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Dear Kay, K-J

Please find attached the 6<sup>th</sup> instalment of documents.

Best regards,  
**Dr Dominika Chalder PIEMA**  
Environment and Consent Manager



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Hornsea Project Three  
Offshore Wind Farm



## Hornsea Project Three Offshore Wind Farm

Appendix 23 to Deadline 4 Submission  
– Welcker et al., 2017

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Hornsea 3  
Offshore Wind Farm

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Front cover picture: Kite surfer near a UK offshore wind farm © Ørsted Hornsea Project Three (UK) Ltd., 2019.



# Nocturnal migrants do not incur higher collision risk at wind turbines than diurnally active species

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Nocturnally migrating birds, particularly passerines, are known to be vulnerable to collision with man-made structures such as buildings, towers or offshore platforms, yet information with respect to wind farms is ambiguous. We recorded bird flight intensities using radar during autumn migration at four wind farms situated within a major migration flyway in northern Germany and simultaneously conducted systematic searches for collision fatalities at the same sites. We found that migration traffic rates at rotor height estimated by radar observations were significantly higher during the night, yet strictly nocturnal migrants constituted only 8.6% of all fatalities at the wind farms. In contrast to the situation at other vertical structures, nocturnal migrants do not have a higher risk of collision with wind energy facilities than do diurnally active species, but rather appear to circumvent collision more effectively.

**Keywords:** bird collision, fatalities, nocturnal migration, passerines, wind energy.

Despite the rapid development of wind energy worldwide, there is still considerable uncertainty with regard to its environmental impacts (Drewitt & Langston 2006, Northrup & Wittemyer 2013). Mortality of birds through collision with turbines is a direct consequence of wind farms and has been the focus of several studies in recent years (Marques *et al.* 2014).

The number of bird fatalities at wind facilities depends on a variety of factors. One aspect of particular importance is the siting of the turbines: the number of collisions appears to be highest at wind farms situated in areas of high bird abundance or within highly frequented flight paths of migrating or resident birds (Everaert & Stienen 2007, Ferrer *et al.* 2012, Northrup & Wittemyer 2013, Marques *et al.* 2014). In addition, there is strong evidence that the risk of collision varies substantially across species, depending mainly on their morphology and flight behaviour (Barrios & Rodriguez 2004, Hoover & Morrison 2005, Strickland *et al.* 2011).

Nocturnally migrating birds, particularly passerines, are often thought to be particularly vulnerable to collisions with wind turbines (Erickson *et al.*

2001, Strickland *et al.* 2011), perhaps because nocturnal migrants often represent the majority of fatalities at man-made structures such as buildings, communication towers or offshore facilities (Hüppop *et al.* 2006, Longcore *et al.* 2008, Arnold & Zink 2011). For example, Crawford and Engstrom (2001) showed 15 passerine families that migrate at night constituted more than 90% of fatalities at a television tower. This high collision rate is thought to be related to poorer visibility of obstacles during the night, which may be aggravated during periods of inclement weather (Avery *et al.* 1977). In addition, collision risk may further increase if structures are illuminated and, hence, attract birds (Longcore *et al.* 2008). However, evidence for an increased collision risk of nocturnal migrants at wind energy facilities is ambiguous (Johnson *et al.* 2002, Krijgsveld *et al.* 2009).

We tested the prediction that nocturnal migrants are at a greater risk of colliding with wind turbines than are diurnally active birds. We recorded the number of flight movements recorded by radar observations at four wind farms on the island of Fehmarn, Germany, during the autumn migration period and simultaneously documented the number of bird fatalities at these

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wind farms. Fehmarn, situated in the southwestern Baltic Sea, was a particularly suitable site for our study as it is located within a major migration flyway between Scandinavia and the European mainland that is frequented by several million birds each year (Berndt *et al.* 2005).

## METHODS

Data were collected between 31 August and 10 December 2009 at four wind farms at the northern part of the island of Fehmarn (54°30'N, 11°20'E). The wind farms comprised 11, 17, 21 and 25 turbines, respectively, with a maximum height of 100 m and a mean distance between turbines of *c.* 300 m. Rotor diameters ranged between 66 and 70 m. Turbines were not illuminated during the night.

