DONG Energy

Anholt Offshore Wind Farm

Post-construction Monitoring of Bird Migration

DONG Energy

REPORT ON RAPTOR MIGRATION SURVEY IN 2014-2016

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1. SUMMARY

The Anholt Offshore Windfarm (AOWF) is situated in Kattegat halfway between Djursland and the island of Anholt. The wind farm consists of 111 wind turbines arranged in rows perpendicularly to the flightpath used in spring by land birds migrating from Djursland via Anholt to Sweden. It could be feared that collisions with turbines could lead to bird mortality but also that the rows of wind turbines might act as barriers to the traveling birds.

This study compares data from pre- and post-construction studies of migrating raptors to determine if the AOWF has changed the flight pattern of the migrating birds and impose a significant collision risk.

Fieldwork for the post-construction studies took place on the mainland coast at Gjerrild in 2014 & 2015 and on an offshore substation c. 1.75 km west of the AOWF in 2014-2016. Digital laser type rangefinders, radars and binoculars were used to compile data. The observers on the substation also recorded any avoidance behaviour of the raptors approaching the turbines.

The study showed that the raptors generally left land at a lower height after the construction of the AOWF, which suggests that they could be attracted to the AOWF. However, other flight parameters gave inconclusive results and overall there is no strong evidence for the migrating birds considering the AOWF a “stepping stone”.

The modelling of the collision risk revealed relatively high numbers of fatalities of Common Buzzard (24 birds/year), Sparrowhawk (6 birds/year) and Honey Buzzard (3 birds/year), the last species is listed on Annex I of the Birds Directive. For these species this represents 0.8 – 1.4% of the total number that passes the AOWF each spring. The estimated fatalities represents 0.02% or less of their biogeographical populations and less than 1% of the PBR for all species. It is concluded, that the modelled number of fatalities has insignificant impact on the biogeographical population or the PBR for all species including species listed on Annex I of the Birds Directive.

When the migrating raptors got nearer to the wind farm large numbers showed strong avoidance behaviour. From the Substation (1.75 km from the nearest turbine), macro-avoidance was observed for 1/3 of the migrating raptors, including 59% of the Red Kites, 45% of the Kestrels and 42% of the Sparrowhawks. After migrating c. 20km over the sea, about 75% of these birds turned and flew back towards Djursland while the rest continued perpendicular to the wind farm without entering the farm for as long as they were within sight. This strongly suggests that the AOWF acts as a barrier preventing these birds from crossing Kattegat at Djursland or prolonging their migration route significantly. The impact of this on survival and fitness of the individuals concerned is unknown.

Skov et al. (2009, 2012a) propose that the spring migration corridor between Djursland and Sweden is of international importance. Our data and other recent observations suggests that only moderate numbers of raptors use this route compare to for example migration corridors across Zealand and at Skagen in northernmost Jutland. Since the Djursland – Sweden corridor is of secondary importance to the raptor species in question, the observed barrier effect probably has limited impact at the population level. However, macro-avoidance behaviour of the scale observed at the AOWF could potentially have significant impact on raptor populations if the offshore wind farm was located across a major migration route.

2. INTRODUCTION

Wind power has emerged as a leading renewable energy technology in Denmark and in particular, the number of offshore wind farms are set to rise in the coming years. However, there are concerns that offshore wind farms when poorly sited for example from the perspective of bird migration can have detrimental impacts through collisions and barrier effects.

Anholt Offshore Windfarm (AOWF) is situated in Kattegat halfway between Djursland and the island of Anholt. The wind farm consists of 111 wind turbines (3.6 MW) arranged in rows perpendicularly to the flightpath used in spring by land birds migrating from Djursland via Anholt to Sweden. It could therefore be feared that collisions with turbines could lead to bird mortality but also that the rows of wind turbines might act as barriers to the traveling birds.

Migration counts at the coast of Djursland as well as baseline studies in 2009 and 2011 (Skov et al. 2009, 2012a) in connection with the Anholt Offshore Windfarm project have documented that the sea between Djursland and Anholt is a significant migration corridor in spring, in particular for raptors. For example were 547 migrating raptors belonging to 14 species recorded at Gjerrild Klint on the Djursland coast during the baseline studies in 2011.

Among the migrating raptor species recorded during the baseline studies were several threatened species adopted on the Annex I of the EU Birds Directive: Osprey, Honey Buzzard, Red Kite, White-tailed Eagle, Marsh Harrier, Hen Harrier, Golden Eagle, Merlin, and Peregrine Falcon. Further Annex I species regularly recorded at Gjerrild include Black Kite, Montagu's Harrier and Red-footed Falcon.

The baseline studies found that raptors heading north-eastwards from the coast of Djursland have a high probability of passing through or above the AOWF. The studies further indicated that Anholt has a true stepping stone effect[1] on migrating raptors.

With the Anholt Offshore Windfarm installed in 2013 DONG Energy commissioned a post-construction study of raptor migration that was carried out during the spring season 2014 – 2016.

This report presents the result of this field study and assesses to what extent AOWF poses a significant collision risk and barrier effect for migrating raptors at individual and population level.

[1] Many migrating land birds try to reduce the length of a sea crossing by heading towards islands in the approximate migration direction and use the islands as "stepping stones".

3. ANHOLT OFFSHORE WINDFARM

The AOWF is located in the sea area Kattegat between Djursland and the island of Anholt (Figure 3-1) in an area with water depths of about 15 to 19 meters.

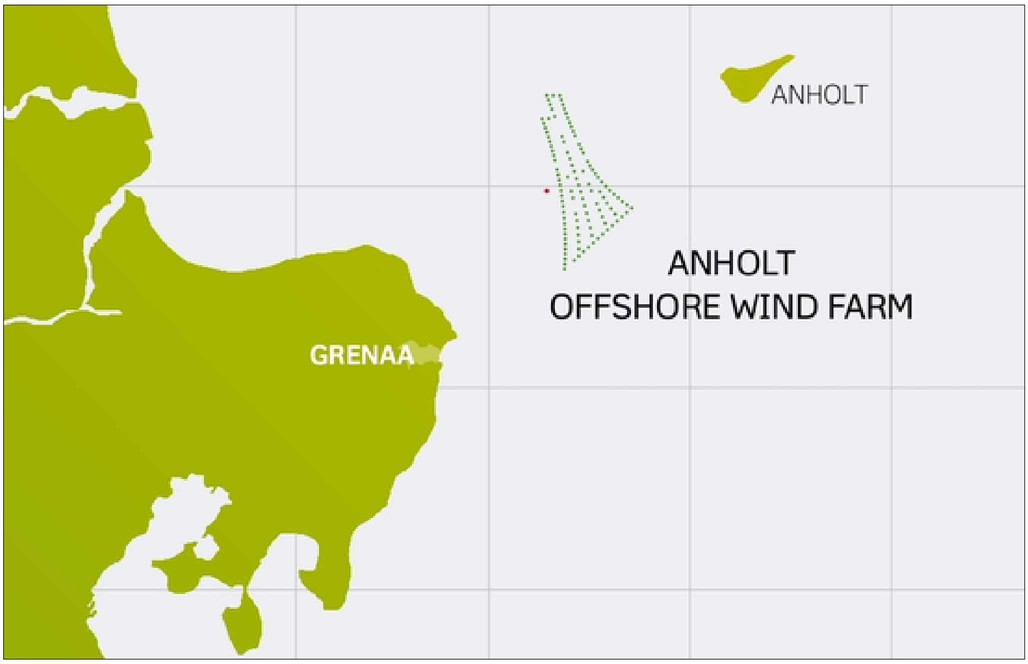

Figure 3-1. The location of Anholt Offshore Wind Farm in Kattegat. The red dot indicates the position of the Substation.

The 400 MW wind farm consists of 111 turbines and is approx. 20km long and up to 5km wide. The shortest distance to Djursland is approx. 15km, while there are 20km to the island of Anholt.

The Substation positioned 1,75 km west of the wind farm and transmits the energy from the wind turbines to the electrical grid on land.

Each of the 3.6 MW turbines has a rotor diameter of 120 m. The minimum height from the sea surface to the rotors is 21.6 m and the highest point of the rotor is 141.6 m.

4. SCOPE OF WORK

4.1. The purpose of the study

The purpose of this post-construction monitoring study, as defined by DONG Energy, is to collect the necessary data to enable a firm and conclusive assessment of the weather dependent collision risk for raptors passing the AOWF during spring migration. In addition, the potential impact of the windfarm on the migrating raptors should be firmly assessed and, if possible, quantified.

The scope further points out that particular efforts must be made to describe the migration of Annex I species with small populations such as Osprey, Honey Buzzard and Peregrine Falcon. Finally, the post-construction monitoring surveys should be designed and carried out as close to the BACI (before-after-control-impact) principle as possible and should therefore be designed and undertaken following the same overall methodology as applied during the baseline programme.

4.2. The study methodology

DONG requested that the monitoring programme should be based on one or more hypotheses, which reflect the objectives of the post-construction study, the focus on raptors with small population sizes and also take into account the results of the baseline programme.

To meet these requirements, hypotheses were formulated that assess potential impacts at two levels; the potential impact on the individual migrating raptor, and the potential impact on the biogeographic population of the raptor species in question.

This implies that the first set of hypotheses can be answered directly based on the data compiled and analysed from the field study, whereas the hypotheses that deal with the potential impact at population level must also include data on population size, survival rates, reproductive potential and other parameters.

4.3. Hypotheses addressing impact

To meet the DONG requirements, including taking into account the results of the baseline study, the following hypotheses were formulated that address the potential impact of the AOWF on individual birds.

Hypothesis 1

It was hypothesized during the baseline studies that migrating raptors will perceive the AOWF as a stepping stone and therefore will initiate their sea crossing at a lower altitude after the wind farm has been constructed than before. The first hypothesis intends to test this:

1. The weather-dependent flight altitude of migrating raptors leaving the coast of Djursland at Gjerrild is unchanged from the pre-construction situation.

Hypotheses 2 and 3

The central part of the AOWF and the Substation are located directly on the main migration corridor between Djursland and Anholt. Our second and third hypothesis intend to test whether the AOWF has an attracting, a neutral or a repelling effect to migrating raptors:

2. The weather-dependent flight direction of migrating raptors leaving the coast of Djursland at Gjerrild is unchanged from the pre-construction situation.

3. Migrating raptors approach the offshore wind farm in numbers comparable to those leaving the Djursland coast at Gjerrild.

Hypothesis 4

The baseline studies demonstrated that migrating raptors approaching Anholt descended towards the island (stepping stone effect). Our fourth hypothesis intends to test whether the AOWF has a similar stepping stone effect, which may increase collision risk. This hypothesis is only relevant for birds migrating at an altitude above rotor height and is not intended to cover the phenomenon of birds descending below the rotor-swept area as a means of avoidance (see Hypothesis 5).

4. Migrating raptors reduce their flight altitude when approaching the offshore wind farm.

Hypothesis 5

The null hypothesis is that migrating raptors do not adjust their flight path when approaching the turbines. Any significant deviation from this will affect collision risk. The fifth hypothesis intends to test this:

5. Migrating raptors approaching the rows of turbines adjust their flight path in the horizontal and/or vertical plane to avoid the turbines and the rotors.

Hypothesis 6

The sixth hypothesis concerns the risk of a migrating raptor colliding with a turbine:

6. Passing the AOWF during spring migration does not pose any significant collision risk to raptors.

This hypothesis will be investigated using a modelling approach, taking into account the answers to Hypothesis 1 to 5.

Hypothesis 7

The last hypothesis builds on the answers from all the previous six ones and takes a population perspective to the potential impact of the offshore wind farm:

7. Passing the AOWF during spring migration does not pose a collision risk to raptors that is likely to effect the biogeographical populations of the species involved.

This hypothesis will also be investigated using a modelling approach, taking into account the answer to Hypothesis 6 and the vulnerability of the populations involved.

5. METHODS

5.1. Post-construction monitoring design

In order to answer the questions the hypotheses raise and to fulfil the overall objective and conditions for the survey, as outlined by DONG, the post-construction survey was designed to compile the following:

- Data on altitude and migration direction of raptors as they leave the Djursland coast;
- Data (species, numbers) on the approach of raptors to the AOWF;
- Data on the behaviour of migrating raptors when approaching the AOWF;
- Data on the behaviour of migrating raptors flying between the turbine rows of the AOWF; and
- Data on the interactions of raptors with the rotor blades.

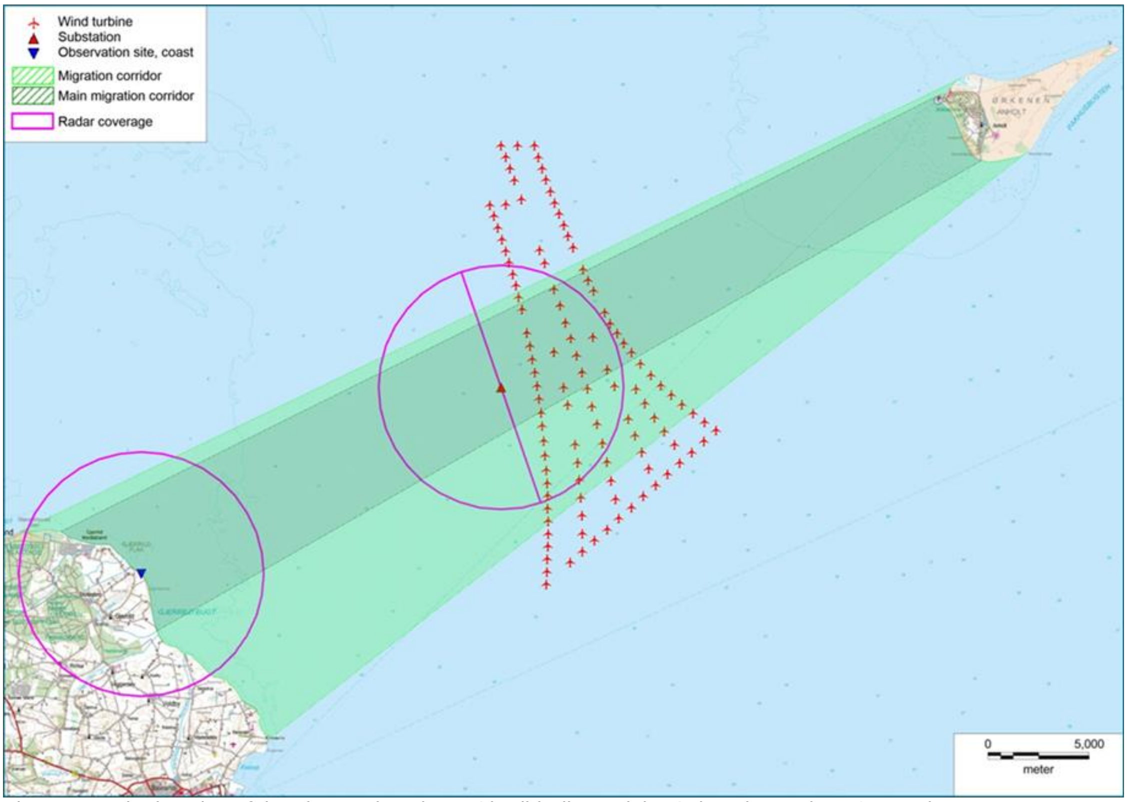

Figure 5-1. The location of the observation site at Gjerrild Klint and the Substation at the AOWF. The expected corridor of the migrating raptors, the position of the AOWF turbines and the presumed radar coverage is also shown.

5.2. Field survey

Observations of migrating raptors leaving the mainland were carried out at the same location on the Djursland coast (Gjerrild Klint) as in the baseline study (Figure 5-2).

Figure 5-2. The observation site at Gjerrild (21 m above sea level) with the radar surrounded by a “clutter fence” to the left.

However, while observations were made on the island of Anholt during the baseline study no observations were carried out at this site during the post-construction monitoring. Instead, a new observation post was established on the transformer platform next to Anholt Offshore Windfarm – in the following named the “Substation” (Figure 5-3). This location enabled the observers to cover a major part of the raptor migration as the birds approached and passed the turbines and to compile information on flightpath, altitude and their behaviour.

Observations of migrating raptors were made at Gjerrild and the Substation from mid-March to early June in 2014 and 2015. Since fewer than expected data were collected from the Substation, observations at the Substation were carried out during one additional spring season (March – May 2016).

Figure 5-3. The Substation with the helicopter deck (top left side and 23 m above sea level) which was used for observations and rangefinder tracking of migrating raptors. Photo Lars Maltha Rasmussen.

5.3. Survey methods

5.3.1 Rangefinder

A digital laser type rangefinder with magnetic compass built into a pair of binoculars with 7 x magnification (Vectronix 21 Aero) was used to track the migrating birds (Figure 5-4).

Connected to a laptop (Gjerrild) or a GPS (Substation) the rangefinder collected precision data on the positions of the migrating raptors (Figure 5-5) and the birds' altitude. With more than one position recorded, the migration direction could also be calculated.

The migrating birds were tracked for as long as possible to get the most accurate picture of the migration direction and altitudinal profile. Small raptors (such as Sparrowhawks and falcons) could typically be followed to a distance of 1.5 km from the observer while larger birds (buzzards, eagles) could be tracked for up to 2 - 2.5 km.

Figure 5-4. Tracking migrating raptor with laser rangefinder. When pushing the button the bird's position and altitude is stored.

Figure 5-5. Example of flight paths recorded with the rangefinder at Gjerrild. Each path consists of a series of positions. The bird's altitude is also recorded at each position.

5.3.2 Radar

Tracking of the migrating raptors with horizontally mounted radars was used to supplement the rangefinder data. A single JRC Marine surveillance radar was used at Gjerrild. Two Furuno Type FAR2127 surveillance radars were placed at the Substation, one facing 180° towards SW and one facing 180° towards NE in order to avoid hazards from radar radiation on the Substation.

A “clutter-fence” (Figure 5-2) to reduce the “noise” generated by sea waves surrounded the radar at Gjerrild. Due to technical reasons, it was not possible to have clutter-fences in front of the radars on the Substation.

Under calm weather conditions with wave heights less than c. 0.5 m, migrating raptors could be radar tracked further away than with the rangefinder (up to 4 – 5 km). In a few instances, migrating raptors were tracked by radar only, since the birds were too far from the observation point to allow tracking with the rangefinder.

At Gjerrild, the individual raptors were radar-tracked real time that is the position of the individual birds were recorded and stored as the bird moved over the sea. Typically, the bird was first tracked simultaneously with rangefinder and radar, but when it moved outside the range of the rangefinder the flight path could frequently be tracked by radar for another kilometre or two.

