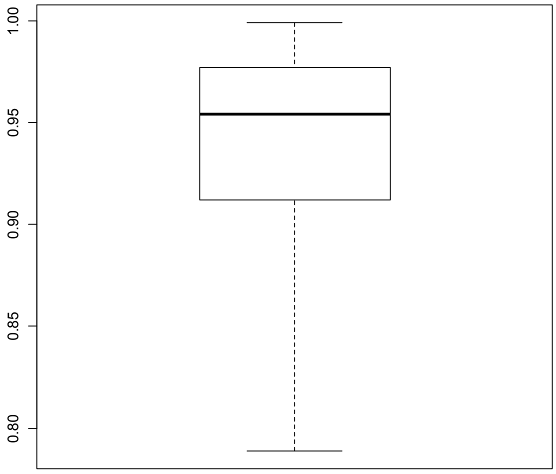


Figure 5. *Box plot showing the correction factor for the Band collision risk model. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile), whereas the dots indicate outliers.*

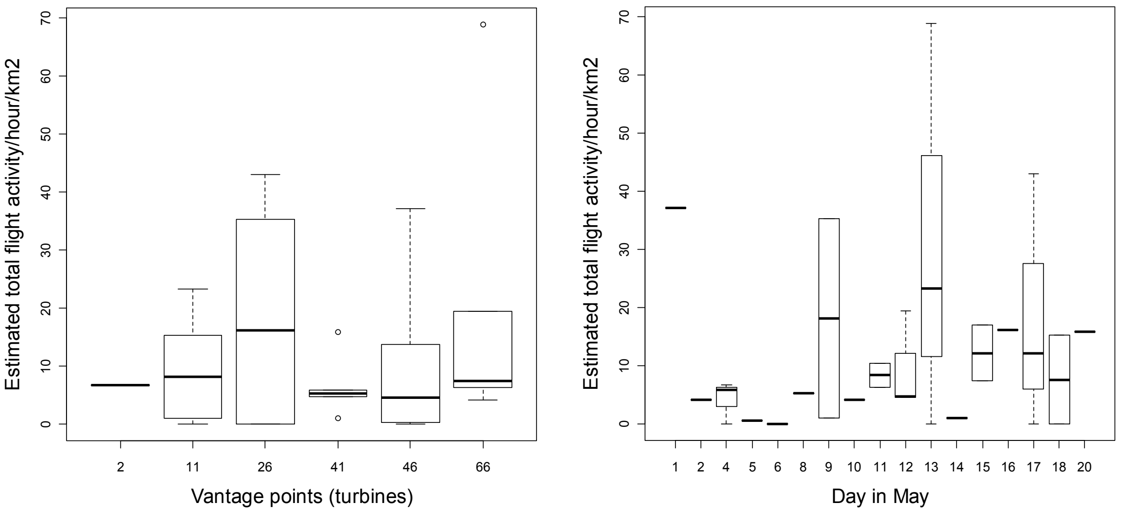
3.3 Verification using VP data collected May 2009

3.3.1 Collision risk for 11 and 16 RPM

Flight activity was calculated for each observation session at each VP separately (n = 29). Thereafter we tested for possible effects of time-of-day and week using a mixed-effects linear model; controlling for possible grouping effects on VP (Table 4, Figure 6). The data indicated no significant variation in flight activity over the day and over the weeks.

