Pink-footed Goose and Common Crane exhibit high levels of collision avoidance at a Danish onshore wind farm

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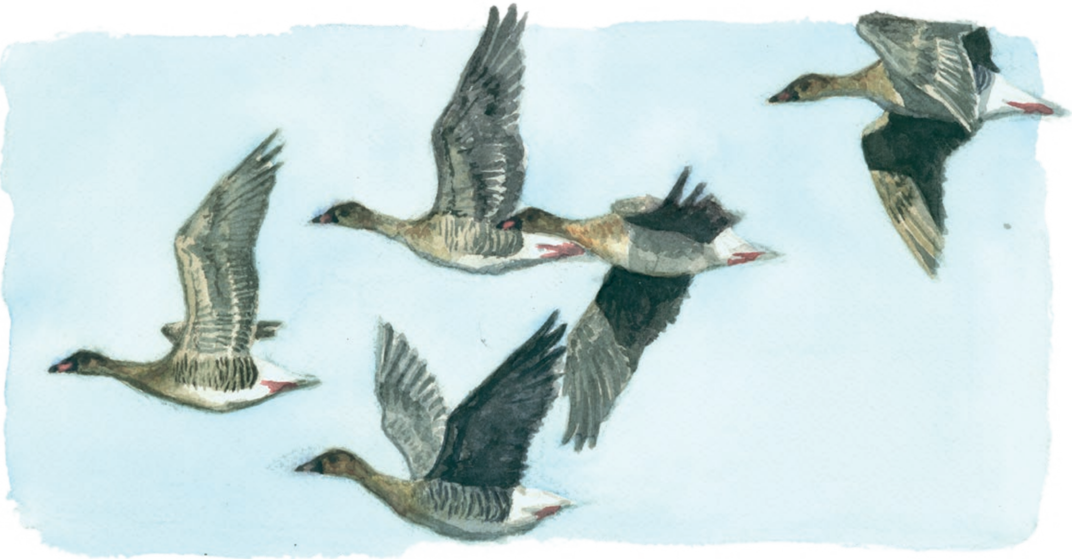

(Med et dansk resumé: Kortnæbbet Gås og Trane udviser stor evne til at undvige kollision med vindmøller i en dansk vindmøllepark)

Abstract A wide range of bird species are reported to collide with the towers and the moving blades of wind turbines, and their susceptibility to collision is related to morphological and behavioural traits. The collision risk of individual birds depends among other behavioural traits on their avoidance rate, which takes into account the proportion of birds likely to avoid a collision. Our study investigated the collision risk and avoidance rates of Pink-footed Goose *Anser brachyrhynchus* and Common Crane *Grus grus* at a wind farm at Klim Fjordholme, Denmark. Detailed studies of the two species and their behaviour were conducted at the windfarm at one and three years after construction. The number of annual fatal collisions of Pink-footed Goose with the turbines was estimated at 10-17 individuals in year 1 and 35-58 in year 3. No fatal collisions of Common Crane were recorded during the two study years. Avoidance rates of the two species were inferred using the Band model. The inferred avoidance rates for Pink-footed Goose were 99.92-99.95% and 99.81-99.88% for year 1 and 3, respectively, and for Common Crane were 99.93-100% and 99.88-100% for the two years, respectively. Both species thus showed very high avoidance rates at the wind farm, but the two species exhibited different avoidance strategies. Pink-footed Geese avoided collisions mainly by avoiding the entire wind farm, while Common Cranes were observed to be able to avoid individual turbines during movements within the wind farm area.

Introduction

During the last two decades, wind power installations have increased steadily across Europe (Pineda & Tardieu 2018). Due to climate change and the corresponding demands for reduction in the emission of greenhouse gases, this increasing trend is likely to continue in the coming years because wind energy is renewable and has relatively limited CO_2 emissions. The negative impacts of both onshore and offshore wind farms on birds are widely discussed and of global concern (Langston & Pullan 2003, Dai *et al.* 2015, Wang *et al.* 2015, Smith & Dwyer 2016). The topic of bird collisions at wind turbines is considered to be of particular importance, but wind farms may also cause displacement of foraging birds and act as barriers for dispersing and migrating birds (Masden *et al.* 2009, Marques *et al.* 2014, Smith & Dwyer 2016, Marques *et al.* 2020).

Birds have been found to collide both with the towers and the moving blades of wind turbines (Krijgsveld *et al.* 2009). A wide range of species are reported to collide with wind turbines (Dürr 2020), with susceptibility to collision being linked to morphological and behavioural traits (Smallwood *et al.* 2009, Marques *et al.* 2014). Avian mortality rates due to collisions vary widely between wind farms, ranging from small numbers of deadly collisions (De Lucas *et al.* 2008), which are not expected to affect population size, to higher numbers that possibly affect local population persistence (Hunt & Hunt 2006, Everaert & Stienen 2007). However, even low rates of mortality might have significant consequences at population levels in the case of *K*-strategists like vultures (Carrete *et al.* 2009) or for species of high conservation concern.