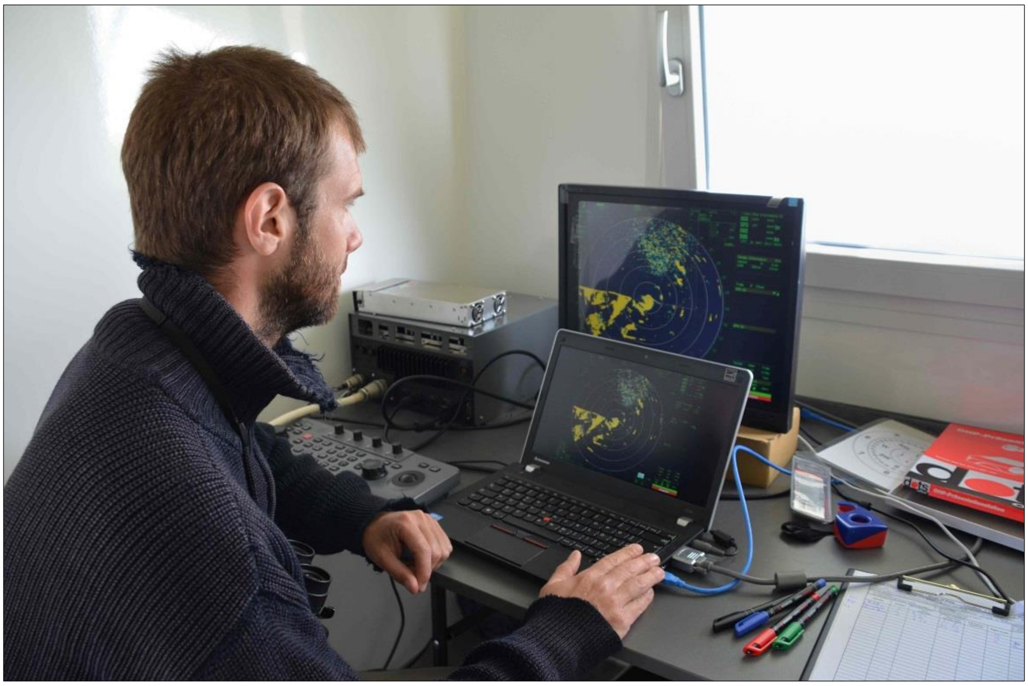

Figure 5-6. Tracking migrating raptor with radar at Gjerrild.

At the Substation, automated radar recording was used. Because it was not possible to have clutter-fences in front of the radars, the high elevation of the radars above the sea level and due to the frequent sea clutter (because of high waves) most of the time, radars only provided limited additional information as compared to the rangefinder tracking. Consequently, a set up was chosen with automatic storage of screen shots of the two radar screens every minute during the observation periods. After the field season data from periods with low sea clutter have been searched to identify and potentially match and extend the rangefinder tracks.

During the observation periods, the observer focused on collecting data on the raptors' behaviour close to, within the wind farm, and on possible interactions with the rotor blades.

5.3.3 Visual observations

Visual observations assisted by binoculars and telescopes were used at both sites to detect and identify the migrating raptors. At the Substation, binoculars with 30-x magnification (Figure 5-7) were also used to observe the behaviour of the raptors as they approached and passed the wind turbines.

Figure 5-7. Whenever the weather permitted this large pair of binoculars were used at the Substation to observe the behaviour of migrating raptors when they arrived to and passed the wind turbines. Photo Lars Maltha Rasmussen.

At Gjerrild, the raptors were often discovered 0.5 – 2 km inland. The birds were then followed as they approached the coast and when it was clear that they intended to initiate a sea crossing, one observer started tracking it with the rangefinder, while the other observer recorded its flight path with the radar.

At the Substation the raptors were usually first discovered, when they were quite close. This is because most birds near the Substation were flying quite low, often below the horizon, which made them difficult to detect at long distance. As soon as an approaching raptor was located and identified, one observer started tracking it with the rangefinder while the other observer followed the bird passing the platform and on towards the wind turbines with the 30 x binoculars (the two radars simultaneously tracked the area automatically). When possible (that is when the visibility was at least 2-3 km) the migrating raptors were followed all the way to the first row of turbines, and sometimes onwards in between the turbines. The behaviour of the bird was observed, described and recorded using a Dictaphone, and the observations were later entered into a pre-defined protocol.

The purpose of these visual observations was to quantify macro, meso and micro avoidance behaviour of the raptor when approaching the turbines, if such activities took place. Therefore, whenever possible the following information was recorded for each raptor:

1. The **altitude** of the raptor when it arrives to the wind farm (compared to the wind turbine), for example “flying twice the height of a turbine, flying under the swept area etc.”
2. Any **change** of flight altitude when the raptor starts passing the first turbines (is the raptor gaining height and fly over the swept area/losing altitude to fly under)?
3. Is the raptor a**voiding** the turbine by hesitating and starting to circle or flying parallel to the row of turbines or even turning back?
4. Is the raptor taking a path between the turbines?
5. Is the raptor (apparently) ignoring the turbines and flying very close to or through the swept area?
6. Are any close-range (“last moment”) evasive movements visible?

The collected data range from a few records of the flight altitude and reaction to the turbines when the bird arrived to the first turbines, to observations lasting 40 minutes when the birds hesitated and were flying parallel to the turbine row before eventually passing the wind farm (or turning back).

6. COLLECTED DATA

6.1. Observation periods

Data for the post-construction survey was collected during 30 observation days carried out simultaneously at Gjerrild and the Substation in spring 2014 and 2015. An additional season of 30 days of observations at the Substation only was carried out in 2016 (Table 6-1).

Between 7 and 12 hours of observations were made from early morning (6-7 am) until mid-afternoon (when no more migrating raptors were observed). The observations were only carried out on days with good visibility, no precipitation (except for brief showers) and low wind speed (< 6 m/s).

Due to high waves and risk of lightning, the observers had to evacuate the Substation in a few instances. However, since these evacuations typically took place in the afternoon and the observers could be back the next morning this had little impact on the recording of migrating raptors.

Table 6-1. Observation periods in 2014, 2015 and 2016.

2014	2015	2016
20 – 24 March	7 – 10 March	30 March – 4 April
28 – 31 March	26 – 28 March	12 – 16 April
10 – 13 April	8 – 11 April	29 April – 2 May
23 – 27 April	22 – 25 April	7 – 11 May
7 – 10 May	8 – 12 May	18 – 22 May
21 – 23 May	20 – 24 May	27 – 31 May
1 – 4 June	1 – 5 June	

6.2. Weather data

Data on wind (wind speed and wind direction) were sourced from DMI (Tirstrup airport, c. 25 km south of Gjerrild). The wind data used are 1-hour mean values.

Figure 6-1 shows the prevailing wind directions during the pre- and post-construction survey periods.

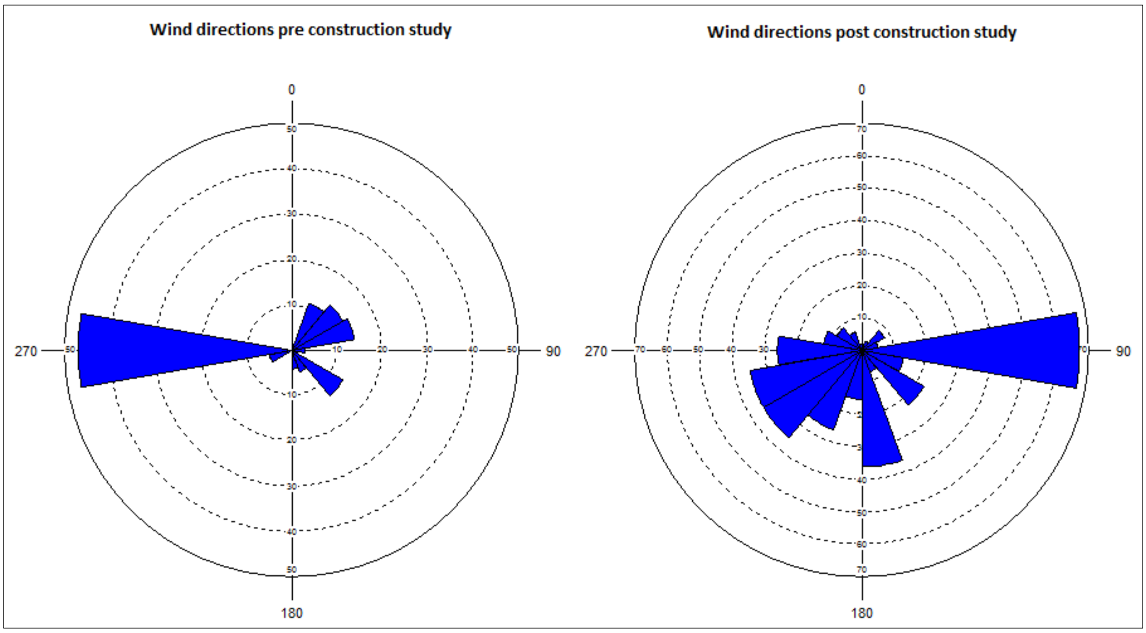

Figure 6-1. Prevailing wind directions during the pre-construction study (left) and the post-construction surveys (right).

6.3. Key specifications of the AOWF turbines

Table 6-2 lists selected key specifications of the Siemens 3.6 MW turbines of the AOWF. This information is included in the calculations of the collision risk.

Table 6-2. Key specifications of the Siemens 3.6 MW turbines of the AOWF.

Turbine specifications	
Number of rotor blades	3
Rotor-diameter (m)	120
Hub height (m a.s.l.)	81.6
Maximum width of rotor blade(m)	4.2
Rotor speed (U/min)	11.7 [1]
Increase of rotor blades (°)	30
Number of turbines	111
Maximum length of turbine row (km)	19

[1] 90% of max. speed (13.0 U/min) is used as realistic worst case.

6.4. Number of migrating raptors

Raptors migrating from Djursland towards Anholt and Sweden leave the coast at several points. This most important are Gjerrild Klint, Gjerrild Nordstrand and Fornæs. Considering the width and orientation (perpendicular to the migration corridor) of the AOWF, all birds migrating from Djursland may be assumed to cross the wind farm as a worst-case estimate.

To estimate the total number of migrating raptors we compiled data from all key exit points by using the spring total compiled by local ornithologists and reported in DOFBasen (2016). Since more raptors appeared to use the Djursland-Anholt-Sweden migration corridor in 2014 than in the following two years we used data from 2014 - see Table 6-3.

Table 6-3. Number of observed raptors at Gjerrild Klint (this study) and the total number of raptors observed migrating at all key locations on Djursland (data from DOFbasen 2016). Species marked with * are adopted on the Annex I of the EU Birds Directive.

Raptor species	**Observed migrating raptors at Gjerrild Klint spring 2014 (this study)**	**Observed migrating raptors leaving Djursland in spring 2014**
Honey Buzzard *Pernis apivorus**	35	190
Red Kite *Milvus milvus**	20	159
Black Kite *Milvus migrans**	2	7
White-tailed Eagle *Haliaetus albicilla**	1	13
Marsh Harrier *Circus aeruginosus**	16	91
Hen Harrier *Circus cyaneus**	6	40
Sparrowhawk *Accipiter nisus*	79	822
Goshawk *Accipiter gentilis*	1	2
Common Buzzard *Buteo buteo*	207	2161
Rough-legged Buzzard *Buteo lagopus*	2	22
Osprey *Pandion haliaetus**	8	68
Kestrel *Falco tinnunculus*	15	162
Merlin *Falco columbarius**	7	58
Hobby *Falco subbuteo*	5	19
Peregrine Falcon *Falco peregrinus**	5	30

6.5. Size of population passing the AOWF

The raptors, which migrate through the AOWF in spring, belong to biogeographical populations, which have their breeding grounds to the north and northeast of Denmark. The main breeding areas for these birds are in Sweden and Norway but for some species, also the Finnish or part of the Finnish populations migrate through Denmark. Others, such as the Finnish Honey Buzzards, generally take a more easterly migration path and will not migrate through Denmark (FMNH 2016). In the case of Common Buzzard, around half of the Finnish population migrates to or through Denmark. By far the majority of raptors breeding further to the northeast in Russia is believed to take a more easterly migration route through the Baltic States and is therefore not considered here.

The sizes of biogeographical populations used in this study are shown in Table 6-4. The number of birds is calculated from the breeding population listed for Sweden in Ottosson et al. (2012) and for Finland and Norway sourced from Finnish Museum of Natural History (2016) and Heggøy & Øien (2014), respectively. Since the migratory populations also include young non-breeding birds, the size of the biogeographical population is estimated by multiplying the number of nesting pairs by three. Details on to what extent birds from the Finnish populations are included in the biogeographical populations sizes are given in Annex A.

Table 6-4. Size of populations, which the various raptor species that passes the AOWF in spring belong to. Species marked with * are adopted on the Annex I of the EU Birds Directive

Raptor species	Size of biogeographical population (number of birds)
Honey Buzzard*	22,200
Red Kite*	6,150
Black Kite*	96
White-tailed Eagle*	12,375
Marsh Harrier*	7,959
Hen Harrier*	7,150
Sparrowhawk	173,550
Goshawk	40,950
Common Buzzard	103,650
Rough-legged Buzzard	39,600
Osprey*	14,592
Kestrel	52,950
Merlin*	41,250
Hobby	17,064
Peregrine Falcon*	4,452

6.6. Radar & rangefinder tracks

All observed raptors passing within reasonable distance (<1 km) from the observers at Gjerrild Klint and the AOWF and with a behaviour that suggested that the bird was migrating (in any direction) was tracked with the rangefinder and radar simultaneously.

Tracks of raptors recorded at Gjerrild that obviously gave up the sea crossing when reaching the shore was subsequently deleted. Such migration attempts are a well-known phenomenon and since the distance to the nearest wind turbine is around 20 km it is considered unlikely that this behaviour is an example of macro avoidance.

Table 6-5 shows the number of tracks of the individual raptor species (radar and rangefinder combined) during the 2014, 2015 and 2016 field surveys.

Table 6-5. Number of tracks of the individual raptor species (radar and rangefinder combined) during the 2014, 2015 and 2016 field surveys.

Raptor species	Gjerrild Klint		AOWF Substation		
	2014	2015	2014	2015	2016
Honey Buzzard	20	11	9	1	7
Red Kite	13	11	8	2	1
Black Kite	-	1	-	-	-
White-tailed Eagle	2	-	1	1	1
Marsh Harrier	16	6	10	2	2
Hen Harrier	6	5	4	1	-
Sparrowhawk	49	42	40	18	26
Goshawk	-	-	-	1	-
Common Buzzard	50	42	37	17	5
Rough-legged Buzzard	1	2	-	1	-
Osprey	7	10	3	4	2
Kestrel	15	18	2	4	9
Merlin	1	10	3	3	3
Hobby	5	3	-	-	-
Peregrine Falcon	-	1	5	1	1
Total number of tracks	**185**	**162**	**122**	**56**	**57**

The same migrating raptor was often tracked by both rangefinder and radar. In these cases the first part of the path (closest to the observer) consists of rangefinder data (which include the height of the bird) and the last part, when the bird could no longer be followed with the rangefinder due to distance, is based on data from the radar without height information. This gives a longer path (up to 4-5 km) and more accurate information on the migration direction of the bird.

Examples of rangefinder tracks recorded at Gjerrild and around the Substation are shown below (Figure 6-2 – 6-9). At Gjerrild, the colours indicate the altitude measured when the bird passed the coastline. For the Substation, the colours indicate the altitude measured at the first recorded position (the beginning of the track).

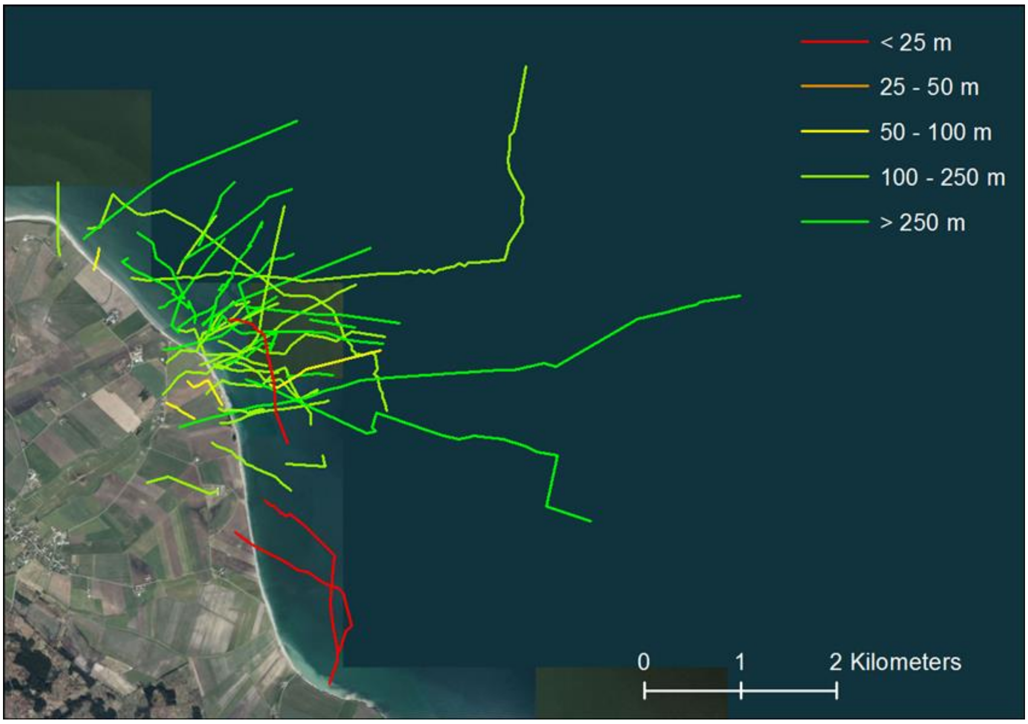

Figure 6-2. Tracks of migrating Common Buzzards (*Buteo buteo*) at Gjerrild in 2015. The colour of the tracks shows the flight altitude when the bird was crossing the coastline.

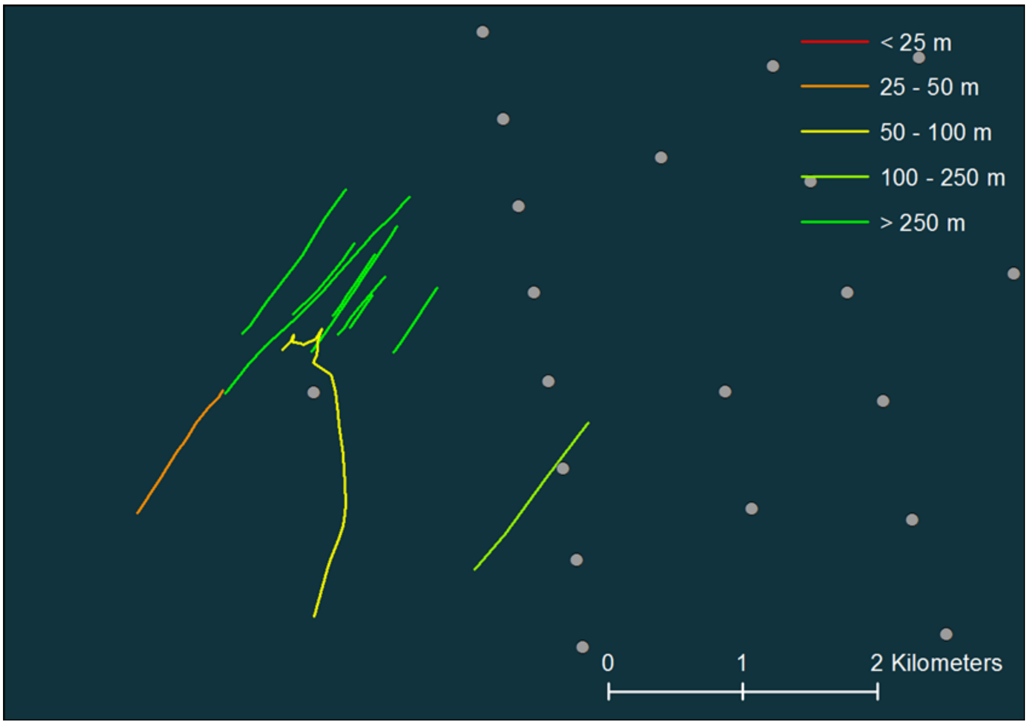

Figure 6-3. Tracks recorded of Common Buzzards (*Buteo buteo*) at the Substation. Colour codes indicate the flight altitude (see text for explanation).