Table 4. *Results from the mixed-effects linear model.*

Covariate	df	F-value	P-value
(Intercept)	1,5	14.889	0.012
Week	16,4	0.548	0.827
Time-of-day	3,4	1.684	0.307



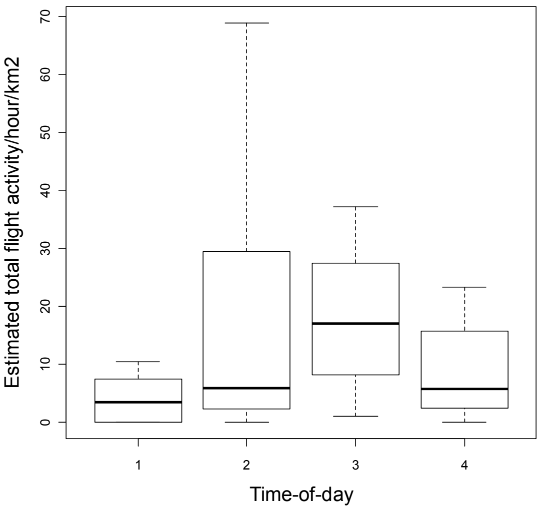


Figure 6. *Box plots showing the estimated total flight activity (bird-seconds) per vantage point; over days and time-of-day. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile), whereas the dots indicate outliers. All VP's were placed inside the wind-power plant; the numbers indicate the turbine number. Time-of-day was defined as 2-hour periods over the day (0800-1900, see Table 1).*

The white-tailed eagle occupancy of the wind-power plant area (step 6) was 17.6 hours for May. The bird occupancy of the volume swept by the rotors (step 9) was 44 bird-seconds. From this, and a transit time of 0.274 seconds, the number of bird transits through the rotor swept zone (step 11) was 159 for May. The likelihood of collision (stage 2) was calculated for the two gears with which the wind turbines at the Smøla wind-power plant operate: 11 and 16 RPM. The probabilities were respectively 0.094 and 0.118. The correction factors (CF1; stage 3) resulting from the outcome of stage 1 and 2, and the actual collisions (1), were 93.3% and 94.7% for 11 and 16 RPM, respectively.

As for the 2008 data, these values assume that the wind turbines operated continuously with the respective RPMs. During the observation period in May 2009, 28.7% of the time the turbines operated at 11RPM, whereas 63.5% of time they operated at 16 RPM. For the rest of time they were either idling at low wind speeds (7.7%). Using the same formula as given in paragraph 3.2.1 the adjusted correction factors for 11 RPM (92.7%) and for 16 RPM (94.2%) can be averaged using a weighted mean (over the proportion of time for each RPM), to derive an overall correction factor; for Smøla, this was 93.8%.

3.3.2 Collision risk including uncertainty levels

Average wind speed at nacelle-height (70 m) for the period 1-22 May 2009 was 7.50 $^{m}/_{s}$ ± 3.37 SD (12.77 ± 4.61 RPM). Average bird speed was 10.2 $^{m}/_{s}$ ± 4.6 SD. The flight activity was averaged over weeks and time-of-day; producing six VP-based estimates. From this the average and standard deviation in flight activity was derived.

Using these estimates, we iterated the Band-model calculations 10,000 times to produce robust estimates of the correction factor. Given the wind speed during 1-22 May 2009, and the variation in bird speed, the mean hit probability was 0.126 ± 0.060 SD. The average correction factor (CF2) for the Band-model (i.e. "avoidance rate") was 0.898 ± 0.106 SD (95% confidence interval: 0.896 – 0.900; median: 0.930; Figure 7). 95% of the estimated correction factors were found within the range 0.691 – 1.0000 (± 1.96 SD).

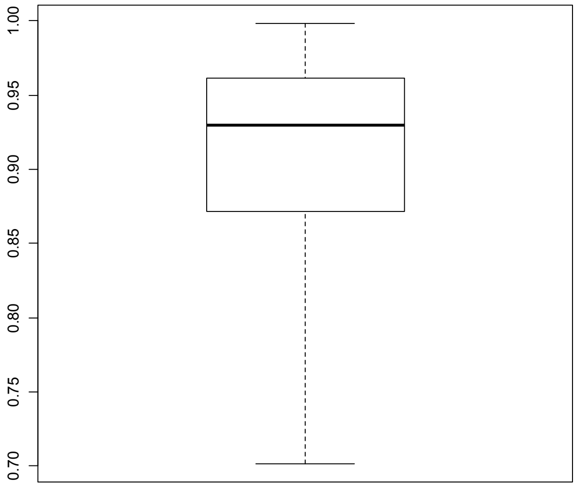


Figure 7. *Box plot showing the correction factor for the Band collision risk model. The box indicates the 25th and 75th percentile; while the whiskers indicate the 5th and 95th percentile. The thick line indicates the median (50th percentile), whereas the dots indicate outliers.*