During environmental impact assessment (EIA) studies of wind farms, estimates of the number of collisions between birds and turbines are often predicted using collision risk models (CRMs; Masden & Cook 2016). CRMs are used to assess the potential impacts of wind turbines on birds (Masden & Cook 2016). These models require data on bird and turbine characteristics, including bird flight parameters such as flight height and flight speed, and turbine specifications such as rotor speed and turbine size. Several of the input parameters for CRMs, like dimension of the applied turbines and morphological aspects of the bird species of concern, are given in advance. However, bird flight parameters, such as flight height, flight speed and flight activity within the wind farm area, need to be measured or estimated by field studies at each wind farm. Collision estimates from CRMs are sensitive to input of bird flight parameters (Chamberlain *et al.* 2006, Douglas *et al.* 2012) and it is therefore vital to ensure accurate and robust estimation of flight parameters during data collection for EIAs. Flight speed data can be obtained from existing values in the literature (e.g., Bruderer & Boldt 2001, Alerstam *et al.* 2007), but on site measurements will be preferable when applying CRMs in EIAs.

A variety of CRMs have been developed to predict avian collision risk at wind turbines (Masden & Cook 2016). In Denmark, the UK and elsewhere, however, the model developed by Band *et al.* (2007) remains the standard method for predicting collision rate for a range of bird species at proposed wind farm sites. This model was developed to enable calculation of the expected collision risks in wind farms based on baseline monitoring of flight activity of birds prior to construction of a wind farm (Scottish Natural Heritage 2000, Band *et al.* 2007, NatureScot 2021a, 2021b).

Among other behavioural traits, the collision risk of individual birds depends on their avoidance rate which takes into account the proportion of birds likely to actively avoid a collision (Masden & Cook 2016). When applying the Band model, the predicted collision rate is highly sensitive to the avoidance rate of birds on a path of potential collision. Small variations in avoidance rates result in relatively large changes in predicted collisions, and the effect of variation in avoidance rate is far higher than any other variable in the CRM (Chamberlain *et al.* 2006). Therefore, the accuracy of the Band model in determining actual collision risk depends greatly on the application of reliable avoidance rates obtained from monitoring of existing wind farms (Chamberlain *et al.* 2006, Madders & Whitfield 2006, Band *et al.* 2007).

During 2016-2019, we investigated the collision risk and avoidance rates of Pink-footed Goose *Anser brachyrhynchus* and Common Crane *Grus grus* at a wind farm at Klim Fjordholme in the northern part of Jutland, Denmark. The wind farm was repowered from 35 smaller to 22 larger turbines in 2015 and is located next to the Special Protected Area (SPA) Vejlerne, where large numbers of Pink-footed Geese stage and forage, and where both staging and breeding Common Cranes occur in high numbers. In an assessment of the potential impact of the repowering of the wind farm on birds, Pink-footed Geese and Common Cranes were identified as being at risk of having their local populations adversely affected (Kahlert *et al.* 2010). Detailed studies of the two species and their behaviour were therefore conducted at the wind farm one and three years after the construction of the new and larger turbines (Drachmann *et al.* 2020).

The post-construction study of the flight behaviour of Pink-footed Goose and Common Crane was conducted with the currently best available survey methods using a combination of radar surveys, transect counts and bird flight measurements by laser rangefinder. The numbers of fatal collisions of Pink-footed Goose and Common Crane at the wind farm were derived from carcass surveys. Based on these survey data, we used the Band model to infer the avoidance rates of the two target species. The purpose of our current paper was 1) to document species-specific avoidance behaviour in the two species and 2) quantify avoidance rates of the two species.

Material and methods

Study species

The Pink-footed Goose breeds in East Greenland, Iceland and Svalbard. The breeding population from Greenland and Iceland winters in Scotland and England, while the