Figure 6-4. Common Buzzard (*Buteo buteo*) is the raptor migrant that occur in highest numbers at the AOWF. Photo Johannes Limberg.

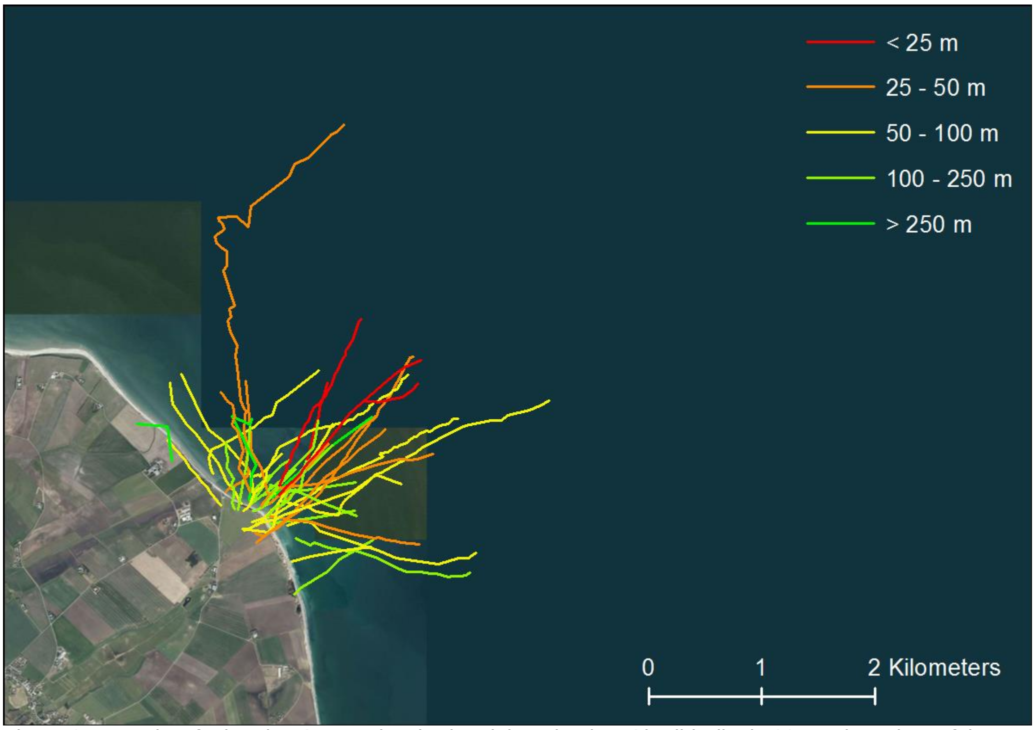

Figure 6-5. Tracks of migrating Sparrowhawks (*Accipiter nisus*) at Gjerrild Klint in 2015. The colour of the tracks show the flight altitude at the first recorded position.

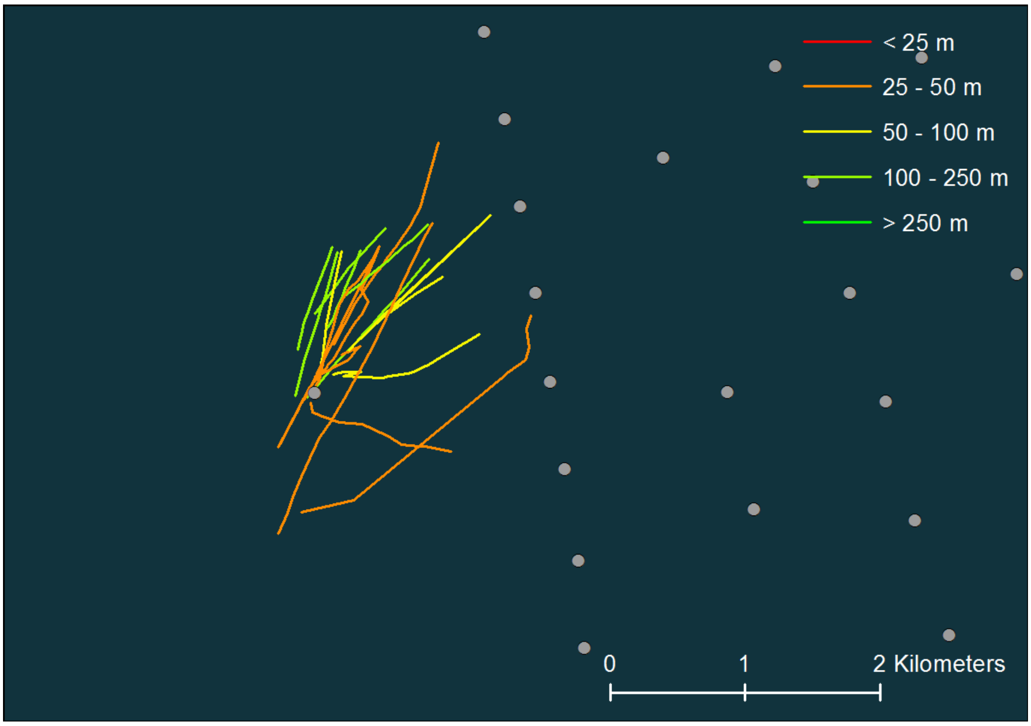

Figure 6-6. Tracks of migrating Sparrowhawks (*Accipiter nisus*) recorded around the Substation in 2015. Colour codes show the flight altitude at the first recorded position.

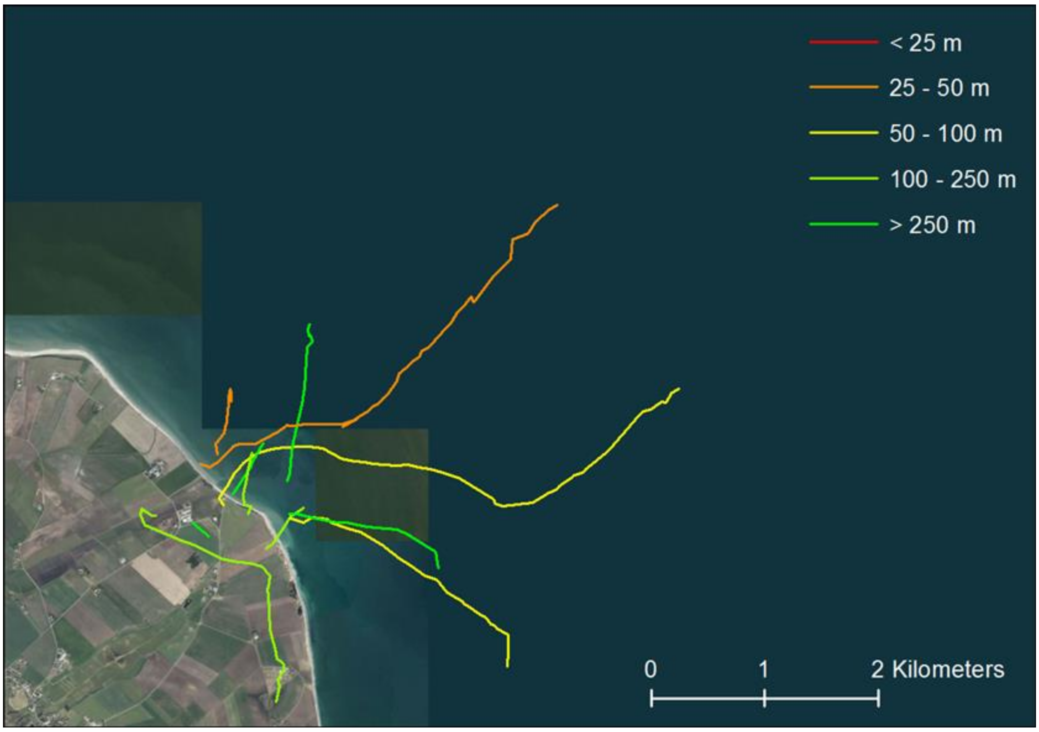

Figure 6-7. Tracks of migrating Red Kite (*Milvus milvus*) at Gjerrild in 2015. The colour of the tracks show the flight altitude.

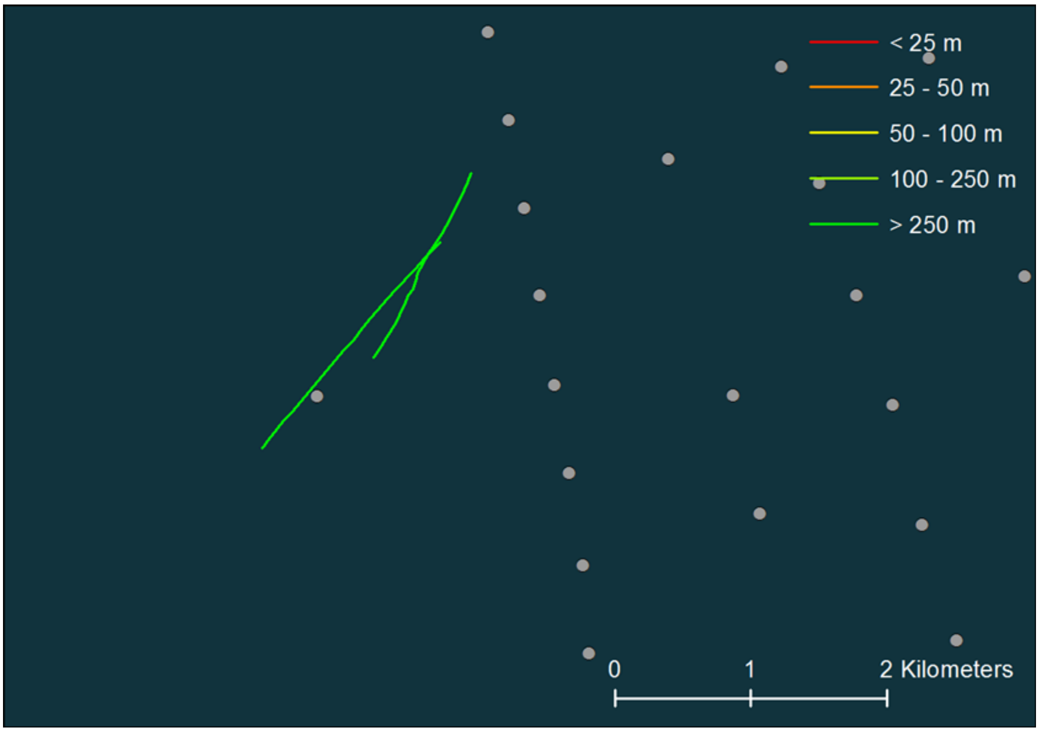

Figure 6-8. Tracks of migrating of Red Kite (*Milvus milvus*) at the Substation in 2015. The colour of the tracks show the flight altitude.

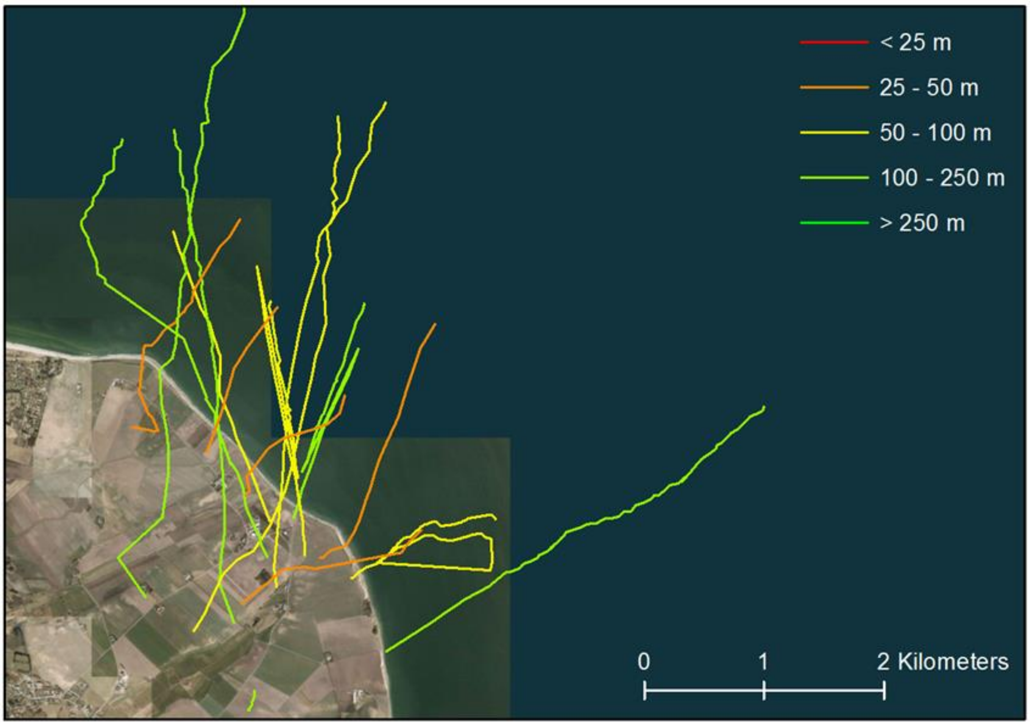

Figure 6-9. Tracks recorded of migrating of Honey Buzzard (*Pernis apivorus*) at Gjerrild in 2014. The colour of the tracks show the flight altitude at the first recorded position.

6.7. Visual behaviour observations from Substation

The number of visual observations of avoidance behaviour of raptors approaching the turbines recorded from the Substation is listed in Table 6-6.

Table 6-6. Observed behavioural responses when the migrating raptors approached the windfarm. Number of behavioural responses recorded is the total number of recorded avoidance behaviours per species. A bird may show no avoidance, macro avoidance, vertical and/or horizontal meso avoidance, micro avoidance or a combination of meso and micro avoidance (more than one avoidance reaction for a single bird). Number of birds involved is the total number of birds recorded during the visual observations.

Raptor species	Number of recorded behavioural responses			Number of birds involved		
	2014	2015	2016	2014	2015	2016
Honey Buzzard	5	2	9	8	2	17
Red Kite	23	1	2	24	4	4
White-tailed Eagle	1	1	1	1	1	1
Marsh Harrier	9	2	5	19	5	5
Hen Harrier	1	2		5	2	
Sparrowhawk	47	12	29	62	23	34
Goshawk					1	
Common Buzzard	80	33	8	121	57	17
Rough-legged Buzzard					1	1
Osprey	1	2	5	5	5	5
Kestrel	4	5	10	5	5	12
Merlin		3	2	4	3	7
Peregrine falcon	3		1	5		2

Additional data regarding the relevant raptor species survival, breeding biology, size, flight mode etc. relevant for the collision risk assessments are listed in Table 6-7 and Table 6-8. Some species were only observed in very small numbers. No collision risk assessment were made for these species.

Table 6-7. Overview of species-specific parameters used in the collision risk assessment for migrating raptors. Proportion of birds at rotor height was estimated from the mean flight altitudes (per track) as recorded by the rangefinder on the substation.

Raptor species	Length (m) [1]	Wingspan (m) [1]	Flight speed (m/s) [2]	Flight mode [3]	Proportion of birds at rotor height (%)
Honey Buzzard	0.55	1.425	11.3	G	75
Red Kite	0.61	1.55	12.0	G	64
Marsh Harrier	0.52	1.175	10.65	G	46
Sparrowhawk	0.34	0.675	10.65	G	68
Common Buzzard	0.54	1.205	12.45	G	70
Osprey	0.55	1.53	12.35	G	63
Kestrel	0.34	0.725	10.1	G	79[6]
Merlin	0.30	0.625	11.3 [5]	G	79[6]

[1] www.dofbasen.dk.

[2] Alerstam et al. (2007). Where two values are given in Alerstam et al. the average has been used.

[3] G: gliding.

[4] Based on Urquhart (2010), Cook et al. (2012) and references in these

[5] not included in Alerstam et al. (2007); value for Hobby used instead.

[6] Kestrel and Merlin pooled to get a more robust estimate.

Table 6-8. Overview of species-specific breeding data used in the assessment of possible population effects.

Raptor species	Adult survival (s) [1]	Age at first breeding (year) (α) [2]	Max. net productivity rate (R_{max})	Min. biogeographical population (N_{min})	Recovery factor (f) [3]
Honey Buzzard	0.86	2.5	0.1983	17,100	0.3
Red Kite	0.61	2	0.3547	5,700	0.7
Marsh Harrier	0.74	3	0.2202	6,615	0.5
Sparrowhawk	0.69	1	0.5568	102,900	0.7
Common Buzzard	0.90	3	0.1523	66,000	0.5
Osprey	0.85	3	0.1791	12,270	0.7
Kestrel	0.69	1.5	0.4059	14,200	0.5
Hobby	0.745	2	0.2990	14,835	0.5
Merlin	0.62	1	0.6164	28,500	0.5

[1] BTO Bird Facts ()

[2] www.dofbasen.dk.

[3] 0.3 for populations in decline, 0.5 for stable populations and 0.7 for increasing populations (data soured from BirdLife Datazone (2016))

7. DATA ANALYSIS AND MODELLING

7.1. Radar and rangefinder data

The records of all birds/flocks tracked by rangefinder were transformed into three-dimensional tracks. From these tracks, distances, flight directions, flight altitudes and changes in flight direction and altitude (slope) were calculated in ArcGIS using each sample point of the track. When possible tracks recorded by the radar were used to "extend" the rangefinder data (in two dimensions).

Each three-dimensional track has several track sections between sample points in the database with respect to the subject's horizontal and vertical position during the exit from the coast and during the approach of the AOWF. Obvious outliers, wrongly located points within tracks etc. were removed by visual inspection of the tracks. Tracks of raptors, which were not indicating migration behaviour, were removed.

The "cleaned" data set provided the necessary post-construction information for the testing of Hypothesis 1, 2 and 4 and contributed to the testing of Hypothesis 5. Similar data from the pre-construction (baseline) studies were made available by DONG for the testing of Hypothesis 1 and 2 concerning possible changes in migration altitude and direction for raptors leaving the coast.