To estimate the number of bird movements at the wind farms, we used two identical marine surveillance radars (10 kW, X-band, JMA-5310-6; JRC, Tokyo, Japan). The devices were operated simultaneously at two wind farms for about 2 days at a time (mean 40.0 h, range 26.6–50.2 h) and were regularly alternated between sites. Each wind farm was sampled at a regular 14-day interval throughout the study period. Radar observations were conducted independently of weather conditions and included periods of harsh weather. Rain clutter may mask bird signals, so radar data recorded during periods of rain were omitted prior to analysis (see below). In total, radars ran for about 14 days at each wind farm, collecting 1119 h of data.

The radars were placed directly outside (< 500 m) three of the four wind farms. For logistical reasons, the fourth radar site was located *c.* 3.5 km outside the fourth wind farm. Radars were tilted vertically and the beam was aligned perpendicular to the main migration direction during autumn, which was assumed to be southwesterly. The radar range was set to 1600 m. The 'target trail' function was set to 30 s afterglow. Thus, each radar signal was displayed with a trail of its positions during the past 30 s leading to characteristic bird tracks that were easy to identify. A screenshot of the radar screen was stored on a hard disk every 4 min. Later, all radar signals considered to represent a bird track were manually marked using purpose-built software (HaSoTec, Rostock, Germany) which automatically calculated the

horizontal, vertical and absolute distance of the signal to the radar.

To estimate the number of collision fatalities at the wind farms, we conducted systematic weekly line transect searches and accounted for search efficiency and carcass persistence rate. During the study period, 12 searches were conducted in all four wind farms. Searches were performed regularly every 7 days along standardized straight transects which connected the wind turbines of each wind farm. The tracks were recorded by GPS. Search effort was concentrated within 10 m of the transect line. In total, 65 wind turbines were covered by four parallel transects for each search. Due to time limitations, nine turbines of one wind farm could not be included in the carcass search effort.

To determine searcher efficiency and to correct for imperfect detection (see below), we conducted 10 search experiments with four to five observers. In each experiment, on average 25 bird carcasses were placed at different distances from the transects at different wind turbines in locations unknown to the observers. Detection probability may depend on the size (visibility) of a bird as well as the vegetation cover of the search area. Therefore, search experiments were conducted for three size classes of birds (small birds < 50 g, medium-sized birds 50–200 g and large birds > 200 g) and for three different classes of vegetation cover. The species used in search experiments were chosen to closely represent the expected species composition of fatalities. The small size category consisted of small passerines (mainly Robin *Erithacus rubecula*, finches, swallows, pipits, sparrows and warblers). Waders and thrushes (primarily Golden Plover *Pluvialis apricaria* and Blackbird *Turdus merula*) were used for trials on medium-sized birds. Search experiments on large birds were conducted with Oystercatchers *Haematopus ostralegus*, Common Buzzards *Buteo buteo* and a number of gull species.

As carcasses may disappear due to scavengers or decomposition, we additionally determined carcass persistence time by randomly placing 65 fresh bird carcasses of the three different size classes at wind turbines. A species composition similar to that in the search experiments was used in these trials, and a similar proportion of carcasses were placed at the four wind farms included in the study. The disappearance of carcasses was recorded daily for the first three days and at days 7, 10 and 14 after placement.

## Data analysis

The probability of a bird being detected by radar depends on a variety of factors (Bruderer 1997). Most importantly, detectability depends strongly on the distance from the radar. To correct for distance-dependent detectability, we applied a distance sampling approach (Buckland *et al.* 2001) as detailed in Hüppop *et al.* (2006). This was done for the two radar devices separately. We selected all radar signals between 150 and 250 m altitude for the whole range of 1600 m. At this altitude, the horizontal distribution of radar signals within the range of the radar beam was assumed to be independent of topographic or other structures that might influence flight trajectories of birds and, hence, reflects the distance-dependent detectability by the radar. Plots of all radar signals at the different sites were consistent with this assumption. Following Buckland *et al.* (2001), we determined the detection function by fitting half-normal and hazard-rate models with and without cosine series expansion up to the fifth order. The best models, based on Akaike's information criterion (AIC), were half-normal models with fourth- and fifth-order cosines series expansion for the two radar devices, respectively. Radar signal data were then corrected based on these detection functions.