3.4 Assessment of possible sources of bias

Although this was not the focus of the field study in 2008, we here assess possible sources of bias in the data – weather and observer biases. Although this may give insight into possible sources of bias, we cannot deduce from these analyses how this may have affected the model outcome.

The total number of observed white-tailed eagles and their flight activity within the rotor swept zone (RSZ), as calculated for each vantage point observation session (see paragraph 3.3), was regressed against temperature (°C), wind speed ($^{m}/_{s}$) and precipitation (mm). Using a generalized linear model with Poisson distribution, the total number of observed white-tailed eagles during each vantage point observation session decreased with precipitation (z = 2.357, P = 0.018) and wind speed (z = 11.040, P < 0.001), but increased with temperature (z = 3.019, P = 0.003). Using a lognormal model, their flight activity within the RSZ during each vantage point observation session was, however, unaffected by temperature, wind speed and precipitation.

The, possibly non-linear, effect of distance from observer on the proportion of events within and below RSZ was modelled using a generalized additive model with a binomial distribution. The proportion of events within and below RSZ decreased with distance from the observer (χ^2 = 9.765, edf = 1.96, P = 0.012; Figure 8). When only considering the proportion of events below RSZ, no significant distance effect was found. Thus, this effect may be caused by a decreased detectability at higher flight altitudes farther away.

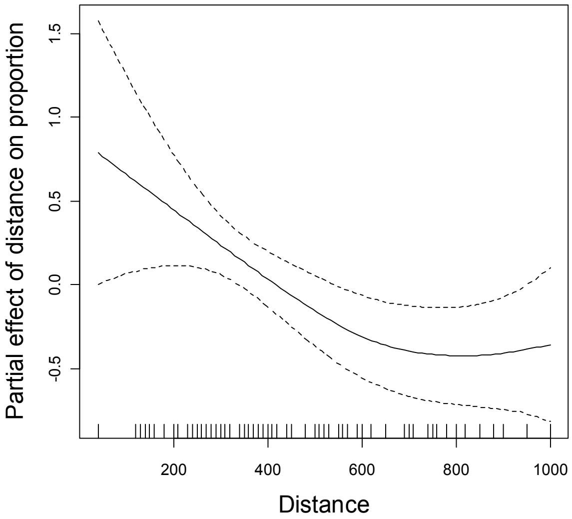


Figure 8. *Smoothed, non-linear effect of distance from observer on the proportion of events within or below RSZ resulting from a generalized additive regression model. The small bars on top of the x-axis show the distribution of the actual observations.*

The, possibly non-linear, effect of distance from observer on the number of recorded events was modelled using a generalized additive model with Poisson distribution (Figure 9 – left-hand panel). However, everything else being equal, the number of observations will increase with distance due to a linear increase in surface area (i.e. a 10-m wide ring closer to the observer will have a smaller surface area than a 10-m wide ring farther away). When taking into account this effect, the number of observations decreased slightly (circa one event less) at larger distances (approximately >750m) from the observer (χ^2 = 44.140, edf = 8, *P* < 0.001; Figure 9 – right-hand panel). Also, only one event was recorded within 100m from the observers.