A potential concern was if magnetic fields produced by transformers on the Substation might disturb the internal compass of the rangefinder, reducing the precision of the geo-positioning of the waypoints. To ratify this, the performance of the rangefinder compass was tested at least once a day by pointing the rangefinder at three wind turbines and comparing the reported compass direction with the true direction calculated using GIS software. On all days, the deviation between the rangefinder reported directions and the true direction was at most ± 2°.

7.2. Statistical analysis – hypothesis 1 - 4

<u>Hypothesis 1</u>: The altitude (meters above sea level) at which the raptor crossed the coastline of Djursland was estimated by way of linear interpolation from each rangefinder track within the cleaned data set. For birds observed only when flying over the sea, the altitude of the first observation point was used. A mean migration altitude was calculated for each combination of species and wind direction (head, tail or cross wind). When calculating the means, each rangefinder track was weighted by the number of observed birds (flock size). These values were compared to the corresponding values from the pre-construction situation, using parametric analysis of variance (with

factors pre-/post-construction and head/tail/cross wind, and with wind speed as covariate).

The testing were performed for all species where sufficient data were available. For species where the effect of wind direction was not significant, a reduced statistical model using only factor pre-/post-construction where used. This also applies to the following analyses and tests.

Hypothesis 2: Based upon the cleaned data set, an overall migration direction was calculated for each bird leaving the coast of Djursland. Mean migration directions were calculated for each species. When calculating the means, each rangefinder track was weighted by the number of observed birds (flock size). The dataset for each species was not separated by wind direction, as this would produce very small sample sizes. A comparison with pre-construction data was performed using circular statistics (Watson-Williams F test).

Hypothesis 3: A comparison of raptor migration volume at Gjerrild and at the Substation was performed, based on the visual observations. No formal testing of this hypothesis has been carried out.

Hypothesis 4: Rangefinder tracks of raptors approaching the AOWF were analysed to yield a vertical slope either positive (indicating ascent), negative (indicating descent) or zero. The mean slope for each species (or species group) was tested to determine if it was significantly different from zero, using wind speed and direction as predictor variables in a parametric analysis of covariance.

7.3. Modelling of collision risk – hypothesis 5 - 6

The expected number of collisions per year was calculated using the "Band Collision Risk Model" which is described in Band (2012). This approach is a further development of the approach defined in Band (2000) and Band et al. (2007) and is generally considered the standard approach to assess the bird collision risk presented by onshore as well as offshore windfarms. The calculations were performed using a spreadsheet developed by Band (2000, 2012) for the Scottish Natural Heritage (see also Annex D). The principle is described below.

Figure 7-1 provides an overview of the model and its relationship with the data collected in the field and other input data on turbine and bird details.

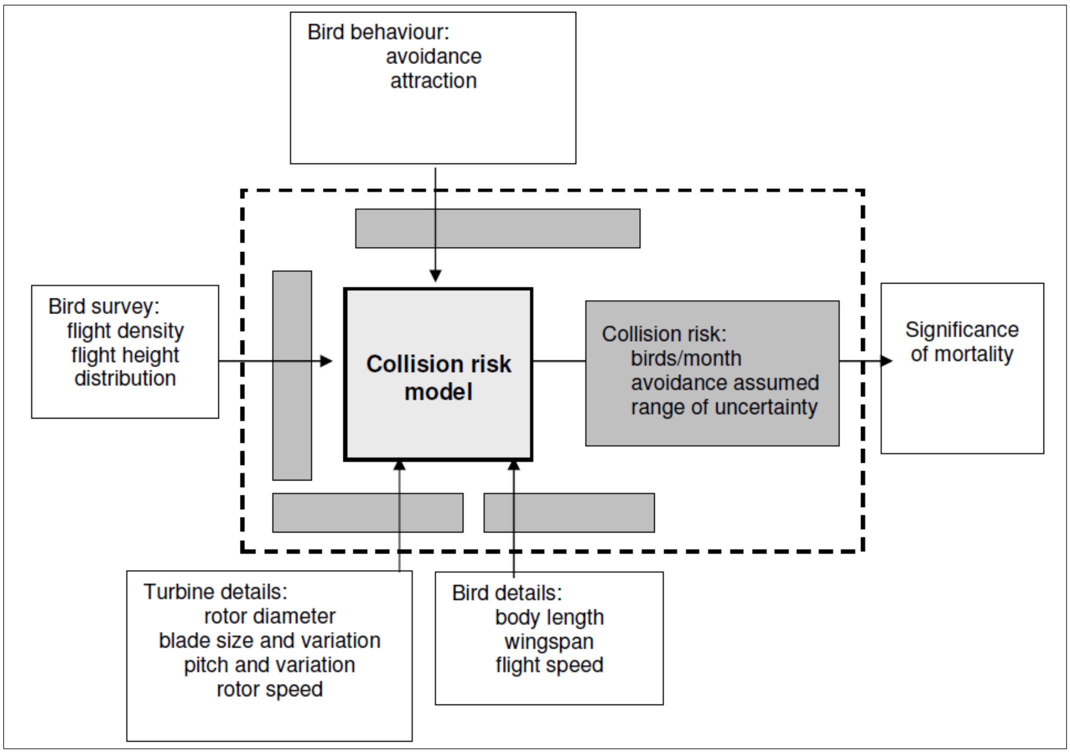

Figure 7-1. *Overview of the collision risk model, the input data required and the expected output. From Band (2012).*

The Band (2012) approach includes five stages, which are described below. Stage A-D estimates the expected number of collisions for each species based on existing, site-specific data concerning the number of birds, and their distribution in the area. The calculations of these steps are performed under the assumption that the birds do not change occurrence and flight pattern due to the wind farm. In Step E the estimates are refined based on existing knowledge about the species reaction to wind farms (avoidance and attraction behaviour).

Stage A aims to estimate the flight activity within the proposed wind farm. This is done by assembling data on the number of flights, which are potentially at risk from wind-farm turbines;

Stage B concerns estimating the number of bird flights through rotors;

Stage C calculate the probability of collision during a single bird rotor transit;

Stage D multiplies these to yield the potential collision mortality rate for the bird species in question, allowing for the proportion of time that turbines are not operational, assuming current bird use of the site and that no avoiding action is taken; and

Stage E allow for the proportion of birds likely to avoid the windfarm or its turbines, either because they have been displaced from the site or because they take evasive action; and allow for any attraction by birds to the windfarm e.g. in response to changing habitats.

The following input parameters have been used:

1) *Migration volume, V*. The number of raptors crossing the area each spring was estimated from the count of migrating raptors at Gjerrild. We believe counts from Gjerrild is a better estimate of the total migration volume than counts from the Substation. Gjerrild serves as a hotspot for migrating raptors, allowing for observation of a large proportion of the total migration volume. At the Substation, the migrating raptors may be distributed across the 19 km wide front of the AOWF. Given the limited range where raptors are visible, this allows for a much smaller proportion of the total migration volume to be observed.

   Allowing for overlooked raptors, the number of birds recorded at Gjerrild was multiplied by 1.2[1]. Observations were carried out during 30 of the c. 75 days of the total migration period. Days with favourable weather for migration were specifically selected for observation periods. To compensate for additional days were migration took place but no observations were made we have multiplied all recorded migration numbers by 1.5.

2) *Proportion of birds entering the wind farm assuming no avoidance, R1*. As the AOWF extends for almost 20 km across the main migration corridor, all raptors leaving the coast at Gjerrild with a migration direction between NW (315°) and SE (135°) were assumed to enter the wind farm as a conservative estimate. While birds migrating directly towards NW or SE were not on a course for the wind farm, we could not rule out the possibility that they adjusted their flight direction towards the wind farm after leaving the visible range of the rangefinder. This may be viewed as a 'worst case' estimate.

3) *Proportion of birds within horizontal reach of rotors assuming no avoidance, R2*. This was estimated from the dimensions of the rotors (sweep area) compared to the total length of each turbine row.

4) *Proportion of birds within vertical reach of rotors assuming no avoidance, R3*. This was estimated from the rangefinder data collected at the transformer platform. The mean flight altitude of each rangefinder track was compared with the vertical reach of the rotors, and a proportion within vertical reach was calculated for each species.

[1]This estimated factor compensates for migrants that remained undetected while the observes were following another bird with rangefinder and radar

5) *Proportion of birds trying to cross the sweep area without showing avoidance, R4*. A value of 92 % (based on Winkelman 1992) has generally been applied in recent Danish risk assessment and monitoring studies (e.g. Kahlert et al. 2011, Skov et al. 2012c). Much lower values, such as 5 % or even 0.1% (i.e. ≥ 95% avoidance), have been quoted by recent reviews (Urquhart 2010, Cook et al. 2012, 2014) but it is unclear to what extent these values may be applied to migrating raptors (as opposed to birds staging in the area). As part of the present study, avoidance rates were estimated by visual observation for nine raptor species (see Section 8.5) and these estimates were used in the modelling.

6) *Probability of a bird crossing the sweep area being hit by the rotor blades by chance, R5.* This is determined by several factors, such as the size and flight speed of the bird, the dimensions of the rotor blades, rotor speed etc. and was estimated within the spreadsheet developed by Band (2000, 2012). We used input data from www.dof.dk and Alerstam et al. (2007) on bird dimensions and flight speed (Table 6-7) and data from DONG Energy on rotor blade dimensions, mean operational rotor speed etc. (Table 6-2).

7) *Proportion of time with rotors stopped, R6*. Raptors are not assumed to collide with stationary rotors. It was assumed that the rotors was stationary 10% of time, either due to very low wind speed or due to technical problems, maintenance etc.

The number of birds colliding with the turbines (N_C) was then estimated as:

$$N_C = V \times R1 \times R2 \times R3 \times R4 \times R5 \times R6$$

Since the AOWF consists of several rows of turbines, with different numbers of turbines and different distances between the turbines in each row, the total number of turbines was used in the calculations and the "Large array correction" function of the "Band Collision Risk Model" spreadsheet was used to estimate the total number of collisions.

7.4. Population risk modelling – hypothesis 7

The estimated number of raptors killed by collision with the turbines of the AOWF during spring migration was further assessed by relating the number of estimated casualties to the size of the biogeographical populations involved. This population level assessment was performed for most species. A few species with a very small number of estimated collisions (< 0,01 per spring migration) were not considered.

To this end we have considered two different "populations" for each of the relevant species:

1) The local population, defined as the number of birds using the Djursland - Anholt migration corridor during spring.

   The size of this population was estimated from data compiled in the annual reports issued by DOF - BirdLife Denmark (cf. the estimation of migration volume above).

2) The biogeographic population, defined as the total number of birds breeding within the area from which the migrants originate.

   The size of this population has been estimated as the number of breeding birds in Sweden, Norway and Finland, which is known to migrate through Denmark.

In order to provide an objective assessment of the possible population impact, we used the so-called PBR (Potential Biological Removal) concept and estimate the additional mortality (removal) that the populations in question may sustain.

PBR is calculated using the following general equation (Wade 1998):

$$PBR = 0.5 \times R_{max} \times N_{min} \times f$$

where R_{max} is the maximum annual recruitment rate, N_{min} is the minimum population size, and f is the so-called population recovery factor (see below).

R_{max} is calculated from the maximum annual population growth rate λ_{max} as follows:

$$R_{max} = \lambda_{max} - 1$$

where λ_{max} is estimated using the Niel & Lebreton (2005) method of demographic invariants, which requires only two parameters: the annual survival rate of adult birds (s) and the age of first reproduction (α). Niel & Lebreton (2005) provides two equations for estimation of λ_{max}, of which the following may be used for long-lived species such as raptors:

$$\lambda_{max} \approx \frac{(s\alpha - s + \alpha + 1) + \sqrt{(s - s\alpha - \alpha - 1)^2 - 4s\alpha^2}}{2\alpha}$$

A major advantage of the Niel & Lebreton (2005) method is that estimation of λ_{max} is based on those demographic parameters, which are usually most easy to obtain. Despite its simplicity it provides an acceptable fit to λ_{max} values derived from more complete demographic data (such as age-dependent survival rates and fecundity data) for a broad spectrum of bird species with different life history traits (Niel & Lebreton 2005, Dillingham & Fletcher 2008).

Also taking into account the uncertainties associated with the estimation of the other factors in the PBR equation, as well as the uncertainties related to the estimation of collision risk, we consider that the Niel & Lebreton (2005) method provides a sufficiently robust estimate of λ_{max} for the present purpose.

Concerning the minimum population size N_{min}, we used the estimate of migration volume V for the local population, as this is already a minimum estimate of the population involved.

For the biogeographic population (sum of Swedish, Norwegian and Finnish populations), we used the lower bound as N_{min} if the population size was given as an interval. If only one number was given, we followed Dillingham & Fletcher (2008) and estimated N_{min} as the 20th percentile assuming a log-normal distribution and a coefficient of variation of 0.5.

Concerning the population recovery factor f, we use f = 0.1 for rapidly declining populations, f = 0.3 for declining populations, f = 0.5 for stable populations and f = 0.7 for increasing populations. Population trends were assessed from the most recent national reports compiled by BirdLife International (BirdLife Datazone 2016).

8. RESULTS

8.1. Flight altitude when leaving the coast

The recorded flight altitudes when the raptors leave the coast at Gjerrild and start the sea crossing before and after the construction of the AOWF were compared. The results of the analysis is presented in Annex B, while selected graphics are presented in Figure 8-1 and Figure 8-2.

Figure 8-1 shows the mean migration altitude of Common Buzzard and Kestrel during the pre- and post-construction surveys in cross-, tail- and head wind situations.

Figure 8-2 shows the migration altitudes of Sparrowhawk, Red Kite, Honey Buzzard, Osprey, Marsh Harrier and Hen Harrier. For these species, the effect of wind direction was not significant. For the other raptor species observed during the pre- and post-construction surveys, the number of records were too low to permit comparison of before and after migration height.

Figure 8-1 shows that Common Buzzards left the Djursland coast significantly higher in tail wind after the construction of the AOWF than before while the opposite was the case during cross- and head wind, although the difference here is much smaller.

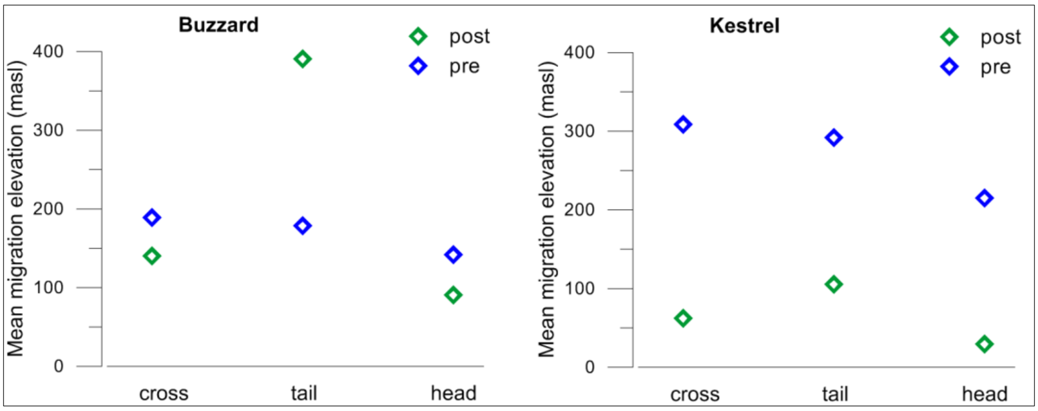

Figure 8-1. Flight altitude of Common Buzzard and Kestrel when leaving Djursland coast at Gjerrild recorded during the pre- and post-construction surveys. The difference in migration height in the different wind situations during the pre- and post-construction surveys is significant.

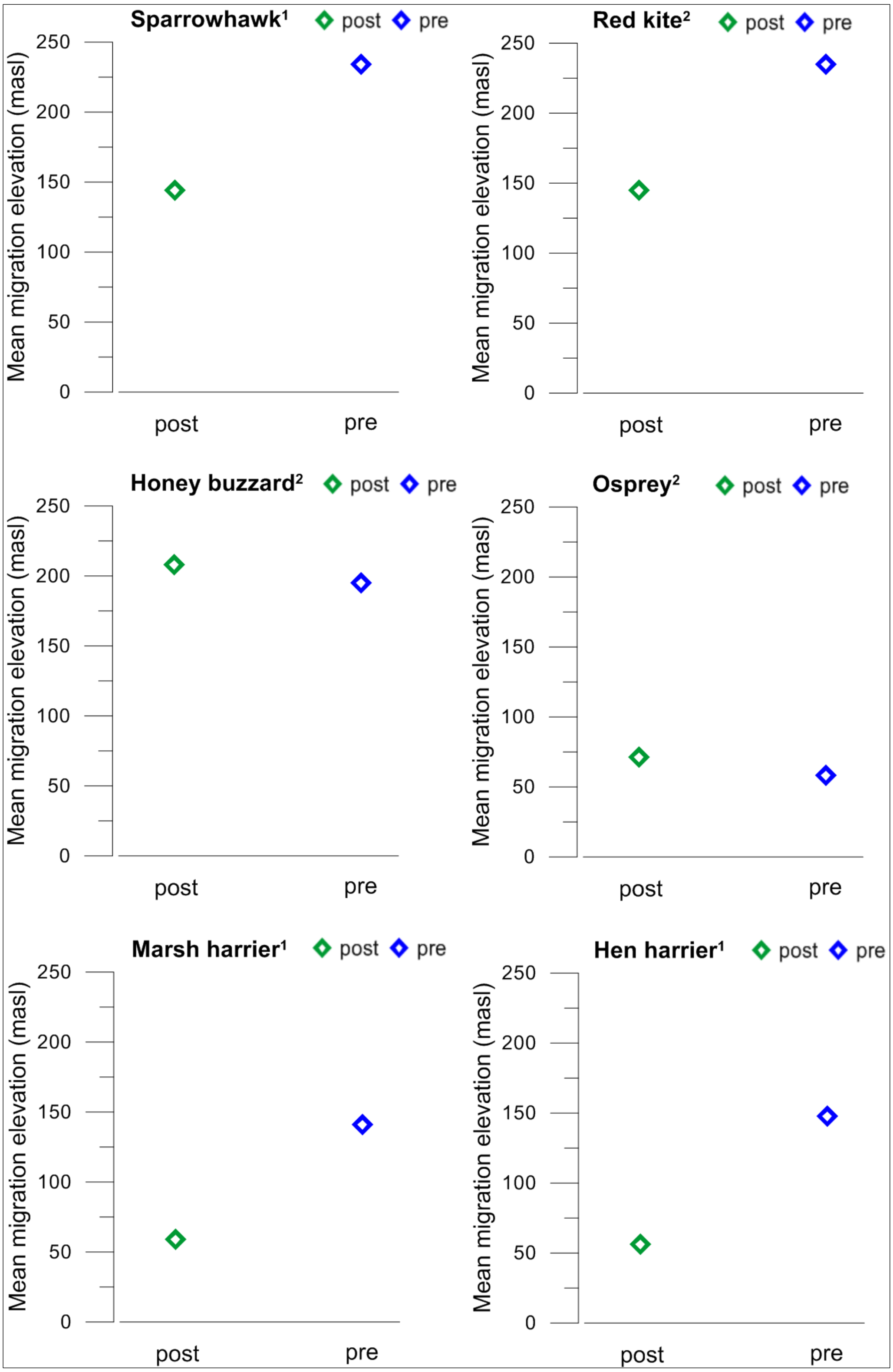

Figure 8-2 Flight altitudes when leaving Djursland coast at Gjerrild during the pre- and post-construction surveys. For species marked with [1] the difference in migration elevation is significant (Annex B).For species marker with [2] the difference is not significant (Annex B).