Based on the corrected signals, we calculated mean migration traffic rates (MTRs – signals per km per h) for 100-m altitude bands (up to 1600 m) combined for all wind farms and observation periods. MTRs were calculated separately for each day (defined as the time period between civil twilight in the morning and evening) and each night. Only data from complete days and nights were used. To determine differences in MTR between day and night, we ran a least-squares ANOVA with time of day (day vs. night) and altitude band as explanatory variables. MTRs were log-transformed to obtain normality of data. Within the lowest 100 m altitude, bird signals were partly masked due to interference with ground structures such as trees, buildings or wind turbines. As these interferences did not vary between day and night we did not correct for lower detectability at low altitudes. The software R and the package 'Distance' were used for these analyses (R Core Team 2014, Miller 2015).

Collision mortality was estimated according to Korner-Nievergelt *et al.* (2015) using the R

package 'carcass' (Korner-Nievergelt *et al.* 2016). First, we estimated the proportion of bird carcasses that fell into the search area within 10 m of either side of the line transects. Based on the recorded search tracks and using a geographical information system, we calculated the proportion of the area that was searched for 20-m distance rings around each wind turbine (up to a distance of 160 m, the maximum distance of detected carcasses). These proportions were then multiplied by the proportion of birds found within each distance ring. The resulting proportion of birds that fell into the search area was 0.252.

Secondly, we estimated daily carcass persistence probability for the three bird size classes using survival models for right-censored data. Persistence probability may vary with time as the probability to be scavenged may be higher for fresh compared with older carcasses (Warren-Hicks *et al.* 2013). We therefore fitted a parametric survival model with a Weibull error distribution allowing for time-dependent removal probability and compared it with an exponential model assuming constant removal probability using a likelihood ratio test (LRT). As the Weibull model did not significantly decrease deviance (LRT,  $df = 1$ ,  $P = 0.14$ ), we used the exponential model to estimate daily persistence probability. To determine searcher efficiency, we used a generalized linear model with a binomial error distribution as implemented in the function 'search.efficiency' of the R package 'carcass'. Searcher efficiency was estimated separately for the different bird size and vegetation cover categories.

Finally, we used the function 'estimateN' (Korner-Nievergelt *et al.* 2016) to estimate the number of collision fatalities based on estimates of persistence time, searcher efficiency and the proportion of birds falling into the search area. As the search area was defined as a 10-m strip on both sides of the transects, carcasses found accidentally outside the strip width were removed from the dataset prior to estimating total collision fatalities. In addition, birds that were dead for more than 7 days at the first carcass search were omitted (Table 1). The function 'estimateN' is based on Bayes' theorem with a uniform prior distribution and returns the median of the posterior distribution. This approach takes into account the randomness of the count process (carcass searches) and the uncertainty of the estimates of persistence time and

**Table 1.** Number of bird fatalities found at four wind farms on the island of Fehmarn, Germany, in autumn 2009. The total number of carcasses (including accidentally found remains) and the number of carcasses found on standardized transects are given (see Methods for details). In addition, the estimated number of fatalities after accounting for experimentally determined search efficiency and carcass persistence time and the estimated total number of fatalities at the four wind farms are given. The Goldcrest *Regulus regulus* was the only strict nocturnal migrant found during the study period (highlighted in bold text).