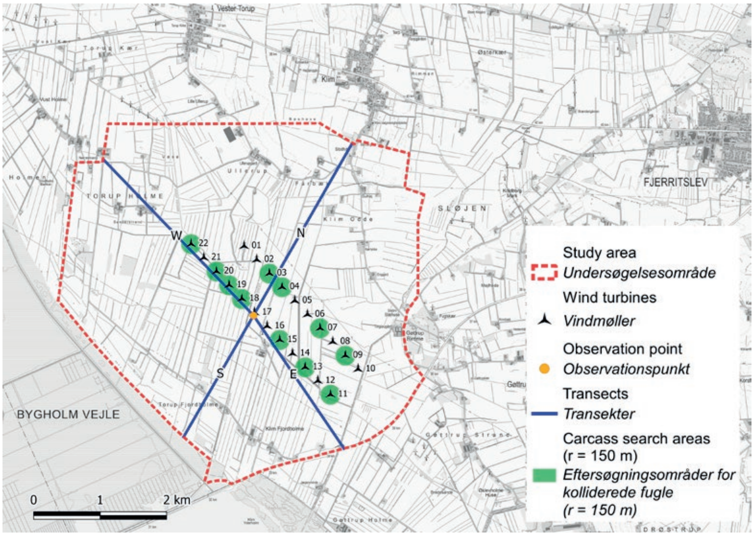

Fig. 1. The study area at Klim Fjordholme showing the wind turbines, the observation point and the four transects used during registration of flight activity of Pink-footed Goose and Common Crane. The 11 turbines searched for dead birds due to collisions are indicated by green circles and labelled with turbine number. *Undersøgelsesområdet ved Klim Fjordholme med angivelse af vindmøllerne, observationspunktet og de fire transekter anvendt ved registrering af flyveaktiviteten af Kortnæbbet Gås og Trane. De 11 møller, der blev eftersøgt for kollisionsdræbte fugle, er markeret med grønne cirkler.*

breeding birds from Svalbard winters in Denmark, The Netherlands and Belgium. The number of Pink-footed Geese wintering in the Special Protected Area (SPA) Vejlerne adjacent to the wind farm study area has increased in recent years from 5500 individuals in 2010 to 24 000 in 2019 (H.H.N. pers. obs.). The Pink-footed Geese staged within our study area from September to March in the two study years and utilised Bygholm Vejle (see Fig. 1) as the night roost in both years.

The number of breeding Common Cranes in Denmark has increased in recent years, with the current Danish breeding population estimated at around 500 pairs (Vikstrøm & Moshøj 2020). The breeding population within Vejlerne has increased from 4-6 pairs in 2009 to 15 pairs in 2019, and hundreds of Common Cranes roost within Vejlerne and the adjacent agricultural landscape outside the breeding season from February to November. During June and July, approximately 50 non-breeding Common Cranes were observed foraging and roosting in Vejlerne and the surrounding landscape during our study periods (H.H.N. pers. obs.).

Study area and period

The wind farm at Klim Fjordholme (57°3′ N, 9°8′ E) consisted of 22 3.2 MW turbines with a hub height of 93 m, a rotor diameter of 113 m and a total height of 149.5 m. The flight activity and behaviour of Pink-footed Goose and Common Crane were studied within an area of 23.16 km² that encompassed the wind farm (Fig. 1). The studies were conducted during the operational phase of the wind farm one year (year 1: August 2016 - May 2017) and three years (year 3: August 2018 - May 2019) after construction of the wind farm. The flight behaviour of the two species was not investigated during the summer months June and July. During these months Pink-footed Geese did not occur in the area, and the collision risk of Common Cranes was assessed to be low during the summer when, compared to outside the breeding season, only small flocks of non-breeding Common Cranes occurred within the study area.

Carcass searches and field experiments

To estimate the annual numbers of Pink-footed Goose and Common Crane killed by collision with the turbines, systematic searches for carcasses of the two species were conducted at 11 turbines during both year 1 and 3. The 11 turbines were selected to cover most of the wind farm, but lack of permission by a few landowners constrained searching some fields (Fig. 1). Using fixed GPS locations, a carcass search area of 70 686 m² (radius = 150 m) below each of the selected turbines was systematically searched for carcasses of Pink-footed Goose and Common Crane. The search at each turbine was conducted by walking in a spiral from the tower and out to the outer perimeter of the search area. The detailed search pattern was adapted according to the landscape and vegetation height. For instance, at a few turbines, large ditches had to be crossed to cover the entire search area, and this influenced the search pattern. All turbines were situated on agricultural fields, and at most of the searched turbines the vegetation height was low (i.e. < 20 cm). However, at four turbines the vegetation height was relatively high (i.e. 20-50 cm) within the whole or part of the search area during autumn in both study years. During searches in high vegetation, the spiral search pattern was combined with star-shaped searches out from each circle around the turbine tower in order to thoroughly cover the search area.

The search radius of 150 m was equal to the maximum tip height of the rotor blades, and this is the standard range within which collision victims can be expected (Kunz *et al.* 2007). Based on ballistics theory, Hull & Muir (2010) described the fall zone of birds of various sizes after colliding with different sized turbines. Their results show that large birds (i.e. Wedge-tailed Eagles *Aquila audax*) will fall within a radius of 135 m when colliding with large turbines (i.e. hub height of 94 m and a rotor diameter of 112 m). Therefore, it was very unlikely that Pink-footed Geese and Common Cranes that were victims of collision would fall outside of our search radius of 150 m, and consequently we did not correct for possible collision victims outside the search circle.