In contrast, Kestrels migrated at significantly greater height in all wind situations before the AOWF was built than after. This is in line with the behaviour recorded for Sparrow hawk, Marsh Harrier and Hen Harrier and the same tendency was also observed for Red Kite although the difference for this species is not significant (Figure 8-2).

Honey Buzzard and Osprey show no significant difference in migration height before and after the construction of the AOWF.

With the exception of Common Buzzards in tail wind situations, the compiled data suggests that most raptors leave the Djursland coast at lower height after the AOWF was built than before. There is no obvious explanation why Common Buzzards flew higher on days with tail wind after the AOWF was built.

8.2. Flight direction when leaving the coast

The direction of migration when the raptors leave the coast at Gjerrild and start the sea crossing before and after the construction of the AOWF was compared.

Table 8-1 shows the average migration direction of raptors recorded during the pre- and post-construction surveys. Honey Buzzard was the only species which showed a statistically significant change in mean migration direction ($p = 0.009$) when comparing pre- and post-construction surveys. During the pre-construction survey Honey Buzzards chose a heading aiming directly for Anholt (47°) while post-construction the birds chose a more northern heading (26°) aiming towards the north tip of the AOWF (Figure 8-3).

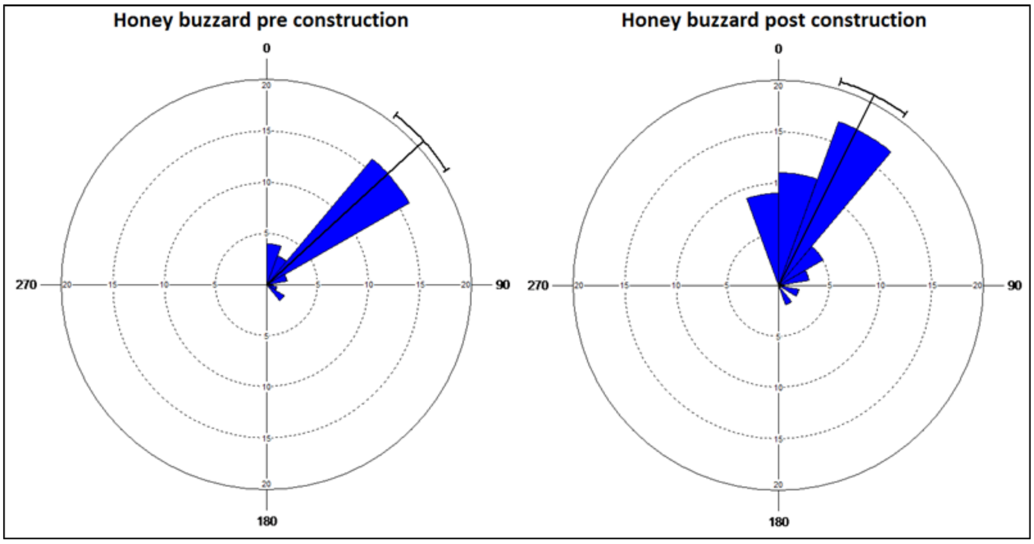

Figure 8-3. The recorded direction of migration for Honey Buzzard when leaving the coast at Gjerrild during the pre-construction survey (left) and during the post construction survey (right). Straight line is the mean migration direction; error bars are ±1 standard deviation.

Kestrel and Rough-legged Buzzard had p-values approaching significance at the 5% level (p = 0.097and p = 0.089 respectively), but the number of recorded birds during pre-construction (Kestrel & Rough-legged Buzzard) and post construction (Rough-legged Buzzard) was very small. All other birds showed no significant change in migration direction (Table 8-1). Pre- and post-construction migration directions of selected species are shown in Figs. 8-4 to 8-7.

Table 8-1. Migration direction when leaving the coast at Gjerrild. F and p values from Watson-Williams F-tests.

Species	N[1] pre construction	N[1] post construction	F	p	Est. mean migration direction PRE	Est. mean migration direction POST	Change in migration direction
Honey Buzzard	28	49	7.2	0.009	47	26	↑21°N
Red Kite	3	38	0.56	0.46	96	73	↑23°N
Marsh Harrier + Hen Harrier	9	33	1.06	0.31	25	39	↓14°S
Sparrowhawk	24	124	1.99	0.16	73	59	↑14°N
Common Buzzard	86	266	0.35	0.55	71	70	↑1°N
Osprey	4	15	0.25	0.62	36	46	↓10°S
Kestrel	4	23	2.98	0.097	355	37	↓42°S
Hobby	4	8	0.011	0.92	46	48	↓2°S
Rough-legged Buzzard	3	3	5.02	0.089	110	51	↑59°N

[1] N refers to number of unique rangefinder tracks per species in the pre and post construction surveys.

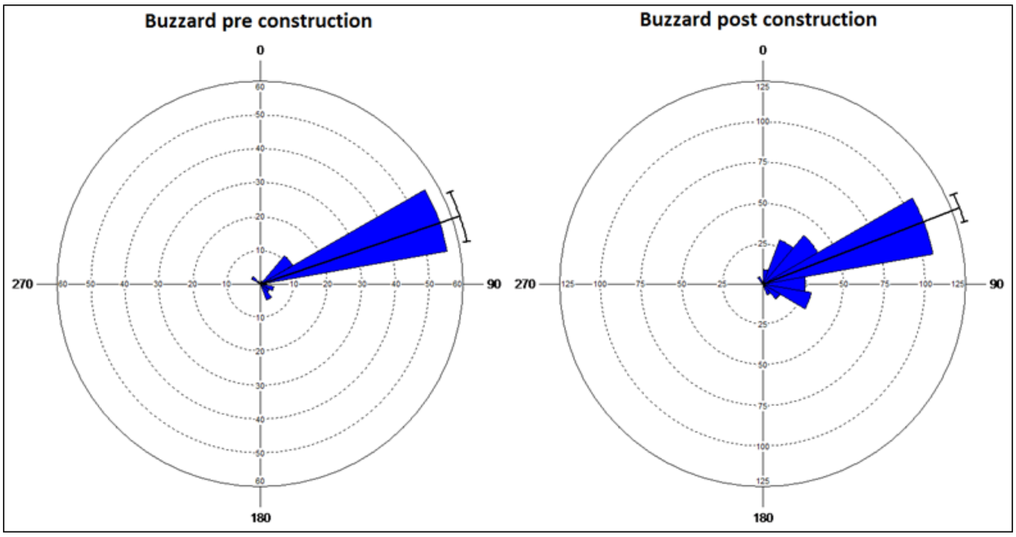

Figure 8-4. The recorded direction of migration for Common Buzzard when leaving the coast at Gjerrild during the pre-construction survey (left) and during the post construction survey (right). Straight line is the mean migration direction; error bars are ±1 standard deviation.

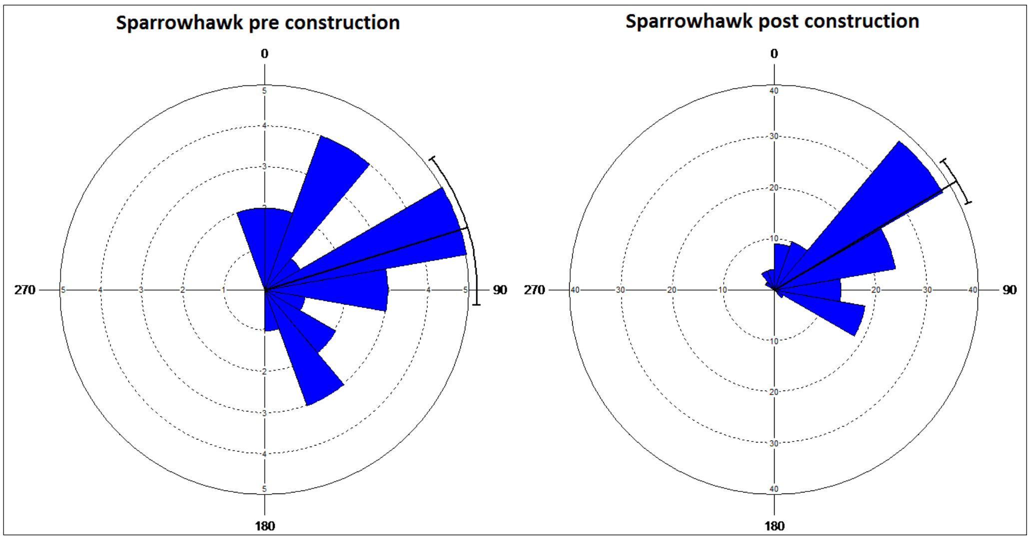

Figure 8-5. The recorded direction of migration for Sparrowhawk when leaving the coast at Gjerrild during the pre-construction survey (left) and during the post construction survey (right). Straight line is the mean migration direction; error bars are ±1 standard deviation.

Figure 8-6. Sparrowhawk (*Accipiter nisus*). Photo Johannes Limberg.

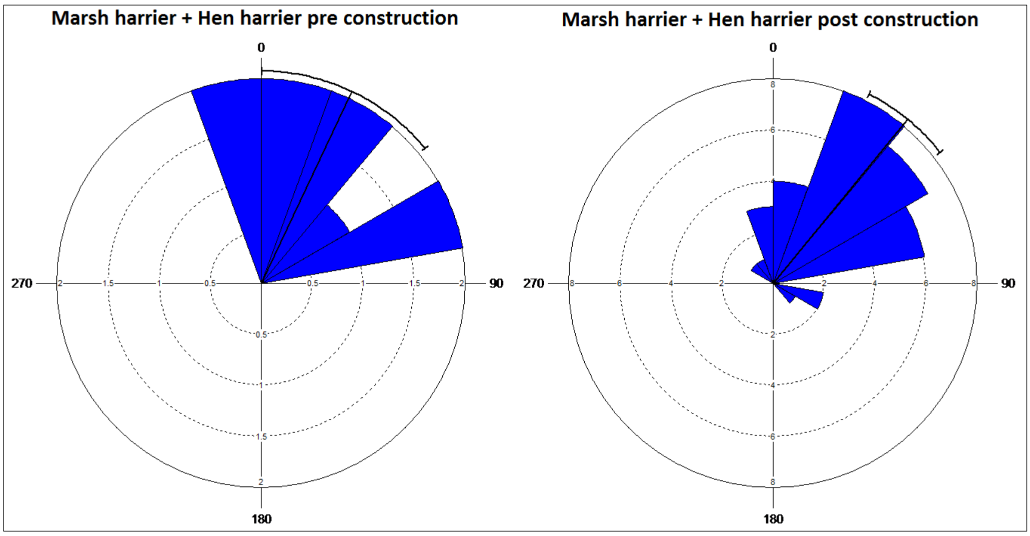

Figure 8-7. The recorded direction of migration for Marsh Harrier + Hen Harrier when leaving the coast at Gjerrild during the pre-construction survey (left) and during the post construction survey (right). Straight line is the mean migration direction; error bars are ±1 standard deviation.

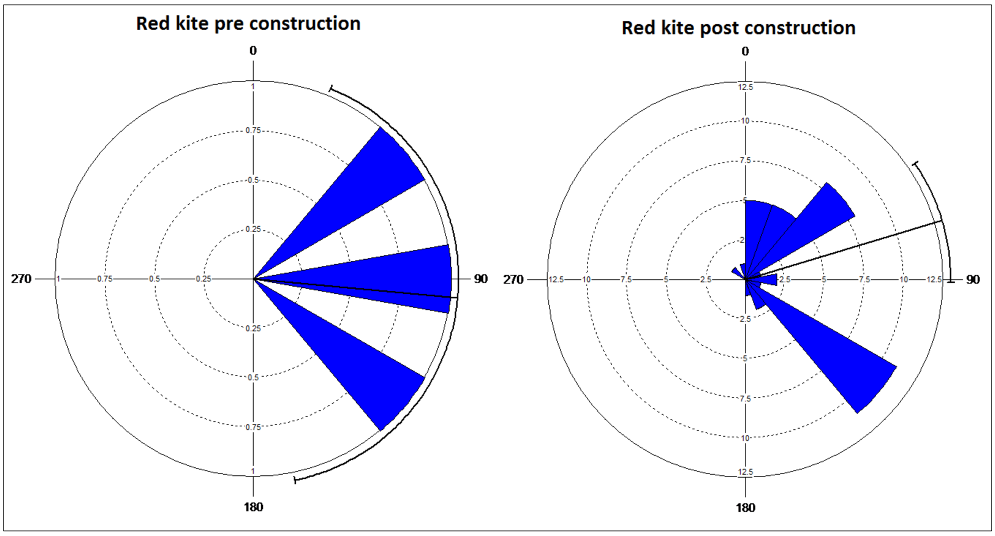

Figure 8-8. The recorded direction of migration for Red Kite when leaving the coast at Gjerrild during the pre-construction survey (left) and during the post construction survey (right). Straight line is the mean migration direction; error bars are ±1 standard deviation.

8.3. Numbers of raptors at wind farm compared to coast

The numbers of migrating raptors at Gjerrild and at the Substation were compared to determine if they were comparable (Table 8-2). For this comparison the observed raptors at Gjerrild in 2014 was used (the year with the highest number of migrating raptors). The observed numbers were multiplied by 1.2 to compensate for overlooked birds. These figures were compared with the number of raptors recorded at the Substation in 2014 multiplied by 2.0 (as more birds are believed to be overlooked at the Substations due to the open ocean around the platform, which makes it much harder to detect the migrating birds).

Table 8-2. Comparison of number of raptors at Gjerrild Klint and the Substation. The numbers are observed raptors during this study multiplied by 1.2 for Gjerrild and 2.0 for Substation to compensate for overlooked birds.

Raptor species	Estimated migrating raptors Gjerrild	Estimated migrating raptors Substation	Number of raptors at Substation as percentage of Gjerrild
Honey Buzzard	60	20	33%
Red Kite	47	48	103%
Black Kite	2	0	-
White-tailed Eagle	0	4	-
Marsh Harrier	26	24	91%
Hen Harrier	13	10	76%
Sparrowhawk	148	170	115%
Common Buzzard	412	268	65%
Rough-legged Buzzard	4	4	111%
Osprey	18	12	67%
Kestrel	29	6	21%
Merlin	10	8	83%
Hobby	10	0	-
Peregrine Falcon	0	10	-

The number of Red Kite, Marsh Harrier, Hen Harrier, Sparrowhawk, Rough-legged Buzzard and Merlin were found to be comparable (that is numbers at the Substation > 75% of the numbers observed at Gjerrild). All other species were recorded in lower numbers, in particular for Honey Buzzard and Kestrel where the numbers were only 1/3 and 1/5 of the records at Gjerrild, respectively.

8.4. Slope of flight path when approaching wind farm

The mean slope of the flight paths recorded from the Substation are shown in Figure 8-9 & Figure 8-10, and the results of the statistical analysis are shown in Annex C.

No species displayed a clear ascending or descending trend. According to the statistical analysis, no species of raptor had a mean slope significantly different from zero (intercept not significant, Annex C). For Sparrowhawk and Honey Buzzard the effect of wind direction was significant (i.e. slope seems to vary according to wind direction), while all other species showed no significant effect of wind direction.

For Common Buzzard, Kestrel and Sparrowhawk the effect of elevation was significant (i.e. the slope depends on initial flight height when approaching the AOWF).

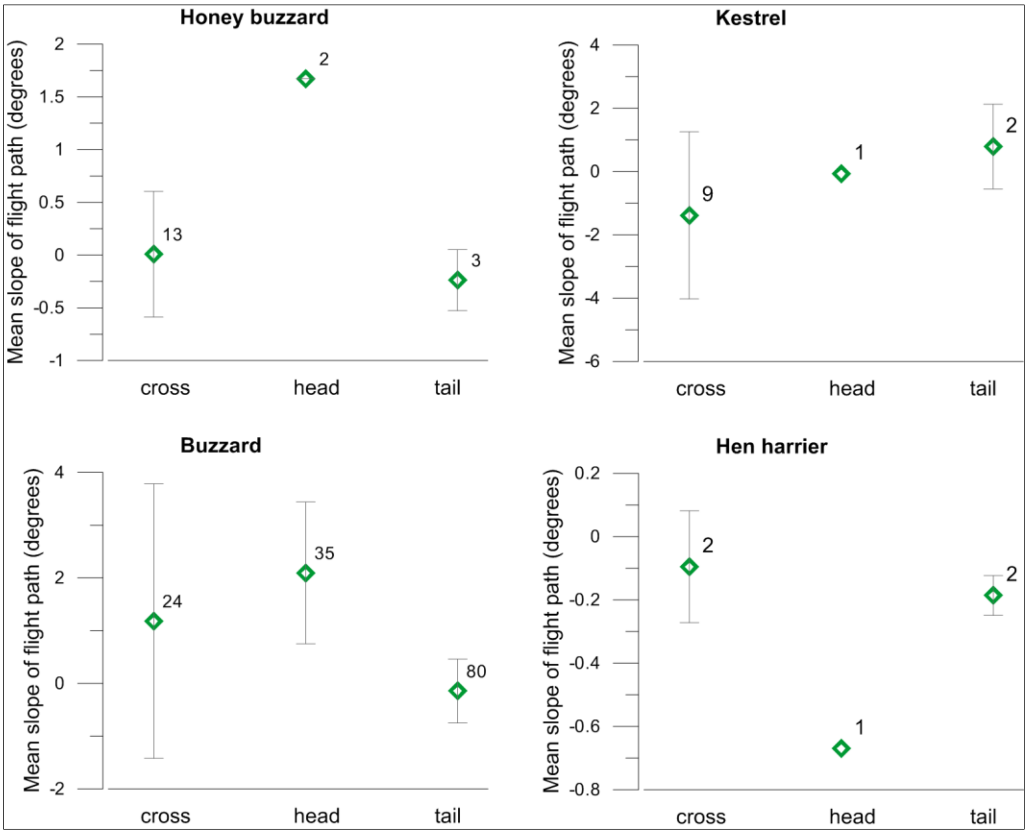

Figure 8-9. Mean slope of flight path (degrees) when approaching the AOWF. Error bars is ± 1 SD. Data point labels is number of birds (N) in the specific combination of species, wind direction. NB Y-axis scale varies between species.