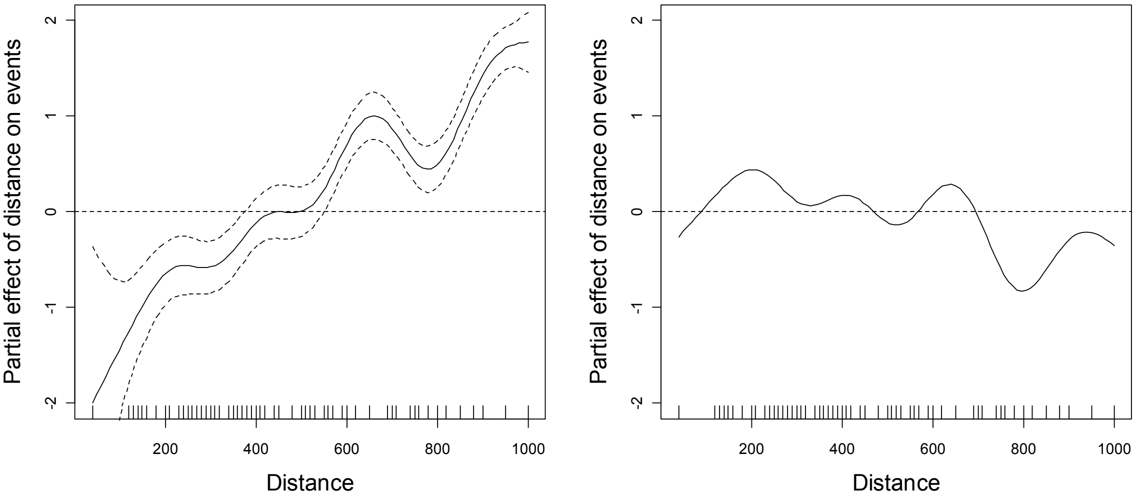


Figure 9. *Smoothed, non-linear effect of distance from observer on the number of events resulting from a generalized additive regression model (left-hand panel). The right-hand panel shows the detrended distance effect, controlling for an increase in surface area over distance. The small bars on top of the x-axis show the distribution of the actual observations.*

4 Discussion

Given our vantage point observations data the correction factor (i.e. “avoidance rate”) derived from the Band collision risk model for white-tailed eagles was 97.8 and 97.9% for 11 and 16 RPM, respectively. These values, however, assume that the wind turbines operated continuously with the respective RPMs. The correction factor adjusted for the actual wind speed distribution at Smøla WPA was 95.8%. We also derived uncertainty levels in the modelling, which resulted in a mean correction factor of 92.5% ± 9.7 SD. Although the values for the two RPMs are similar, the modelled value including uncertainty is lower than the value given in the guidance note from SNH (2010). 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). Hopefully, this report can be used to present a more up-to-date correction factor resulting from actual vantage point-based collision risk modelling. Although the correction factors for the two given RPMs are similar to other raptors (95-99%; SNH 2010), the factor including uncertainty is lower. This may be due to wind speed distribution during the period of interest, affecting both bird speed and flight activity. This would decrease the total period of interest; and lower the number of bird transits through the rotor swept zone (stage 2). Visual observations, with few white-tailed eagles showing any avoidance behaviour in the vicinity of wind turbines, fit with the relatively low correction factor modelled. The flight activity data from 2008 covered the peak display period, whereas in 2009, the peak had already occurred before fieldwork commenced.

Although the correction factor often is thought to be related to avoidance, we did not find any difference in flight activity inside/outside the wind-power plant (2008 field study, Table 3, Figure 4). The estimated correction factor therefore cannot 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 structure 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*: not all birds may be observed, especially at longer distance from the vantage point. Decreased detectability affects the calculated flight activity. Also, the number of collisions may be underestimated because of observer, removal and crippling biases.
- *Terrain conditions*: the area visible at ground level from the vantage point (i.e. the viewshed or zone of visible influence) likely underestimates the volume which is visible at rotor swept heights given that the observer will look upwards.
- *Seasonal and daily variation*: diurnal flight activity levels are likely to be influenced by observation points and activity of territorial birds.
- *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 calculated flight activity assumes a uniformly distributed activity throughout the wind-power plant area. Also, note that the hit probability (stage 2) never reaches zero; even when the rotor blades are barely moving (minimum = 7.9% given similar input values as used within the modelling; Figure 10).