In year 1, carcass searches were conducted every three days during three periods in autumn (9 September - 12 October), winter (27 December - 29 January) and spring (13 March - 15 April), amounting to 12 searches per period. In year 3, carcass searches were conducted every three days in autumn (1 October - 3 November) covering 12 searches in that period. During winter (15 December - 18 January) and spring (7 March - 10 April), the frequency of carcass searches was increased to every other day due to more available manpower i.e. 18 carcass searches per period. The standardised searches were conducted in all types of weather conditions, and hence did not exclude periods with low visibility and potential high collision risk.

For each carcass encountered during the searches, we recorded species, age, sex, GPS location and type of remains found. Most of the records consisted of feathers or other remains from dead birds scavenged by predators, so most carcasses of geese could be identified only to genus level. The few complete carcasses found during the searches were collected and stored at -18 °C in a freezer for further analysis.

Carcass searches were not expected to effectively detect every bird killed by the turbines because some carcasses may have been removed by scavengers and others may have been overlooked by the searchers. Correction factors for persistence time of the carcasses and search efficiency of the searchers were experimentally determined by placing test carcasses of wild geese in the field. The test carcasses used in the experiments were individuals of Pink-footed Goose, Greylag Goose *Anser anser*, White-fronted Goose *Anser albifrons* and Barnacle Goose *Branta leucopsis* shot and provided by local hunters. All carcasses were stored in a freezer until their use in the field experiments.

When conducting experiments on searcher efficiency and scavenging rates, it is important to use carcasses that are as close as possible to the target species, since carcass species and size can strongly influence scavenging rates and detectability for the searchers (Borner *et al*. 2017, DeVault *et al.* 2017).

Scavenging rates

All wind-energy facilities will potentially be inhabited by a variety of avian and mammalian scavengers. Therefore, a field experiment designed to estimate the scavenging rates at Klim Fjordholme was conducted in year 1 after the construction of the wind farm. In order to avoid attracting scavengers to the wind farm area, the scavenger experiments were conducted at a comparable agricultural habitat 3.5 km southeast of the wind farm. Both the wind farm area and the experimental area were dominated by agricultural fields with crop types of a height of less than 20 cm during the field work, and in both areas agricultural machinery was regularly in use for common activities. There were no regular hunting activities either in the experimental area or in the vicinity of the searched turbines.

In the experimental area, we placed 50 goose carcasses in autumn (3-8 October 2016), 36 carcasses in winter (18-23 January 2017) and 49 carcasses in spring (3-8 April 2017). Each carcass was individually marked, placed in the study area with at least 40-50 m between carcasses, and the GPS location was recorded. In each of the three experiments, all carcass locations were subsequently checked every day during the following six days, and the state of the carcasses were recorded on a scale from 0-5 (0 = intact, 1 = 0-25% of the carcass removed, 2 = 26-50% of the carcass removed, 3 = 51-75% of the carcass removed, 4 = > 75% removed and 5 = the carcass was removed). Additionally, the type of scavenger was recorded if it could be discerned from tracks and signs at the carcass location.

When scavengers left feathers or other remains of a carcass within the wind farm area, these findings would always be judged by the searchers to be a potentially turbine-related fatality. Therefore, during the analysis of the scavenger experiments, only carcasses that were removed without leaving behind any signs of the carcass (i.e. going from intact (0) to completely removed (5) between visits) were recorded as being missed by the searchers.

To compare the scavenging rates between the experimental study area and the wind farm area, two scavenger experiments were conducted in both areas in December 2017. During 4 -10 December, two experiments each with 40 goose carcasses were thus conducted simultaneously in the two areas following the same protocol as in the previous scavenger experiments.

Searcher efficiency

The standardised searches at the wind farm for carcasses were performed by two experienced observers. It is well-known that searcher efficiency or observer detection (i.e. the rates at which searchers detect carcasses) varies among individuals (Morrison *et al.* 2001). Therefore, searcher efficiency of the two observers was tested by three carcass experiments within the wind farm area during year 1.

In each experiment, five to ten fresh test carcasses of either Pink-footed Goose or Greylag Goose were placed randomly within the eleven carcass search areas. All test carcasses were individually labelled and placed by an independent field assistant who did not take part in the standardised searches. Prior to the standardised searches, the assistant placed the test carcasses and recorded their GPS position during the night at dates unknown to the searchers to be tested. The searchers were thus unaware of the position and number of placed carcasses, as well as the timing of the occurrence of test carcasses within the wind farm area. The three experiments were conducted on 24 September 2016 (N = nine Greylag Geese), 10 January 2017 (N = six Greylag Geese and three Pink-footed Geese) and 2 April 2017 (N = seven Greylag Geese and two Pink-footed Geese). When encountered during the searches, the searchers could easily recognise the test carcasses by the label used to mark the individual geese.

Number of fatal collisions

The total number of fatal collisions per turbine (F) of Pink-footed Goose and Common Crane at the wind farm during the carcass searches was estimated by the formula $F = (N / Sp * S_o) / T$ (Kahlert *et al.* 2010), where N was the number of collision-killed birds recorded, S_p the probability of scavengers removing carcasses between two searches, S_o the probability of searchers finding killed birds, and T the number of turbines searched for fatal collisions.