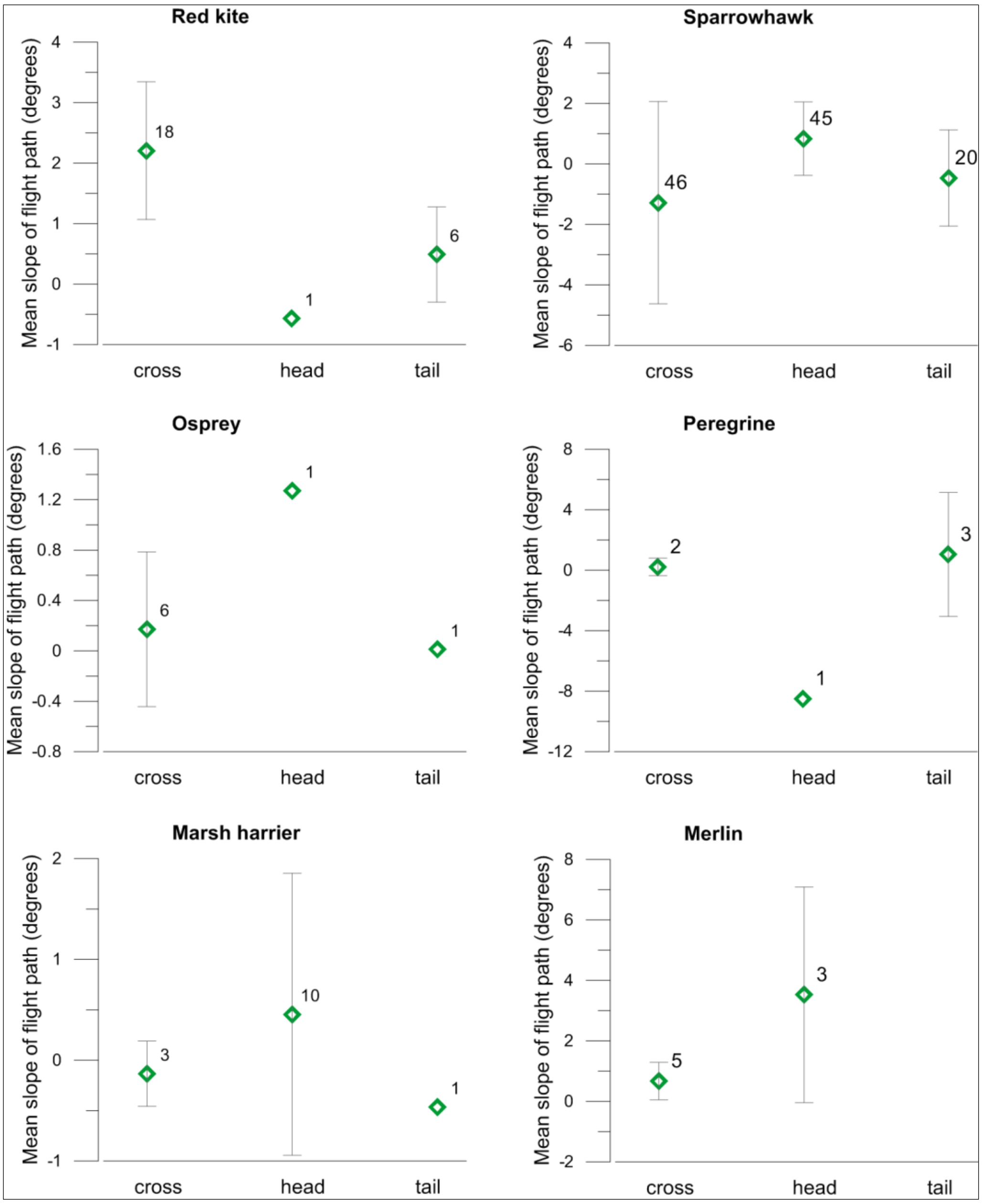

Figure 8-10. Mean slope of flight path (degrees) when approaching the AOWF. Error bars is ± 1 SD. Data point labels is number of birds (N) in the specific combination of species, wind direction. NB Y-axis scale varies between species.

For Common Buzzard, the mean slope of birds approaching the AOWF at an altitude lower than the top of rotor was slightly positive (0.50 degrees [SD: ±1.8]) while it was slightly negative (-0.2 degrees [SD: ±0.99]) for birds approaching at an altitude above the rotors. While this may indicate a potential attraction towards the windfarm (i.e. stepping stone effect), the absolute effect (slope) is very small, and zero (no attraction) is well within the standard deviation of the observed birds.

For Kestrel, the mean slope of birds approaching the AOWF at an altitude lower than the top of rotor was slightly negative (-0.25 degrees [SD: ±0.94]). A single Kestrel was observed approaching at an altitude above the rotors. This bird showed a more pronounced decent (-8.1 degrees).

For Sparrowhawk, the mean slope of birds approaching the AOWF at an altitude lower than the top of rotor was slightly negative (-0.7 degrees [SD: ±2.49]) while it was slightly positive (0.15 degrees [SD: ±1.08]) for birds approaching at an altitude above the rotors. This may indicate a repelling effect of the wind farm (i.e. avoidance behaviour). However, as with Common Buzzard, the absolute effect (slope) is very small and zero (no avoidance) is well within the standard deviation of the observed birds.

8.5. Avoidance responses

The observed species-specific avoidance responses of the migrating raptors as they approach the front row of turbines are summarized in Table 8-3. This information was collected from the Substation positioned approximately 1.75 km from the nearest turbine row.

Macro avoidance: This is when the windfarm acts as a physical barrier, impeding the most direct route to the bird's destination. The migrating raptors respond by changing flight direction in order to avoid entering the wind farm. Typical macro-responses observed at the AOWF are migrating raptors turning back to Djursland when approaching the AOWF or changing direction and starting to fly parallel to the front row of turbines.

Meso avoidance: These are responses within or very close to a windfarm, where birds may respond to the presence of a turbine either by altering the altitude at which they fly (vertical meso-avoidance), or by altering the flight path they take, termed horizontal meso-avoidance, for example by flying parallel to the turbine rows (inside the wind farm).

Micro avoidance: This is when the birds very close to a turbine chooses a new route, which pass between rotors; or fly higher or lower to avoid the rotors; or take emergency action in-flight to escape an approaching blade.

Table 8-3. Number and percentage of avoidance types for the migrating raptor species. Avoidance is given as number of observed avoidance behaviours (N) and as percentage of the total number of observed birds (%).The column "total" gives the number and percentage of birds who showed at least one type of avoidance behaviour. Note: A bird performing macro avoidance may not perform any other kind of avoidance. A bird performing meso avoidance may also perform micro avoidance and vice versa. The same bird may perform both horizontal and vertical meso avoidance.

Raptor species	**Macro avoidance**		**Meso vertical avoidance**		**Meso horizontal avoidance**		**Micro avoidance**		**Total avoidance**	
	N	%	N	%	N	%	N	%	N	%
Honey Buzzard	8	30	4	15	5	19	0	0	16	59
Red Kite	19	59	6	19	1	3	0	0	26	81
Marsh Harrier	6	21	8	28	3	10	2	7	16	55
Hen Harrier	2	29	0	0	1	14	1	14	3	43
Sparrowhawk	50	42	33	28	11	9	7	6	88	74
Common Buzzard	52	27	67	34	13	7	1	1	121	62
Osprey	2	13	4	27	5	33	1	7	8	53
Kestrel	10	45	6	27	5	23	0	0	19	86
Merlin	2	14	2	14	3	21	0	0	5	36
All species	151	33	130	28	47	10	12	3	302	66

The highest total avoidance responses were observed for Kestrel (86%) and Red Kite (81%), followed by Sparrowhawk (74%), Common Buzzard (62%) and Honey Buzzard (59%).

The highest macro avoidance values were recorded for Red Kite (59%), Kestrel (45%) and Sparrowhawk (42%). Approximately ¾ of the birds displaying macro avoidance left the AOWF in a direction indicating they were returning to the mainland[1]. The remaining birds flew either north or south parallel to the first row of turbines suggesting they were trying to navigate around the wind farm.

Also high values of vertical and horizontal meso-avoidance were recorded for several species. The highest vertical avoidance value was recorded for Common Buzzard (34%), but high values were also recorded for Marsh Harrier and Sparrowhawk (both 28%) and Osprey and Kestrel (both 27%). The highest value of horizontal meso-avoidance was recorded for Osprey (33%), followed by Kestrel (23%) and Merlin (21%).

[1] It should be noted that this macro-avoidance behavior refers to birds observed from the Substation only – that is raptors that turn back when approaching the wind farm after migrating 20 km over the sea. Raptors that give up the sea-crossing before they get within c. 3 kilometers of the wind farm are not included.

Micro-avoidance was only recorded for a few species (Marsh Harrier, Sparrowhawk, Common Buzzard and Osprey). With the exception of Sparrowhawk where seven birds showed micro-avoidance, the number of birds that showed this avoidance behaviour was low (1-2 birds per species).

Among the observed avoidance behaviours, macro-responses – behavioural responses outside the windfarm – were generally relatively easy to record from the substation.

Meso-avoidance was more challenging because of the distance from the observer to the bird, with horizontal avoidance often much more difficult to detect compared to a bird climbing or descending. However, overall the observed meso-avoidance values are also believed to give a good indication of the bird's reactions to the turbines.

The low micro-avoidance values recorded are also considered a good indication the real situation, although a few avoidance incidents could have been overlooked because of the distance from the observer to the turbine. Low micro-avoidance values for raptors are also in line with observation at wind turbines on land (for example Hötker et al. 2013 and May et al. 2015).

Overall, we assess the registered avoidance values as a good measure of the raptors reaction to the wind farm.

8.6. Collision risk

The risk for colliding with one of the AOWF turbines was calculated by means of the "Band Collision Risk Model". The estimated numbers of collisions is shown in Table 8-4. Only species with calculated collision rates > 0.01 are included in the table. For reference, an example of the Band Collision Risk Model calculation for Sparrowhawk is shown in Annex E.

Table 8-4. Number of migrants passing the AOWF during a spring season, the estimated numbers of collisions during one season using the “Band Collision Risk Model” and the estimated collisions as percentage of the total number of migrants passing the AOWF per year.

Raptor species	Number of migrating raptors during a spring season (birds)	Number of estimated collisions (birds)	Collisions in percentage of birds passing AOWF
Honey Buzzard	190	3	1.42
Red Kite	159	1	0.55
Marsh harrier	91	1	0.98
Sparrowhawk	822	6	0.75
Common Buzzard	2,161	24	1.12
Osprey	68	1	1.27
Kestrel	162	1	0.49
Merlin	58	1	1.99

Common Buzzard has by far the highest collision risk (24 birds/year) followed by Sparrowhawk (6 birds/year) and Honey Buzzard (3 birds/year). All other species have values of 1 bird per year or less.

For Merlin, the number of collisions represents 2% of the total number that passed the wind farm each spring. For Honey Buzzard the corresponding values is 1.4%, while it is 1.3% for Osprey and 1.1 for Common Buzzard. For all other species, the value is less than 1%.

8.7. Population impact

Table 8-5. shows the calculated collision rates as percentages of the biogeographical populations and Potential Biological Removal (PBR) for the migrating raptor populations at the AOWF.

The table shows that the calculated annual collision fatalities make up less than 1 ‰ of the biogeographical populations the raptors belong to.

In addition, the collision values, as percentage of PBR is low. Common Buzzard has the highest value with 0.96% of PBR while the value for Honey Buzzard is 0.53%. All other species have values below 0.25%.

Table 8-5. Calculated collisions as percentage of biogeographical population and Potential Biological Removal (PBR).

Raptor species	Size of biogeographical population (number of birds)	Collisions in percent of biogeographical population	Potential Biological Removal (PBR)	Collisions in percentage of PBR
Honey Buzzard	22,200	0.01%	509	0.53%
Red Kite	6,150	0.01%	708	0.12%
Marsh Harrier	7,959	0.01%	364	0.25%
Sparrowhawk	173,550	< 0.01%	20,053	0.03%
Common Buzzard	103,650	0.02%	2,513	0.96%
Osprey	14,592	0.01%	769	0.11%
Kestrel	52,950	< 0.01%	1,441	0.06%
Merlin	41,250	< 0.01%	4,392	0.03%
Hobby	17,064	-	1,109	-

9. DISCUSSION AND CONCLUSION

9.1. AOWF as a "stepping stone" for migrating raptors

This section discusses to what extent the results of the study suggest that the AOWF acts as a "stepping stone" (that is an island) for the migrating raptors when leaving the Djursland coast at Gjerrild and starting the sea crossing towards Sweden.

9.1.1 Hypothesis 1 – flight altitude at Gjerrild

It is well known that many land birds when having to migrate over water try to reduce the length of the sea crossing by heading towards islands in the approximate migration direction and use them as "stepping stones" (Alerstam et al. 1997, Bruderer & Liechti 1998). It was therefore hypothesized during the baseline studies that migrating raptors will perceive AOWF as a potential "stepping stone" (island) and therefore would initiate their water crossing flight at a lower altitude after the wind farm was constructed than before.

To test if the AOWF has a "stepping stone effect" on the migrating raptors the following null hypothesis was formulated: *"The weather-dependent flight altitude of migrating raptors leaving the coast of Djursland at Gjerrild is unchanged from the pre-construction situation".*

It is a built-in assumption in the hypotheses that the bird's flight altitude should be tested under different weather conditions with particular focus on the wind direction. Unfortunately, the average weather conditions during the pre- and post-construction surveys were very different. While the majority of observations during pre-construction took place on days with mostly westerly winds, the post-construction observations were mainly carried out on days with easterly winds. This implies that the number of observations that are directly comparable as far as wind direction is concerned is small and comparisons are only possible for a limited number of raptor species. The statistical analysis showed however, that the effect of wind direction on estimated flight altitude was only significant for two species. This suggests that the sample data from the pre and post construction surveys are comparable despite the marked difference in wind directions. Using a reduced statistical model without the effect of wind direction made it possible to perform pre- and post-construction comparisons for all species.

Analyses of the pre- and post-construction data showed that with the exception of Common Buzzards in tail wind situations, the raptors left the Djursland coast at lower – or for a few species the same – height after the AOWF was constructed than before.

This implies that the null hypotheses must be rejected and that the studies indicate that the raptors when leaving the Djursland coast could perceive the AOWF as a “stepping stone”. This was the case for Red Kite, Marsh Harrier, Hen Harrier, Sparrowhawk and Kestrel.”

9.1.2 Hypothesis 2 – flight direction at Gjerrild

To further test if the AOWF has an attracting, a neutral or a repelling effect to migrating raptors a comparison was made of the flight direction of the birds leaving the coast at Gjerrild by comparing the baseline and post-construction data.

The island Anholt some 44 km from Gjerrild is under most conditions the only land area likely to be visible for the raptors when initiating the sea crossing at Gjerrild[1]. On days with good visibility, it has therefore been assumed that the migrating raptors were heading initially towards Anholt on their way to Sweden.

The AOWF is now situated across the direct flightpath between Gjerrild and Anholt. Raptors heading towards Anholt or the AOWF will therefore fly in the same direction as before the AOWF was built. A change in flight direction should only be observed if the AOWF has a repelling effect.

To address this the following hypotheses was formulated: *The weather-dependent flight direction of migrating raptors leaving the coast of Djursland at Gjerrild is unchanged from the pre-construction situation.*

Because of the same weather-related challenges as mentioned under hypothesis 1, it was not possible to test if a weather-dependent change in flight direction had taken place.

Analyses of the collected data showed that with the exception of Honey buzzard no significant change in the flight direction was recorded. During the pre-construction period Honey buzzards chose a heading aiming directly for Anholt. Post-construction the birds chose a more northern heading aiming past the north tip of the AOWF. This behaviour may indicate a repelling effect of the AOWF on Honey Buzzards. Further indication of a repelling effect was recorded from the Substation where Honey Buzzards were noted to have a marked tendency to fly parallel to the front row of turbines, completely avoiding entering the wind farm area.

Since by far the majority of migrating raptors showed no significant change in flight direction, the null hypotheses must generally be accepted. This implies that it can be re-

[1] On days with extreme visibility and when the migrants are flying very high it is possible that they can see the coast of Sweden 100 km away when they start the sea crossing.

jected that the AOWF has a repelling effect on migrating raptors when the birds are initiating the sea crossing. Instead, the AOWF must have either a neutral or an attracting effect to the birds. The fact that most raptor species now seem to leave the coast at a lower height than before (cf. hypothesis 1) *may* indicate that the AOWF is perceived as a stepping-stone and thus initially has an attracting effect.

Honey Buzzard may constitute a special case where the null hypothesis is rejected by the statistical analysis. The AOWF may have a repelling effect on Honey Buzzards, something that is also supported by the observed macro avoidance behaviour at the Substation. This also fits well with the fact that the flight height in this species is unchanged from the pre-construction situation.

9.1.3 Hypothesis 3 - same number of birds at the AOWF as leaving the cost

To evaluate if the AOWF has an attracting, a neutral or a repelling effect to migrating raptors it was also tested if the numbers of migrating raptors approaching the AOWF were comparable to those leaving the Djursland coast at Gjerrild.

This was formulated as *migrating raptors approach the AOWF in numbers comparable to those leaving the Djursland coast at Gjerrild.*

At the Substation in front of the AOWF, it was found that six out of 14 species were recorded in numbers comparable to the numbers observed at Gjerrild while five species recorded in lower numbers. In addition, two species were recorded at the Substation but not at Gjerrild and one species was recorded at Gjerrild but not from the Substation. This suggests that the null hypotheses should be rejected and that the AOWF for many species has a repelling effect rather that a attracting or neutral.

However, it should also be considered that while the coastline of Anholt perpendicular to the flight direction is around 5 km (and is 44 km away from Gjerrild), the front row of turbines of the AOWF is 19 km long – and only 20 km away from the coast. Because of the much broader “island front” and because the AOWF is much closer to Gjerrild the migrating raptors can be less directional in their flight path but still be heading for the AOWF (if they perceive it as a “stepping stone”). This could imply that the migrating birds could be following a rather broad migrating corridor towards the AOWF and therefore not necessarily pass the Substation.

Also the fact that most of the migrating raptors concentrate at projecting points along the coast (one of which is Gjerrild Klint) when starting the sea crossing makes it more likely to observe more birds at one of these points than at the Substation which has not such an effect.

To conclude, although a direct comparison of the number of birds recorded at Gjerrild and the Substation does not suggest that the AOWF has a “stepping stone effect” and may even suggest a repelling effect, a neutral or attracting effect cannot be ruled out for most species if the wind farm’s far greater geographical extent is taken into account.

9.1.4 Hypothesis 4 – flight altitude when approaching AOWF

The baseline studies demonstrated that migrating raptors approaching Anholt descend towards the island (which was seen as a “stepping stone effect)”. Our fourth hypothesis intended to test if the AOWF has a similar effect: *Migrating raptors reduce their flight altitude when approaching the AOWF.*

Analyses of the survey results from the Substation revealed that there is no indication that the migrating raptors consistently loose height as they approach the wind farm. The null hypotheses must therefore be rejected. Thus, the AOWF is apparently not perceived as a stepping-stone when the raptors approach the wind farm.

9.2. Collision risk assessment

This section discusses to what extent the results of the study suggest that the turbines of the AOWF impose a significant collision risk on the migrating raptors, in a second step it is assessed if the collision-induced additional mortality has an effect at the population level.