Species	Number of fatalities		
	Found	Transects	Estimated total
Mallard <i>Anas platyrhynchos</i>	2	2	11
Common Eider <i>Somateria mollissima</i>	1	1	6
Osprey <i>Pandion haliaetus</i>	1	0	0
Red Kite <i>Milvus milvus</i>	1	0	0
Common Buzzard <i>Buteo buteo</i>	4	2	11
Moorhen <i>Gallinula chloropus</i>	1	1	8
Golden Plover <i>Pluvialis apricaria</i>	3	2	14
Black-headed Gull <i>Larus ridibundus</i>	9	7	32
Common Gull <i>Larus canus</i>	3	2	11
Herring Gull <i>Larus argentatus</i>	15	8	37
Feral pigeon <i>Columba livia domestica</i>	1	1	8
Wood Pigeon <i>Columba palumbus</i>	2	1	11
Collared Dove <i>Streptopelia decaocto</i>	1	1	8
Bank Swallow <i>Riparia riparia</i>	3	1	18
Barn Swallow <i>Hirundo rustica</i>	3	2	28
House Martin <i>Delichon urbicum</i>	7	6	69
<b>Goldcrest <i>Regulus regulus</i></b>	<b>2</b>	<b>2</b>	<b>28</b>
Rook <i>Corvus frugilegus</i>	1	1	6
Tree sparrow <i>Passer montanus</i>	1	1	18
Total	61	41	265 <sup>a</sup>

<sup>a</sup>The total number of collision fatalities does not correspond to the sum of the estimated fatalities of all species. See Methods for details.

searcher efficiency (Korner-Nievergelt *et al.* 2011). Differences in searcher efficiency depending on vegetation cover were incorporated by estimating fatalities separately for each vegetation class and then calculating the weighted average based on

the proportion of search effort within each vegetation class.

To compare the number of fatalities of nocturnal migrants and diurnally active species, we estimated the number of casualties for each species found. To determine the total number of collision fatalities during the study period (fatalities per wind turbine), we re-ran the analysis based on all carcasses found per bird size class. This was done because a simulation study has shown that the relative error of fatality estimates based on small numbers of detected carcasses (single species) is large and that sums of these estimates will overestimate the total number of fatalities at the level of whole wind farms (Korner-Nievergelt *et al.* 2011, 2015).

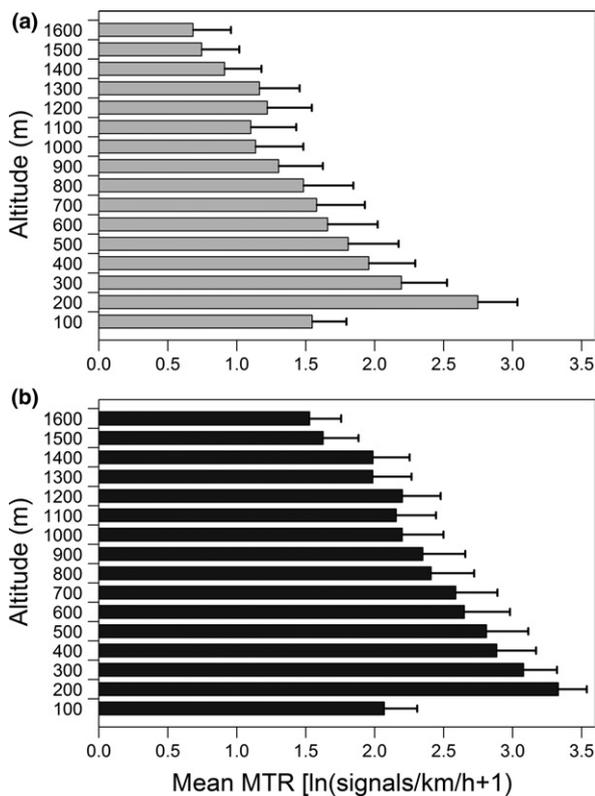
## RESULTS

Mean MTR was significantly higher during the night than during the day (ANOVA  $F_{1,624} = 69.2$ ,  $P < 0.001$ ) and varied significantly with altitude ( $F_{15,624} = 5.8$ ,  $P < 0.001$ ). The difference between day and night was similar at all altitudes (Fig. 1; ANOVA  $F_{15,624} = 0.1$ ,  $P = 1.0$ ). Within rotor height (< 100 m), mean MTR during the day (4.70 signals/km/h) was 40.7% lower than during the night (7.93 signals/km/h; Fig. 2).