Due to lack of suitable carcasses, experiments on scavenging rates and searcher efficiency could not be repeated in year 3. The correction factors for persistence time of carcasses (S_p) and searcher efficiency (S_o) were therefore solely based on the experiments conducted in year 1.

Flight activity and altitude

To estimate the theoretical collision risk of Pink-footed Goose and Common Crane at the wind farm, the intensity of diurnal and nocturnal movements of the two species was monitored within the study area. Periods of intense flight activity during dawn and dusk were included as part of the diurnal flight activity. A number of methods complemented each other to give a detailed account of the diurnal flight activity. Radar surveys were particularly useful during the morning and evening periods when the geese dispersed between the survey area and their feeding areas in large numbers and high intensity during a short time. Transect crossing counts gave more reliable results during daytime between those two periods. The two methods were supplemented with range-finder altitude measurements enabling calculation of the proportion of birds that occurred within the altitude span of the rotor-swept area. In total, 1087 and 638 flight altitude measurements of Pink-footed Goose were performed in year 1 and 3, respectively. For Common Crane, 401 and 295 flight altitude measurements performed regularly during the field days throughout the seasons were recorded during year 1 and 3, respectively. Additionally, the range finder enabled rangefinder tracking of individual birds and small flocks.

The flight activity of Pink-footed Goose during a full day was calculated using radar data for the inbound and outbound periods and transect crossing count data for the period in between. The flight activity for Common Crane was calculated from transect crossing count data alone.

Transect crossing count surveys

Transect crossing count surveys were performed to monitor the flight intensity of Pink-footed Goose and Common Crane during daytime. The survey followed a method developed for monitoring of flight intensity of geese in wind farm areas (Waagner 2014) to be used as an alternative to vantage point counts. During vantage point counts, the observer may miss more than half of the passing birds within a radius of 3 km due to the observer's inability to be vigilant in all directions at any particular time (Laubek *et al.* 2009).

Flight intensities were recorded at the four transect lines shown in Fig. 1. One observer equipped with binoculars and telescope performed 15-minute counts repeatedly at the four transects, one at the time, during all day. All birds that crossed the transect line in either direction, left or right, were recorded. Distant birds outside the study area were not recorded. The flight activity at the four transects were combined to give a measure of the total flight activity within the survey area expressed as number of bird flights per hour.

Transect crossing counts were performed during autumn to spring in both of the two survey years. The number of 15-minute transect crossing counts conducted in year 1 and 3 was 581 and 631, respectively. In year 1, 22 days of counts were performed during 23 August 2016 - 20 April 2017. In year 3, 23 days of counts were performed during 21 August 2018 - 29 April 2019.

The flight activity expressed as number of bird flights per hour was calculated for each species. The flight activity for Pink-footed Goose was assessed to be zero during the summer season when the species did not occur in the area. The field survey did not cover the whole year and it was therefore assumed that the flight activity of Common Crane during summer was equivalent to the observed flight activity in April and August.

Radar surveys

Movements of birds in and around the survey area were monitored and registered by horizontal radar. The primary strength of the radar survey was that it enabled recording of the precise geographical location of flying birds and flocks of birds that could be detected at larger distances compared to direct visual observations while it was also possible to record many flocks of birds that moved through the survey area simultaneously. A field observer that identified species and counted the number of individuals in the flocks of birds aided the radar observations. The radar surveys were performed during periods with high visibility, i.e. without fog, to enable species identification of the observed birds.

We used a 25 kW X-band radar of the type Furuno FAR-2127 BB with an 8″ antenna for the survey. Bird tracks, including data such as time, species and number of birds, were stored on a computer using geographic information system (GIS) software. Radar surveys were performed from before sunrise to after sunset for seven days during 3 October 2016 - 20 April 2017 in year 1. In year 3, six days of radar surveys were performed during 12 October 2018 - 8 April 2019.

The recorded tracks were categorised as inbound, outbound, or foraging tracks. Inbound tracks were defined as tracks of birds that dispersed from night roosting areas to foraging areas at dawn. Outbound tracks were birds that moved in the opposite direction at dusk. The intervening tracks were defined as foraging tracks.

Based on the recorded tracks of geese, the day was divided into three periods. The inbound period was defined as the period when at least 90% of the geese had dispersed from the night roost areas. The outbound period was defined as the period in the evening when at least 90% of the geese had returned to the night roost areas. The foraging period was the remaining middle of the day. The distinction between the three subdivisions of the day was to enable the use of different data sets to better quantify the diurnal flight activity within the study area during different periods of the day.