9.2.1 Hypothesis 5 – migrating raptors adjust their flight path when approaching the turbines

Many birds react strongly when approaching a wind farm. Such spatial behavioural responses include reactions before the bird reach the wind farm (macro avoidance), behavioural responses inside the wind farm (meso-avoidance) and close to the turbine (micro-avoidance).

To test if the migrating raptors showed any type of avoidance behaviour while approaching or passing the wind farm the following null hypothesis was formulated: *Migrating raptors approaching the rows of turbines do not adjust their flight path in the horizontal and/or vertical plane to avoid the turbines and the rotors.*

Analyses of the collected data revealed that two-thirds (66%) of the raptors showed avoidance behaviour when approaching the AOWF. This ranged from 86% avoidance among Kestrels to 36% for Merlins.

The highest macro avoidance values were recorded for Red Kite (59%), Kestrel (45%) and Sparrowhawk (42%). Also high values of vertical and horizontal meso-avoidance were recorded for a number of raptors. This is in contrast to micro avoidance, which was only observed for a few species and - with exception of Sparrowhawk – only very few times.

The null hypothesis that migrating raptors do not adjust their flight path when approaching the turbines is therefore rejected.

9.2.2 Hypothesis 6 – the AOWF does not impose a significant collision risk

To test the risk that a migrating raptor will collide with a turbine the following hypothesis was formulated: *Passing the AOWF during spring migration does not impose any significant collision risk to raptors.*

This hypothesis was investigated using a modelling approach and the recorded avoidance values for each species. Common Buzzard was found to have the highest collision risk (24 bird/year), followed by Sparrowhawk (6 birds/year) and Honey Buzzard (3 birds/year). For all other raptors the number of fatalities was 1 bird/year or less.

This is comparably high numbers for Common Buzzard, Sparrowhawk and Honey Buzzard. Taking into account the number of birds of each species that passes the AOWF in spring, the impacted portion is 1.4% for Honey Buzzard, 1.1% for Common Buzzard and 0.8% for Sparrowhawk. An even higher percentage was found for Merlin (2%) but this is based on a small number of birds.

Although the number of fatalities of Common Buzzard, Sparrowhawk and Honey Buzzard is high in absolute numbers it only represents 0.8 – 1.4% of the birds of the individual raptor species that passes the AOWF each spring. For this reason we conclude that the AOWF does not pose a significant collision risk to the raptors that pass the AOWF on spring migration. Consequently, the null hypothesis is accepted.

9.2.3 Hypothesis 7 – impact on the population level

The last hypothesis takes a population perspective to the potential impact of the offshore wind farm: *Passing the Anholt Offshore Windfarm during spring migration does not pose a collision risk to raptors that is likely to affect the biogeographical populations of the species involved.*
This hypothesis was also investigated using a modelling approach. For all studied raptor species, it was found that the number of annual collisions (fatalities) represents 0.02% or less of their biogeographical populations.

Comparing the calculated collision risk with the Potential Biological Removal (PBR), i.e. the level of additional mortality that a population is able to sustain, the number of fatalities for all species is less than 1% of the PBR.

To conclude, direct mortality from collisions is estimated to have an insignificant impact on the biogeographical populations and consequently the hypothesis is accepted.

9.3. Conclusion

Four aspects of the migrating raptors' behaviour were tested to determine if the birds consider the AOWF a "stepping stone" when leaving the Djursland coast and starting the sea crossing. The finding that the raptors generally leave land at a lower height after the construction of the AOWF suggests some "stepping stone effect" but the results of the three other tests give inconclusive results. We conclude, therefore, that there is no strong evidence for the migrating birds considering the AOWF a "stepping stone" on their migration across the Kattegat.

When the migrating raptors got nearer to the wind farm large numbers showed strong avoidance behaviour. From the Substation (1.75 km from the nearest turbine), macro-avoidance was observed for 1/3 of the migrating raptors, including 59% of the Red Kites, 45% of the Kestrels and 42% of the Sparrowhawks. After migrating c. 20km over the sea, about 75% of these birds turned and flew back towards Djursland while the rest continued perpendicular to the wind farm without entering the farm for as long as they were within sight. This strongly suggests that the AOWF acts as a barrier preventing these birds from crossing Kattegat at Djursland or prolonging their migration route significantly. The impact of this on survival and fitness of the individuals concerned is unknown.

The spring migration corridor between Djursland and Sweden has been referred to as of international importance due to large numbers of Common Buzzard and Sparrowhawk and with regular occurrence of raptor species with small population sizes (Skov et al. 2009, 2012a). Our data and recent observations uploaded to the DOFbasen suggests that only moderate numbers of raptors use this route compare to for example migration corridors across Zealand and at Skagen in northernmost Jutland. Since the migration path between Djursland and the Swedish coast is of secondary importance to the raptor species in question, the observed barrier effect probably has limited impact at the population level. However, macro-avoidance behaviour of the scale observed at the AOWF could potentially have significant impact on raptor populations if the offshore wind farm was located across a major migration route.

The modelling of the collision risk revealed relatively high numbers of fatalities of Common Buzzard, Sparrowhawk and Honey Buzzard (the last species is listed on Annex I of the Birds Directive). For these species this represents 0.8 – 1.4% of the total number that passes the AOWF each spring.

The estimated fatalities represents 0.02% or less of the biogeographical populations and less than 1% of the PBR for all the raptor species that passes the AOWF in spring

To conclude, the modelled number of fatalities has insignificant impact on the biogeographical population or the PBR for all species including species listed on Annex I of the Birds Directive.

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11. ANNEX A – BREEDING POPULATION OF MIGRANTS

Honey Buzzard

The Honey Buzzard population passing the AOWF on spring migration is considered belonging to the Swedish and Norwegian breeding population. No or only very few Honey Buzzards breeding in Finland are thought to migrate through Denmark since none have been ringed abroad and recovered in Denmark or ringed in Denmark and recovered abroad (Bønløkke *et al*. 2006). Furthermore, results of satellite tracking of Finnish Honey Buzzards suggest that they migrate north through Eastern Europe in spring (Finnish Museum of Natural History 2016). This suggests that the Finnish Honey Buzzards belong to a different biogeographical population than the birds breeding in Sweden.

Red Kite

The Red Kite population passing the AOWF on spring migration is considered belonging to the Swedish population. This raptor species does not breed in Norway or Finland.

Black Kite

The Black Kite population passing the AOWF on spring migration is considered belonging to the Swedish and Finnish population. This raptor species does not breed in Norway.

White-tailed eagle

The White-tailed eagles observed leaving the Djursland coast on spring migration is considered to belong to the Swedish breeding population only. This is because results of satellite tracking of Finnish White-tailed eagles suggest that they winter in Finland, Sweden and Norway and do not migrate to Denmark or further to the south-west (Finnish Museum of Natural History 2016). No or only very few White-tailed eagles leave Norway in winter and there are no recovered from Denmark (Bønløkke *et al*. 2006).

Marsh Harrier

Marsh Harriers passing the AOWF on spring migration is considered to belong to the Swedish, Norwegian and the Finnish breeding population. Ringing results suggest that the migration route of Swedish Marsh Harriers is passing Denmark. Little is known about the migration route followed by the Finnish breeding population except that an immature has been recovered from Denmark (Bønløkke *et al*. 2006). Although it is likely that some Finnish marsh harriers migrate though Eastern Europe bypassing Sweden and Denmark in this study the Marsh harriers passing the AOWF are considered to consist of the Swedish and Finnish population.

Hen harrier

Hen Harriers passing the AOWF on spring migration are considered to belong to the Swedish, Norwegian and Finnish breeding populations, which is in line with ringing recovery data (Bønløkke *et al*. 2006).

Goshawk

Goshawks recorded on spring migration at the AOWF on spring migration are considered to belong to either the Swedish, Norwegian or the Finnish breeding population. This is based on ringing recovery data presented in Bønløkke *et al*. (2006).

Sparrowhawk

Sparrowhawks recorded in connection with this study are considered to belong to the Swedish, Norwegian and Finnish breeding populations. This is supported by ringing results, which comprise many recoveries in Denmark of birds ringed in Norway, Finland and Sweden or birds ringed in Denmark recovered from these countries (Bønløkke *et al*. 2006).

Common Buzzard

Common Buzzards migrating through the AOWS in spring are believed to belong mainly to the Swedish and Norwegian breeding populations but also to include the Finnish breeders. In this study, half of the Finnish breeding population is considered part of the biogeographical population that migrate to the south-west to Denmark. This is based on ringing data, which show that many buzzards ringed in (central) Sweden and a few from south and west Finland have been recovered in Denmark (Bønløkke *et al*. 2006). Some buzzards ringed in Denmark have also been recovered from Sweden and a single from Finland (Bønløkke *et al*. 2006). It should be noted though, that Common buzzards breeding in north and east Finland follow an eastern migration route through the Baltic States on their way to wintering areas in Africa.

Rough-legged Buzzard

Rough-legged Buzzards recorded in connection with the AOWF study are considered to belong to the Norwegian, Swedish and Finnish breeding populations. This is supported by ringing recoveries, which include recoveries in Denmark of Rough-legged buzzards ringed in Norway, Sweden and Finland (Bønløkke *et al*. 2006).

Osprey

The Ospreys passing the AOWF on spring migration are mainly belonging to the Swedish and Norwegian breeding populations plus a few Finnish breeders. In this study, ¼ of the Finnish breeding population is considered part of the biogeographical population that passes Denmark on migration. This is supported by ringing recoveries which include several Ospreys ringed as chicks in Norway, Sweden and Finland and recovered from Denmark (Bønløkke *et al*. 2006). Satellite tracking suggests that the majority of Finnish Ospreys takes a more eastern route and migrates through Eastern Europe in spring and autumn (Finnish Museum of Natural History 2016).

Kestrel

The Kestrels passing the AOWF on spring migration are considered to belong to the Swedish and Finnish breeding populations. This is supported by Danish ringing data, which include many passage migrants ringed in Sweden and Finland (Bønløkke *et al*. 2006).

Merlin

Merlins passing the AOWF on spring migration are considered belonging to the Swedish and Finnish breeding populations. This is supported by a few Danish recoveries of birds ringed in Sweden and Finland (Bønløkke *et al*. 2006).

Hobby

Hobby's passing the AOWF on spring migration are believed to belong to the Norwegian, Swedish and Finnish breeding populations which pass through Denmark on their way to and from the wintering areas in tropical Africa (although this is not supported by ringing results (Bønløkke *et al*. 2006)).

Peregrine

Peregrines migrating through the AOWF in spring are believed to belong to the Norwegian, Swedish and Finnish populations. This is supported by ringed Norwegian, Swedish and Finnish peregrines recovered in Denmark (Bønløkke *et al*. 2006).

Table 11-1. The estimated minimum breeding population (N_{min}) in Sweden, Norway and Finland of the raptor species covered in this study. Data from Ottosson et al. 2012, Heggøy & Øien (2014) and Finnish Museum of Natural History 2016). Populations in brackets are not included.

Raptor species	Breeding population in Sweden	Breeding population in Norway	Breeding population in Finland	Size of biogeo-graphical popula-tion species in-volved
Honey Buzzard	6,650 pairs	750 pairs	2,300 pairs	7,400 pairs
Red Kite	2,050 pairs	0	0	2,050 pairs
Black Kite	15 pairs	0	18 pairs	32 pairs
White-tailed Eagle	625 pairs	3,500 pairs	450 pairs	625 pairs
Marsh Harrier	1,700 pairs	38 pairs	915 pairs	2,653 pairs
Hen Harrier	750 pairs	83 pairs	1,550 pairs	2,383 pairs
Sparrowhawk	44,000 pairs	4,500 pairs	9,350 pairs	57,850 pairs
Goshawk	7,750 pairs	1,650 pairs	4,250 pairs	13,650 pairs
Common Buzzard	31,000 pairs	1,500 pairs	4,100 pairs	34,550 pairs
Rough-legged Buzzard	3,450 pairs	7,500 pairs	2,250 pairs	13,200 pairs
Osprey	4,050 pairs	508 pairs	1,225 pairs	4.864 pairs
Kestrel	6,450 pairs	3,000 pairs	8,200 pairs	17,650 pairs
Merlin	6,250 pairs	4,500 pairs	3,000 pairs	13,750 pairs
Hobby	2,350 pairs	188 pairs	3,150 pairs	5,688 pairs
Peregrine Falcon	365 pairs	925 pairs	194 pairs	1,484 pairs

Table 11-2. The minimum breeding population in Sweden, Norway and Finland of the raptor species covered in this study. Data from Ottosson et al. 2012, Heggøy & Øien (2014) and Finnish Museum of Natural History 2016).

Raptor species	Minimum size of biogeographical population species involved	Minimum number of birds
Honey Buzzard	5,700 pairs	17,100
Red Kite	1,900 pairs	5,700
Black Kite	25 pairs	75
White-tailed Eagle	550 pairs	1,650
Marsh Harrier	2,205 pairs	6,615
Hen Harrier	2,225 pairs	6,675
Sparrowhawk	34,300 pairs	102,900
Goshawk	10,100 pairs	30,300
Common Buzzard	22,000 pairs	66,000
Rough-legged Buzzard	7,200 pairs	21,600
Osprey	4.090 pairs	12,270
Kestrel	17,650 pairs	14,200
Merlin	9,500 pairs	28,500
Hobby	4,945 pairs	14,835
Peregrine Falcon	1,244 pairs	3,732

12. ANNEX B – STATISTICAL MODEL HYPOTHESIS 1 (ALTITUDE GJERRILD)

Model for testing whether the migration direction of raptors leaving Gjerrild is significantly different pre and post construction (i.e. is the effect of “Survey” pre/post significant).

Model: Elevation ~ Intercept + WindSpeed + Survey + WindDir + Survey * WindDir

With:
WindSpeed as covariate
WindDir as factor (levels: cross/head/tail)
Survey as factor (levels: pre/post - construction)

For species where the effect of Wind direction was not significant (i.e. all other species than Common Buzzard and Kestrel), a reduced model was used:

Model: Elevation ~ Intercept + WindSpeed + Survey

With:
WindSpeed as covariate
Survey as factor (levels: pre/post - construction)

Full model results:

Descriptive Statistics

Dependent Variable: Elevation

Species			Mean	Std. Deviation	N
Common buzzard	post	cross	140,3	90,7	132
		tail	390,8	182,6	153
		head	91,1	59,4	12
		Total	267,4	193,0	297
	pre	cross	188,7	93,0	4
		tail	178,9	120,6	30
		head	141,8	78,3	58
		Total	156,0	95,4	92
	Total	cross	141,8	90,8	136
		tail	356,1	190,7	183
		head	133,1	77,4	70
		Total	241,0	181,1	389
Kestrel	post	cross	62,0	20,6	13
		tail	105,2	25,8	3
		head	29,4	4,2	8
		Total	56,5	29,5	24
	pre	cross	308,3	57,6	2
		tail	291,8		1
		head	215,4		1
		Total	281,0	55,4	4
	Total	cross	94,8	90,1	15
		tail	151,9	95,6	4
		head	50,0	62,1	9
		Total	88,6	86,5	28

Full model results:

Tests of Between-Subjects Effects

Dependent Variable: Elevation

Species		Type III Sum of Squares	df	Mean Square	F	Sig.
Common buzzard	Corrected Model	5932287	6	988715	55,63	0,000
	Intercept	1634587,000	1	1634587	91,97	0,000
	WindSpeed	194479,000	1	194479	10,94	0,001
	Survey	15448,000	1	15449	0,87	0,352
	WindDir	928952,000	2	464476	26,13	0,000
	Survey * WindDir	455527,000	2	227764	12,82	0,000
	Error	6788985,000	382	17772		
	Total	35319922,000	389			
	Corrected Total	12721273,000	388			
Kestrel	Corrected Model	192.437.539	6	32.073	71,17	0,000
	Intercept	74.400	1	74.400	165,10	0,000
	WindSpeed	402	1	402	0,89	0,355
	Survey	111.207	1	111.207	246,78	0,000
	WindDir	12.278	2	6.139	13,62	0,000
	Survey * WindDir	3.023	2	1.512	3,35	0,054
	Error	9.463	21	451		
	Total	421.565	28			
	Corrected Total	201.901	27			

Reduced model results:

Descriptive Statistics

Dependent Variable: Elevation

Species		Mean	Std. Deviation	N
Black kite	post	103,9	76,9	3
	Total	103,9	76,9	3
Hen harrier	post	56,2	37,4	10
	pre	147,7	84,9	3
	Total	77,3	62,1	13
Hobby	post	103,6	54,6	7
	pre	186,4	130,3	4
	Total	133,7	92,9	11
Honey buzzard	post	208,3	211,8	41
	pre	195,1	220,4	27
	Total	203,1	213,7	68
Marsh harrier	post	59,1	37,1	20
	pre	140,9	94,0	8
	Total	82,5	68,4	28
Merlin	post	97,9	95,1	8
	pre	195,4		1
	Total	108,7	94,7	9
Osprey	post	71,4	48,7	15
	pre	58,1	17,8	3
	Total	69,2	44,9	18
Peregrine	pre	115,8	119,8	5
	Total	115,8	119,8	5
Red kite	post	145,0	104,1	38
	pre	235,0	166,5	3
	Total	151,5	109,4	41
Rough-legged buzzard	post	278,9	261,3	3
	pre	266,2	250,4	3
	Total	272,6	229,0	6
Sparrowhawk	post	144,1	139,6	122
	pre	234,4	150,4	23
	Total	158,4	144,7	145

White-tailed eagle	pre	171,3	118,4	2
	Total	171,3	118,4	2

Reduced model results:

Tests of Between-Subjects Effects

Dependent Variable: Elevation

Species		Type III Sum of Squares	df	Mean Square	F	Sig.
Black kite	Corrected Model	174.875	1	174,9	0,02	0,922
	Intercept	7.619	1	7619,1	0,65	0,567
	WindSpeed	175	1	174,9	0,02	0,922
	Survey	0	0			
	Error	11.649	1	11649,3		
	Total	44.237	3			
	Corrected Total	11.824	2			
Hen harrier	Corrected Model	25.105.272	2	12552,6	5,92	0,020
	Intercept	39.035	1	39034,6	18,42	0,002
	WindSpeed	5.783	1	5783,2	2,73	0,130
	Survey	22.123	1	22122,9	10,44	0,009
	Error	21.193	10	2119,3		
	Total	124.007	13			
	Corrected Total	46.299	12			
Hobby	Corrected Model	39.201.892	2	19600,9	3,33	0,089
	Intercept	99.316	1	99315,9	16,86	0,003
	WindSpeed	21.746	1	21745,8	3,69	0,091
	Survey	27.981	1	27980,9	4,75	0,061
	Error	47.120	8	5890,0		
	Total	282.940	11			
	Corrected Total	86.322	10			