During the study period, 61 individual birds belonging to 19 species were found dead at the four wind farms (Table 1). Corrected for search efficiency, persistence time and the proportion of carcasses that fell into the search area, this corresponded to an estimated total of 265 fatalities, or 4.1 casualties per wind turbine during the study period. Of the species found, the Goldcrest *Regulus regulus* was the only strictly nocturnal migrant, constituting (after correction) 8.6% of all fatalities or 17.4% of all passerines. Thus, the theoretical risk of collision, expressed as the ratio between flight activity (MTR) at rotor height and the number of estimated casualties, was 19.4 times higher for diurnally active species than for nocturnal migrants.

## DISCUSSION

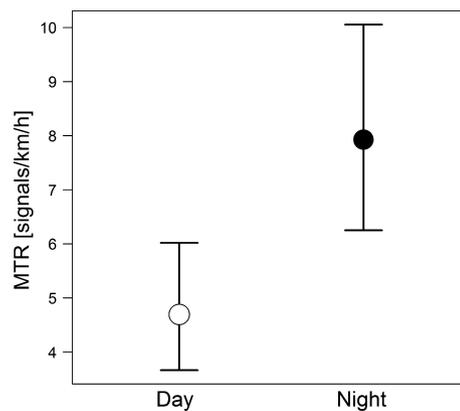
In contrast to our expectation, nocturnally migrating birds represented a low proportion of the estimated total number of collision fatalities despite the fact that estimated bird flight activity was higher during the night than the day. Our



**Figure 1.** Mean migration traffic rates (MTR – signals/km/h, log-transformed  $\pm$  se) at four wind farms on the island of Fehmarn, Germany, during autumn 2009. MTRs are given for 16 100-m altitude bands. (a) MTRs during the day (time period between civil twilight in the morning and evening). (b) MTRs during the night. Note that MTR within the lowest altitude band (100 m) was underestimated due to interference of the radar with ground structures (see Methods for details).

estimates of diurnal and nocturnal MTRs were based on surveillance radar observations. The spatial resolution of these devices is not sufficient to distinguish between a single individual and a small flock of birds (Fijn *et al.* 2015). As diurnal migrants tend more often than nocturnal migrants to migrate in flocks (Berthold *et al.* 2003), our estimates of diurnal MTRs may be biased towards low values and the true difference between diurnal and nocturnal MTRs may be smaller than our data suggest.

Surveillance radar signals do not allow the distinction between species. A large body of literature shows that the species composition of nocturnal migrants in the western Baltic Sea is dominated by some of the most numerous Scandinavian passerines, such as Willow Warbler *Phylloscopus trochilus*, Robin, Goldcrest, Common Redstart *Phoenicurus*



**Figure 2.** Mean migration traffic rates (MTR – signals/km/h,  $\pm$  se) during the day and night at an altitude of between 0 and 100 m at four wind farms on the island of Fehmarn, Germany, during autumn 2009. Means and se were calculated on log-transformed data.

*phoenicurus* and several thrush species (mainly Redwing *Turdus iliacus*, Song Thrush *Turdus philomelos* and Blackbird) (Zehnder & Karlsson 2001, Nilsson *et al.* 2014). In line with our results, it has also been shown by a number of studies that a high percentage of nocturnal migration activity often occurs within the lowest 100–300 m of altitude (Zehnder *et al.* 2001, Hüppop *et al.* 2006, Fijn *et al.* 2015). Assuming a high collision risk of nocturnal migrants, we would therefore expect that fatalities in our study will be dominated by this species group. However, with the exception of the Goldcrest, we did not find strictly nocturnal migrants as collision fatalities. Instead, the species composition was dominated by diurnal migrants, staging and/or resident birds such as gulls, raptors and swallows, which in total constituted 91.4% of estimated fatalities.