The nocturnal flight activity of geese and Common Crane was monitored by radar at six nights in year 1 during 3 October 2016 - 30 March 2017. The radar operator observed potential tracks of geese and Common Crane during the whole night and listened for bird calls if tracks were identified near the radar. Nocturnal monitoring was omitted in year 3, because it was evident after year 1 that the nocturnal activity of the two target species was insignificant in the study area.

Measurements of flight altitude and range-finder tracking

Measurements of the flight altitude of birds was necessary to calculate the proportion of birds that occurred within the altitude span of the swept area of the wind turbine blades.

Flight altitudes were measured with a Safran Vectronix Vector 21 Aero range finder. Data output from the range finder was used to calculate the geographical position of the measured birds in addition to their flight altitude. When two or more measurements of the same birds were performed, it was possible to convert the data into flight tracks. The use of a range finder effectively tracked individuals or small flocks of birds within a range of a few kilometres and was used as a supplement to the radar surveys, which was more efficient for tracking larger flocks of birds at greater distances. Additionally, the observer performed single measurements of flight altitude with the range finder as often as possible during the days with transect counts so as to gather as many altitude measurements as possible.

The Band model and its application

Two standard approaches may be used to calculate the flight activity in a study area when applying the Band model (Scottish Natural Heritage 2000). The first approach can be used for birds that perform regular flights through a wind farm. In this approach, the fact that the flight direction of the birds is regular and predictable is utilised to simplify the method used to record flight activity. The flight activity is expressed as an estimate of the number of birds that fly through a two-dimensional

At 22 large wind turbines in North Jutland, no Common Cranes and only a few tens of Pink-footed Geese were killed annually during two study years in spite of large numbers of birds passing the turbines. Photo: Henrik Haaning Nielsen.
Ingen Traner og kun få Kortnæbbede Gæs blev dræbt årligt ved Klim-møllerne.

vertical cross-section oriented perpendicular to the general flight direction. The method is, however, not applicable for birds that move irregularly within the study area, such as Common Cranes and Pink-footed Geese did during the foraging periods in our study. The second approach is most appropriate when there is some understanding of the likely distribution of flights within the study area, i.e. when data for the three-dimensional distribution of birds within the study area is available. The field surveys for our study were planned and performed specifically to obtain such data. Contrary to the first approach, the second approach may be applied regardless of whether the birds fly in straight lines or irregularly within the study area.

The Band model is based on the assumption that the number of birds colliding with turbines is defined by the number of birds flying through the volume swept by the turbine blades, the probability that a bird will collide with the rotor blades when flying through the rotor, and the avoidance rate. The avoidance rate for a given bird species is the percentage of individuals that actively avoid flying into the volume of air swept by the rotor when comparing the flight pattern in the wind farm area before and after construction of the turbines. During the calculations of theoretical collision risk assuming no avoiding action, it was assumed that the flight activity of the birds observed before construction of the turbines was distributed evenly within the airspace above the study area in the altitude span of the rotors of the turbines.

The calculations of theoretical number of collisions assuming no avoiding action were based on three primary data sets and calculations:

The observed flight activity in the study area based on field monitoring (Scottish Natural Heritage 2000, Band *et al.* 2007).

Calculations on the theoretical numbers of birds flying through the turbine rotor sweep area based on the observed flight activity and a series of physical parameters, including the size of the study area, the number and size of the wind turbines (Scottish Natural Heritage 2000, Band *et al.* 2007).

The risk of a bird colliding with the rotor when flying through the swept area, which is calculated using parameters such as the size and flight speed of the bird and the physical and technical parameters for the wind turbines (NatureScot 2021b).

In our case, the actual number of collisions was derived from the carcass surveys and supporting field experiments. It was therefore possible to use the Band model to infer the site-specific avoidance rates of Pink-footed Goose and Common Crane in the wind farm area at Klim Fjordholme using the observed wind farm related mortality rate during year 1 and 3. Our inferred avoidance rates were compared to the avoidance rates recommended by Scottish Natural Heritage (2018).

An extended version of the Band model has been developed (Band 2012). This takes into consideration that the distribution of birds and the width of the turbine vary with height within the rotor-swept area during calculations of the single transit collision risk. The extended model has, however, not been widely implemented and has primarily been used in offshore studies.

The original Band model is still used as an internationally recognised industry standard and was recommended for example by NatureScot (formerly Scottish Natural Heritage) in 2021. Therefore, we applied the original version of the model to allow our inferred avoidance rates to be applied by other studies using the Band model in baseline and post-construction studies.

Calculation of flight activity within the survey area

Fieldwork to record flight activity performed for wind farm baseline studies often follows internationally recognised recommendations made available by NatureScot (Scottish Natural Heritage 2017). The recommended survey method is vantage point surveys to be performed for a recommended minimum of 36 hours spread over the full daylight period per breeding and non-breeding season. The recommendations include plotting of flight routes on field maps and recording of assessed flight altitudes classified into height bands.