Honey buz-zard	Corrected Model	49.511.992	2	24756,0	0,53	0,589
	Intercept	362.892	1	362892,2	7,83	0,007
	WindSpeed	46.695	1	46695,4	1,01	0,319
	Survey	1.439	1	1439,5	0,03	0,861
	Error	3.010.740	65	46319,1		
	Total	5.864.690	68			
	Corrected Total	3.060.252	67			
Marsh harrier	Corrected Model	39.416.440	2	19708,2	5,68	0,009
	Intercept	41.866	1	41866,3	12,06	0,002
	WindSpeed	1.219	1	1218,7	0,35	0,559
	Survey	36.146	1	36146,4	10,41	0,003
	Error	86.803	25	3472,1		
	Total	316.639	28			
	Corrected Total	126.219	27			
Merlin	Corrected Model	12.540.132	2	6270,1	0,64	0,562
	Intercept	27.971	1	27971,3	2,84	0,143
	WindSpeed	4.097	1	4097,4	0,42	0,543
	Survey	8.493	1	8493,5	0,86	0,389
	Error	59.156	6	9859,3		
	Total	178.125	9			
	Corrected Total	71.696	8			
Osprey	Corrected Model	18.035.825	2	9017,9	8,30	0,004
	Intercept	41.953	1	41953,3	38,63	0,000
	WindSpeed	17.593	1	17592,6	16,20	0,001
	Survey	5	1	5,0	0,00	0,947
	Error	16.292	15	1086,1		
	Total	120.420	18			
	Corrected Total	34.327	17			
Peregrine	Corrected Model	36.668.192	1	36668,2	5,31	0,105
	Intercept	7.168	1	7168,4	1,04	0,383
	WindSpeed	36.668	1	36668,2	5,31	0,105
	Survey	0	0			
	Error	20.713	3	6904,3		
	Total	124.431	5			
	Corrected Total	57.381	4			

Red kite	Corrected Model	25.640.349	2	12820,2	1,08	0,351
	Intercept	107.484	1	107484,5	9,01	0,005
	WindSpeed	3.093	1	3092,9	0,26	0,613
	Survey	19.124	1	19124,0	1,60	0,213
	Error	453.141	38	11924,8		
	Total	1.420.431	41			
	Corrected Total	478.781	40			
Rough-legged buzzard	Corrected Model	120.009.142	2	60004,6	1,27	0,399
	Intercept	235.336	1	235336,0	4,96	0,112
	WindSpeed	119.768	1	119767,9	2,53	0,210
	Survey	38.561	1	38560,6	0,81	0,434
	Error	142.218	3	47406,0		
	Total	708.053	6			
	Corrected Total	262.227	5			
Sparrowhawk	Corrected Model	427.403.043	2	213701,5	11,73	0,000
	Intercept	1.597.263	1	1597263,3	87,65	0,000
	WindSpeed	269.522	1	269521,7	14,79	0,000
	Survey	221.433	1	221432,6	12,15	0,001
	Error	2.587.750	142	18223,6		
	Total	6.654.746	145			
	Corrected Total	3.015.153	144			
White-tailed eagle	Corrected Model	.000	0			
	Intercept	0	0			
	WindSpeed	0	0			
	Survey	0	0			
	Error	14.011	1	14011,4		
	Total	72.699	2			
	Corrected Total	14.011	1			

13. ANNEX C – STATISTICAL MODEL HYPOTHESIS 4 (SLOPE SUBSTATION)

Model for testing the null hypothesis “The mean slope for each species is zero”.

Model: Slope ~ Intercept + Elevation + WindSpeed + WindDir

With:
Elevation and WindSpeed as covariates
WindDir as factor (levels: cross/head/tail)

Descriptive Statistics

Dependent Variable: Slope

Species		Mean	Std. Deviation	N
Common buzzard	cross	1,183571328055260	2,602584833724660	24
	head	2,097137435976430	1,343853387669000	35
	tail	-0,144745804903999	0,605356888924847	80
	Total	0,649106890217132	1,652404886250710	139
Hen harrier	cross	-0,095000000000000	0,176776695296637	2
	head	-0,670000000000000		1
	tail	-0,185693394622417	0,062659002227691	2
	Total	-0,246277357848967	0,258760284446639	5
Honey buzzard	cross	0,008466987544231	0,595617089096618	13
	head	1,672161424270000	0,000000000000000	2
	tail	-0,237678333897333	0,289436297421586	3
	Total	0,152297704717944	0,758086340890315	18
Kestrel	cross	-1,381117867544220	2,640446269666090	9
	head	-0,070000000000000		1
	tail	0,788200249125897	1,338789103772080	2
	Total	-0,910305025803850	2,450212305275820	12
Marsh harrier	cross	-0,134097478950667	0,323548053262195	3
	head	0,456000000000000	1,399104475488990	10
	tail	-0,465790674801140		1
	Total	0,263708349167633	1,215397520660630	14
Merlin	cross	0,669585563591959	0,618552020888798	5

	head	3,522261185410000	3,566110688528020	3
	Total	1,739338921773720	2,455984351016500	8
Northern gos-hawk	tail	-0,023317089143413		1
	Total	-0,023317089143413		1
Osprey	cross	0,172481317248173	0,614266125439291	6
	head	1,270000000000000		1
	tail	0,010940743556606		1
	Total	0,289478580880706	0,655498730811553	8
Peregrine	cross	0,220000000000000	0,579827560572969	2
	head	-8,490000000000000		1
	tail	1,039870875696670	4,098372219467330	3
	Total	-0,821731228818333	4,589094698052720	6
Red kite	cross	2,206528559923000	1,138943139456660	18
	head	-0,570000000000000		1
	tail	0,488485802821156	0,787391415992270	6
	Total	1,683137155821640	1,349735368688400	25
Rough-legged buzzard	tail	-0,756420768239765	0,000000000000000	2
	Total	-0,756420768239765	0,000000000000000	2
Sparrowhawk	cross	-1,281007826343060	3,343950165434840	46
	head	0,836667878889388	1,212998921290220	45
	tail	-0,465195689443381	1,590953491014010	20
	Total	-0,275497470726359	2,556472813576740	111
White-tailed eagle	cross	0,261327527703000	0,224396762297687	2
	tail	-1,149892206169100		1
	Total	-0,209079050254366	0,830074694965170	3

Tests of Between-Subjects Effects

Dependent Variable: Slope

Species		Type III Sum of Squares	df	Mean Square	F	Sig.
Common buzzard	Corrected Model	157.894	4	39,474	24,163	0,000
	Intercept	3,229	1	3,229	1,976	0,162
	Elevation	15,260	1	15,260	9,341	0,003
	Wind-Speed	27,210	1	27,210	16,656	0,000
	WindDir	7,223	2	3,612	2,211	0,114
	Error	218,907	134	1,634		
	Total	435,367	139			
	Corrected Total	376,801	138			
Hen harrier	Corrected Model	.268	4	0,067		
	Intercept	0,011	1	0,011		
	Elevation	0,009	1	0,009		
	Wind-Speed	0,010	1	0,010		
	WindDir	0,145	2	0,072		
	Error	0,000	0			
	Total	0,571	5			
	Corrected Total	0,268	4			
Honey buz-zard	Corrected Model	5.534	4	1,383	4,246	0,020
	Intercept	0,445	1	0,445	1,365	0,264
	Elevation	0,162	1	0,162	0,496	0,494
	Wind-Speed	0,078	1	0,078	0,238	0,634
	WindDir	5,513	2	2,757	8,460	0,004
	Error	4,236	13	0,326		
	Total	10,187	18			
	Corrected Total	9,770	17			

Kestrel	Corrected Model	37.451	4	9,363	2,292	0,159
	Intercept	1,289	1	1,289	0,316	0,592
	Elevation	28,504	1	28,504	6,979	0,033
	Wind-Speed	0,188	1	0,188	0,046	0,836
	WindDir	6,083	2	3,042	0,745	0,509
	Error	28,588	7	4,084		
	Total	75,983	12			
	Corrected Total	66,039	11			
Marsh har-rier	Corrected Model	5.740	4	1,435	0,959	0,474
	Intercept	0,975	1	0,975	0,652	0,440
	Elevation	1,573	1	1,573	1,052	0,332
	Wind-Speed	2,873	1	2,873	1,921	0,199
	WindDir	0,272	2	0,136	0,091	0,914
	Error	13,463	9	1,496		
	Total	20,177	14			
	Corrected Total	19,203	13			
Merlin	Corrected Model	36.955	3	12,318	9,353	0,028
	Intercept	0,095	1	0,095	0,072	0,802
	Elevation	8,199	1	8,199	6,226	0,067
	Wind-Speed	19,306	1	19,306	14,659	0,019
	WindDir	4,985	1	4,985	3,785	0,124
	Error	5,268	4	1,317		
	Total	66,425	8			
	Corrected Total	42,223	7			
Northern goshawk	Corrected Model	.000	0			
	Intercept	0,000	0			
	Elevation	0,000	0			
	Wind-Speed	0,000	0			
	WindDir	0,000	0			
	Error	0,000	0			
	Total	0,001	1			
	Corrected Total	0,000	0			

Osprey	Corrected Model	1.195	4	0,299	0,494	0,747
	Intercept	0,011	1	0,011	0,017	0,903
	Elevation	0,033	1	0,033	0,055	0,830
	Wind-Speed	0,072	1	0,072	0,119	0,753
	WindDir	0,963	2	0,481	0,796	0,528
	Error	1,813	3	0,604		
	Total	3,678	8			
	Corrected Total	3,008	7			
Peregrine	Corrected Model	104.450	4	26,112	30,754	0,134
	Intercept	17,611	1	17,611	20,742	0,138
	Elevation	7,660	1	7,660	9,021	0,205
	Wind-Speed	10,910	1	10,910	12,849	0,173
	WindDir	88,089	2	44,044	51,874	0,098
	Error	0,849	1	0,849		
	Total	109,350	6			
	Corrected Total	105,299	5			
Red kite	Corrected Model	19.441	4	4,860	4,003	0,015
	Intercept	1,887	1	1,887	1,554	0,227
	Elevation	0,869	1	0,869	0,716	0,408
	Wind-Speed	0,158	1	0,158	0,130	0,722
	WindDir	7,589	2	3,795	3,125	0,066
	Error	24,282	20	1,214		
	Total	114,547	25			
	Corrected Total	43,723	24			
Rough-legged buzzard	Corrected Model	.000	0			
	Intercept	0,000	0			
	Elevation	0,000	0			
	Wind-Speed	0,000	0			
	WindDir	0,000	0			
	Error	0,000	1	0,000		
	Total	1,144	2			
	Corrected Total	0,000	1			

Sparrow-hawk	Corrected Model	150.778	4	37,694	7,033	0,000
	Intercept	0,063	1	0,063	0,012	0,914
	Elevation	41,807	1	41,807	7,800	0,006
	Wind-Speed	12,310	1	12,310	2,297	0,133
	WindDir	105,709	2	52,854	9,861	0,000
	Error	568,133	106	5,360		
	Total	727,336	111			
	Corrected Total	718,911	110			
White-tailed eagle	Corrected Model	1.378	2	0,689		
	Intercept	0,477	1	0,477		
	Elevation	0,000	0			
	Wind-Speed	0,000	0			
	WindDir	0,000	0			
	Error	0,000	0			
	Total	1,509	3			
	Corrected Total	1,378	2			

14. ANNEX D – BAND COLLISION RISK MODEL EXAMPLE (SPARROWHAWK)

COLLISION RISK ASSESSMENT

Sheet 1 - Input data

(light green)	used in overall collision risk sheet
(yellow-green)	used in migrant collision risk sheet
(orange)	used in single transit collision risk sheet or extended model
(lavender)	used in available hours sheet
(light yellow)	used in large array correction sheet
(pink)	not used in calculation but stated for reference

	Units	Value	Data sources											
Bird data														
Species name		**Sparrowhawk**												
Bird length	m	0,34												
Wingspan	m	0,68												
Flight speed	m/sec	10,7												
Nocturnal activity factor (1-5)		1												
Flight type, flapping or gliding		gliding												

	Units	Value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bird survey data (Data sources)														
Daytime bird density	birds/sq km		0	0	0	0	0	0	0	0	0	0	0	0
Proportion at rotor height	%	46,0%												
Proportion of flights upwind	%	50,0%												
Birds on migration data (Data sources)														
Migration passages	birds		0	0	0	822	0	0	0	0	0		0	0
Width of migration corridor	km	19												
Proportion at rotor height	%	68%												
Proportion of flights upwind	%	50,0%												

	Units	Value	Data sources
Windfarm data			
Name of windfarm site		**AOWF**	
Latitude	degrees	56,65	
Number of turbines		111	
Width of windfarm	km	19	
Tidal offset	m	0	

	Units	Value	Data sources											
Turbine data														
Turbine model		**3,6 MW**												
No of blades		3												
Rotation speed	rpm	11,7												
Rotor radius	m	60												
Hub height	m	81,6	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly proportion of time operational	%		90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Max blade width	m	4,200												
Pitch	degrees	30												

		Data sources (if applicable)
Avoidance rates used in presenting results	74,00%	
	92,00%	
	99,00%	
	99,50%	

COLLISION RISK ASSESSMENT

Sheet 3 - probability of collision for single bird transit through rotor

(green)	**All input data must be entered on Sheet 1, not here**
(orange)	**However the blade profile (orange) may be revised here to match the actual turbine blades used**
(light blue)	Calculated outputs
(yellow)	Main output copied to sheet 1

Calculation of alpha and p(collision) as a function of radius

						Upwind:			Downwind:	
NoBlades	3		r/R	c/C	α	collide			collide	
MaxChord	4,20	m	radius	chord	alpha	length	p(collision)		length	p(collision)
Pitch (degrees)	30									
Species name	parrowhawk		0,00				1,000			1,000
BirdLength	0,34	m	0,05	0,73	2,90	10,47	0,575		7,41	0,407
Wingspan	0,68	m	0,10	0,79	1,45	6,44	0,354		3,13	0,172
F: flapping (0) or gliding (+1)	1		0,15	0,88	0,97	5,35	0,294		1,66	0,091
Proportion of flights upwind	50%	%	0,20	0,96	0,72	4,86	0,267		0,82	0,045
Bird speed	10,65	m/sec	0,25	1,00	0,58	4,46	0,245		0,26	0,014
Rotor Radius	60	m	0,30	0,98	0,48	4,12	0,226		0,68	0,037
Rotation Speed	11,7	rpm	0,35	0,92	0,41	3,66	0,201		0,89	0,049
Rotation Period	5,13	sec	0,40	0,85	0,36	3,24	0,178		1,01	0,055
			0,45	0,80	0,32	2,96	0,162		1,08	0,060
			0,50	0,75	0,29	2,71	0,149		1,12	0,062
Bird aspect ratio: β	0,50		0,55	0,70	0,26	2,48	0,136		1,14	0,063
			0,60	0,64	0,24	2,25	0,123		1,12	0,062
Integration interval	0,05		0,65	0,58	0,22	2,03	0,111		1,09	0,060
			0,70	0,52	0,21	1,82	0,100		1,04	0,057
			0,75	0,47	0,19	1,66	0,091		1,00	0,055
			0,80	0,41	0,18	1,47	0,081		0,93	0,051
			0,85	0,37	0,17	1,35	0,074		0,89	0,049
			0,90	0,30	0,16	1,15	0,063		0,79	0,044
			0,95	0,24	0,15	0,98	0,054		0,71	0,039
			1,00	0,00	0,14	0,34	0,019		0,34	0,019

Overall p(collision) integrated over disk

		Upwind	**11,8%**	**Downwind**	**5,3%**
Proportion upwind:	downwind				
50%	50%	**Average**	**8,6%**	(copied to sheet 1)	

COLLISION RISK ASSESSMENT								
Sheet 5 - Large array correction factor								
Do not enter data on this sheet, unless to prescribe the number of turbine rows								
All the data below is derived from Sheets 1, 2 or 3								data from Sheet 1
								data from Sheet 2
Number of turbines	111		Number of rows (optional)			4		data from Sheet 3
Rotor radius	60		*(if this is left blank, number is assumed to be sqrt(T)*					data to be entered here (optional)
Width of windfarm	19		Number of turbines in each row			27,75		calculated fields
Average proportion of time operational	0,90							
Collision risk from single rotor transit	0,086							
Assumed number of turbine rows	4,0							
Avoidance rate	74,00%	92,00%	99,00%	99,50%				
Collision risk for single bird passage, before correction	0,01105	0,00340	0,00042	0,00021				
Large array correction factor	**99,59%**	**99,87%**	**99,98%**	**99,99%**				

COLLISION RISK ASSESSMENT (BIRDS ON MIGRATION)

Sheet 2 - Overall collision risk

All data input on Sheet 1:
no data entry needed on this sheet!
other than to choose option for final tables

- from Sheet 1 - input data
- from Sheet 6 - available hours
- from Sheet 3 - single transit collision risk
- from survey data
- calculated field

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	year average
Bird details:															
Species		Sparrowhawk													
Flight speed	m/sec	10,7													
Flight type		gliding													
Windfarm data:															
Number of turbines		111													
Rotor radius	m	60													
Minimum height of rotor	m	81,6													
Total rotor frontal area	sq m	1255380													
Proportion of time operational	%		90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90,0%
Stage A - flight activity															**per annum**
Migration passages			0	0	0	822	0	0	0	0	0	0	0	0	**822**
Migrant flux density	birds/ km		0	0	0	43,263	0	0	0	0	0	0	0	0	
Proportion at rotor height	%	68%													
Flux factor			0	0	0	453	0	0	0	0	0	0	0	0	
Option 1 -Basic model - Stages B, C and D															
Potential bird transits through rotors			0	0	0	308	0	0	0	0	0	0	0	0	**308**
Collision risk for single rotor transit	(from sheet 3)	8,6%													
Collisions for entire windfarm, allowing for non-op time, assuming no avoidance	birds per month or year		**0**	**0**	**0**	**24**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**24**
Option 2-Basic model using proportion from flight distribution			**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**
Option 3-Extended model using flight height distribution															
Proportion at rotor height	(from sheet 4)	9,0%													
Potential bird transits through rotors	Flux integral	0,0128	0	0	0	6	0	0	0	0	0	0	0	0	**6**
Collisions assuming no avoidance	Collision integral	0,00089	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Average collision risk for single rotor transit		7,0%													
Stage E - applying avoidance rates															
Using which of above options?	**Option 1**	0,00%	0	0	0	24	0	0	0	0	0	0	0	0	**24**
Collisions assuming avoidance rate	birds per month or year	74,00%	0	0	0	6	0	0	0	0	0	**0,0**	0	0	**6**
		92,00%	0	0	0	2	0	0	0	0	0	0,0	0	0	**2**
		99,00%	0	0	0	0	0	0	0	0	0	0,0	0	0	**0**
		99,50%	0	0	0	0	0	0	0	0	0	0,0	0	0	**0**
Collisions after applying large array correction		74,00%	0	0	0	6	0	0	0	0	0	0	0	0	**6**
		92,00%	0	0	0	2	0	0	0	0	0	0	0	0	**2**
		99,00%	0	0	0	0	0	0	0	0	0	0	0	0	**0**
		99,50%	0	0	0	0	0	0	0	0	0	0	0	0	**0**