Behavioural differences between resident and nocturnally migrating birds may lead to substantial differences in the collision risk of an individual. For example, a swallow foraging in the vicinity of a wind turbine may incur a higher risk of collision than does a nocturnal migrant passing through the wind farm only once. However, such behavioural differences are reflected in our estimates of flight activity and consequently do not explain the low collision risk of nocturnal migrants in our study. Our estimates of MTR were not based on individual birds but on the sum of flight paths through the radar beam per time. Thus, actively foraging birds were recorded by the radar in proportion to their flight activity at the wind farms.

For the difference in the number of fatalities between nocturnal and diurnal species to be meaningful, it is essential to exclude the possibility of a bias in estimating these numbers. A potential bias may arise due to systematic differences in body size. The majority of expected nocturnal migrants at the study site are small to medium-sized passerines (e.g. warblers and thrushes, respectively), whereas diurnally active species may to a greater extent include large species such as ducks, gulls and raptors. We therefore took body size into account when estimating disappearance rate and search efficiency and, ultimately, the total number of fatalities. In addition, we carefully selected the species used in these experiments to reflect closely the expected species composition of fatalities at the study site. Hence, we are confident that our estimates of disappearance rate and search efficiency are realistic, including for small species such as the Goldcrest.

A bias may also arise if the probability of carcass disappearance of nocturnal migrants is higher during the first hours after collision compared with diurnal species, for example due to high activity of nocturnal scavengers. However, our data do not support this view. During disappearance experiments, only 7.7% of carcasses were removed during the first 24 h (comparable with 13.8% during the following 48 h) and models allowing for time dependence of disappearance rate did not fit the data better than constant models. This strongly suggests that our estimates of search efficiency and disappearance rate were unbiased and hence may not explain differences in collision fatalities between nocturnal migrants and diurnal species.

Several different statistical approaches have been used to estimate collision fatalities (Korner-Nievergelt *et al.* 2011, Bernardino *et al.* 2013, Péron *et al.* 2013, Warren-Hicks *et al.* 2013) and the outcome may vary with the method used. Yet, as stated above, there is no indication in our data that factors affecting the detection probability of carcasses vary systematically between nocturnal and diurnal birds at our study site. Hence, these two species groups have to be treated similarly independent of the statistical approach and, consequently, the effect of the statistical approach on relative differences between groups is likely to be minor.

Even though nocturnal migrants are often considered to be particularly vulnerable to collisions

with wind turbines (Strickland *et al.* 2011), there is little evidence so far to support this. The only other study known to us that combined data on bird flight activity and systematic carcass searches estimated the collision risk of nocturnal migrants (27% of fatalities) to be an order of magnitude lower than that of diurnally active and resident birds (Krijgsveld *et al.* 2009). Data from collision fatality studies indicate that the proportion of nocturnal migrants may vary substantially across sites. In a review of nine studies of systematic carcass searches in the USA, nocturnal migrants constituted only between 0 and 33% (Erickson *et al.* 2001). Similarly, Grünkorn *et al.* (2009) found this group of species to be absent among fatalities in northern Germany. However, Johnson *et al.* (2002) reported that 71% of all fatalities over 4 years at wind farms in Minnesota, USA, were of nocturnally migrating passerines.

These findings suggest that nocturnal migrants are not generally more susceptible to collisions with wind turbines compared with diurnally active birds, but at least at some sites they may be able to elude collisions more effectively (Krijgsveld *et al.* 2009). Hence, results from studies of bird collisions with other anthropogenic structures such as buildings, towers or offshore platforms (Longcore *et al.* 2008) that usually find a high risk of collision of nocturnal migrants do not necessarily reflect the situation at wind facilities.

The reason for the apparent difference in collision risk of nocturnal migrants with wind turbines and other vertical structures remains unknown. Possible explanations may involve differences in illumination or a potentially better capability of birds to perceive wind turbines at night due to movement of rotors and their sound emission. It is well known that lit structures may constitute a hazard to nocturnal migrants (Evans Ogden 1996, Longcore *et al.* 2008, Loss *et al.* 2015), with collision risk often depending on the respective illumination scheme (Jones & Francis 2003, Gehring *et al.* 2009). At our study site, wind turbines were not illuminated, which may have contributed to the low number of casualties of nocturnal migrants (Kerlinger *et al.* 2010).

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