During calculations, the available field data is extrapolated to cover the months during which the target species is present in the study area (Band *et al.* 2007).

A property of the Band model is that collision risk modelling may be conducted regardless of the quality of the data available for the flight activity in the study area. The occurrence and flight activity of the target species may vary depending on time of year, diurnal variation and other temporal factors, and therefore such factors should be taken into consideration during planning of the fieldwork to obtain a representative sample of the flight activity. The relatability of the model is therefore intimately linked to the quality of the field monitoring performed.

The monitoring of the flight activity of Pink-footed Goose and Common Crane in the present study was designed specifically to obtain high quality data suited for calculations using the Band model.

Radar data were useful to quantify the flight activity of geese in the inbound and outbound periods. The duration of the inbound and outbound periods was calculated based on the results of the 13 days of radar surveys in year 1 and 3. The foraging period was subsequently defined as the time between the two periods.

Results of the transect crossing count surveys were used to quantify the flight activity of Pink-footed Goose during the foraging period, excluding transect crossing count data from the inbound and outbound periods. Common Crane was found not to have distinct inbound and outbound periods and was not observed to be active before sunrise or after sunset, therefore the crossing-count data were used to quantify the flight activity of that species during all day, i.e. the period from sunrise to sunset.

Calculation of the occurrence of birds in rotor swept altitudes

The percentage of the two species that occurred in the altitude range of the rotor swept area was calculated. Data for birds within the study area during measurements were used, and the data were weighted according to the number of birds in each of the measured flocks of birds.

Calculations of bird occupancy within the flight risk volume

The flight risk volume was defined as the airspace at rotor height within the study area. The recorded flight activity was used to calculate the bird occupancy within the flight risk volume expressed as bird seconds per year, to be used as input for the Band model (Scottish Natural Heritage 2000).

To calculate the bird occupancy, different approaches were used for data collected using radar and transect crossing surveys.

The portion of the daily bird occupancy for Pink-footed Goose during the inbound and outbound periods was calculated based on the length of the recorded radar track, the flight speed and the number of birds recorded in each track.

The portion of the daily bird occupancy for Pink-footed Goose during the foraging period and for Common Crane during all day, was based on the results of the transect crossing count surveys expressed as bird flights per hour, the length of the foraging period, the flight speed and the average length of recorded tracks of the two species.

The bird occupancy within the flight risk volume during the whole day was thus calculated using a combination of data from the radar and transect crossing surveys. The bird occupancy of both target species was calculated for each week during year 1 and 3, using data from transect crossing counts and radar surveys from the closest date with available data. Pink-footed Goose was not present in the area during the summer season, and therefore occupancy was zero during that part of the year. The annual bird occupancy was subsequently estimated by calculating the sum of bird occupancy during all weeks of the year.

The flight speed used for Pink-footed Goose was 17.8 m/s, which was based on 47 speed measurements of geese performed with radar during our fieldwork. The flight speed was within the interval of 15-20 m/s for geese in Alerstam *et al.* (2007). The flight speed used for Common Crane was 15 m/s based on the results in Alerstam *et al.* (2007).

Calculation of inferred avoidance rates estimated by the Band model

Usually, the Band model is used to calculate the number of collisions using known avoidance rates. In our case, the model was used to infer the avoidance rates of the two target species. The avoidance rate is the proportion of expected collisions that as a result of avoidance behaviour does not occur. The inferred avoidance rate was thus calculated as the percentage of the estimated number of fatal collisions (based on the carcass surveys and field experiments) in relation to the calculated theoretical number of annual collisions assuming no avoidance.

All authors participated in the field work. JD organised the carcass searches, the scavenging rate and searcher efficiency field experiments and undertook the data processing and analyses of those topics. SRW organised the transect crossing count, radar and range-finder surveys and undertook the data processing and analyses including analyses using the Band model. HHN conducted most of the transect crossing counts, carcass searches and scavenger field experiments, and JD and SRW wrote the manuscript.

Results

Number of carcasses found

In year 1, remains of one Pink-footed Goose and one unidentified *Anser* goose were found during the standardised searches (Tab. 1). Additionally, a more or less intact carcass of a Pink-footed Goose was found 220 m from turbine 20 during the searches on 25 March 2017 (Tab. 1), i.e. outside the search area of the standardised searches. This carcass was collected, frozen and later analysed at the certified laboratory Abild Dyreklinik, Brabrand, and proved to have died from natural causes due to starvation and/or disease, and not from collision with the wind turbines.

In year 3, remains of seven unidentified *Anser* geese were found during the standardised carcass searches at the 11 selected turbines (Tab. 1). Additionally, remains of an unidentified *Anser* goose were recorded at turbine 17 on the 3 April 2019, i.e. at one of the turbines not included in the standardised searches.

No carcasses or remains of Common Crane were found during the standardised searches during year 1 and 3 after the construction of the wind farm.