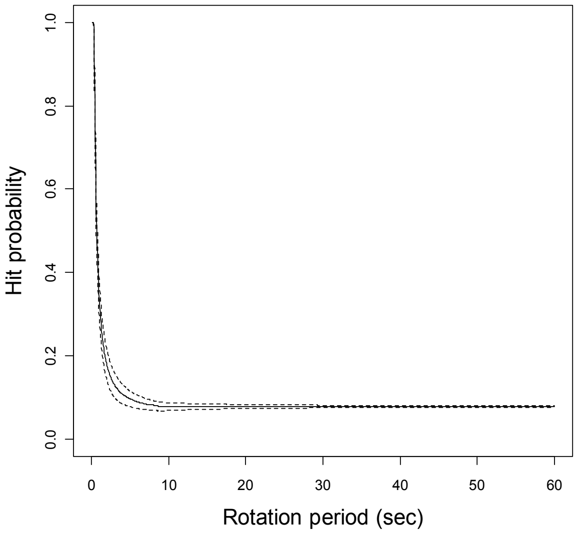


Figure 10. *Hit probability for different RPM's of the wind turbine. Note that the minimum value never reaches zero (0.079); even when the turbine is standing still! The dotted lines indicate the probability for upwind (upper line) and downwind situations; the solid line indicates the mean of these two probabilities. This model was run using typical white-tailed eagle values: bird speed of 10.2* $^{m}/_{s}$*; bird length of 0.8 m; wingspan of 2.315 m. Turbine specifics were: pitch of 10°; max chord of 3.296m.*

As far as possible the standard SNH approach for executing vantage point observations were followed (SNH 2005). Difference between this study and the standard SNH approach were that we observed a full 360 degrees circle instead of 180 degrees half-circle; equivalent to two standard SNH vantage points. This was deemed possible because in the 2008 field study two observers were used. Also, a 1-km maximum observation distance was set, instead of observing birds indefinitely. This avoids the problem of underestimating the actual flight activity because of reduced detection at larger distances from the observer. The methods differed in one important respect, namely that VPs were located both within and outside (only for the 2008 field study) the wind-power plant rather than outside the wind-power plant looking in. The potential for observer effect on bird behaviour is the reason for SNH guidance recommending VPs outside the wind-power plant; however there is a trade-off between reduced influence on bird behaviour and distance over which effective observations can be made.

The 2009 study was not designed to run through the Band collision risk model and violates the standard VP assumptions in several respects. Furthermore, the study was restricted to just one month, limiting its usefulness. Only one casualty was found. There is also an important distinction to be made with respect to the study in May 2009 in that the focus was on flight activity and near-field response to turbines, hence observation points were selected to maximise coverage of several turbines rather than to minimise overlap between observation points. Also, the observations were not limited with a 1-km observation range. This is an important factor in respect of Band modelling. Overlap on a given day was reduced by selecting observation points in different parts of the wind-power plant. However, there is overlap of individuals observed from different observation points – this is known because of territorial individuals whereas in most cases of VPs the extent to which the same individuals are observed may not be known. The unit of interest was flight activity, although clearly there may be bias if that activity includes repeated observations of the same individuals. Overlap is likely to lead to overestimation of flight activity which in turn will lead to overestimation of collision avoidance rate.

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 (e.g. separately for each vantage point) when such, and enough, data are available. However, often the wind-power plant is not large enough to ensure full spatial independence among vantage points. Also, splitting the year into seasons, or months, may hamper robust estimates because of lack of enough actual recorded collisions (e.g. the effect of 0 or 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 and bird directions, and variations in both speeds and directions. Data on these should be fairly easy to obtain from weather stations and vantage points, respectively.

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