Scavenging rates

During the first scavenger experiment in October 2016, four of the 50 carcasses were destroyed by agricultural machinery within the first three days of the experiment. Thus the actual sample size of the first experiment was reduced from 50 to 46. During autumn 2016, 70% of the placed carcasses (N = 46) were eaten by scavengers after six days. During the winter (N = 36) and spring (N = 49) experiments, 86% and 92% of the carcasses were eaten by scavengers, respectively (Fig. 2).

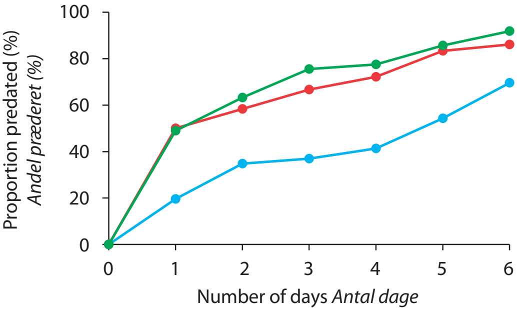

Fig 2. Proportion of carcasses scavenged during the three scavenger experiments in October 2016 (N = 46, blue line), January 2017 (N = 36, red line) and April 2017 (N = 49, green line). *Andelen af ådsler, der blev præderet op til seks dage efter, at de var udlagt i forsøgsområdet i oktober 2016 (N = 46, blå streg), januar (N = 36, rød streg) og april (N = 49, grøn streg).*

Tab. 1. Dead geese recorded during searches of turbines during year 1 and 3 after construction of the wind farm, with distance to the nearest turbine indicated. * Bird not found during the standardised searches.
*Fund af døde gæs under/nær vindmøllerne i løbet af eftersøgningerne i år 1 og år 3 efter møllernes opførelse. Afstand angiver afstanden til nærmeste vindmølle. * angiver at fuglen ikke blev fundet under de standardiserede eftersøgninger.*

Year *År*	**Species** *Art*	**Date** *Dato*	**Turbine** *Mølle*	**Distance (m)** *Afstand (m)*	**Remains** *Rester fundet*
1	*Anser* sp.	26 January	3	129	Feathers, eaten and removed by red fox *Fjer, spist og fjernet af ræv*
1	Pink-footed Goose *Kortnæbbet gås*	22 March	18	118	Feathers, eaten by red fox *Fjer, spist af ræv*
1	Pink-footed Goose* *Kortnæbbet gås**	25 March	20	220	Nearly intact bird *Næsten hel fugl*
3	*Anser* sp.	9 March	22	85	Feathers, eaten by red fox *Fjer, spist af ræv*
3	*Anser* sp.	9 March	9	68	Feathers *Fjer*
3	*Anser* sp.	13 March	13	67	Feathers *Fjer*
3	*Anser* sp.	15 March	17	22	One whole wing *En hel vinge*
3	*Anser* sp.	15 March	17	21	Eaten carcass and feathers *Skrog og fjer*
3	*Anser* sp.	25 March	4	82	Feathers *Fjer*
3	*Anser* sp.	1 April	13	76	Feathers *Fjer*
3	*Anser* sp.*	3 April	17	3	Eaten carcass *Skrog*

Based on tracks and signs left by scavengers, red fox *Vulpes vulpes* was identified as the most frequent scavenger in the study area. Scavenging birds like Common Buzzard *Buteo buteo*, Red Kite *Milvus milvus*, Greater Black-backed Gull *Larus marinus* and Common Raven *Corvus corax* were also observed eating the carcasses.

The proportion of carcasses still traceable during the three scavenger experiments is shown in Fig. 3. When pooling data from all three experiments, on average 83% and 84% of carcasses were still recognisable two and three days, respectively, after they were placed in the study area.

When comparing the scavenging rates between the experimental study area and the wind farm area in December 2017 (Fig. 4), the carcass survival rate was significantly higher in the wind farm area than in the experi-

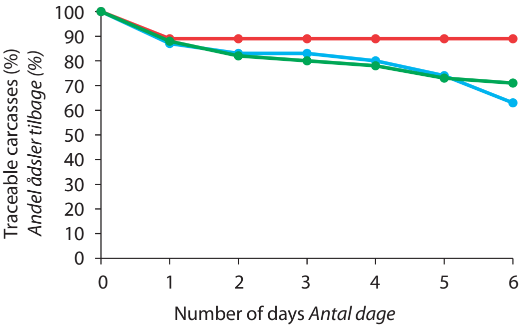

Fig 3. Proportion of carcasses still traceable after being placed in the experimental study area in October 2016 (N = 46, blue line), January 2017 (N = 36, red line) and April 2017 (N = 49, green line).
Andelen af ådsler, der stadig kunne spores, efter at de var udlagt i oktober 2016 (N = 46, blå streg), januar (N = 36, rød streg) og april (N = 49, grøn streg).

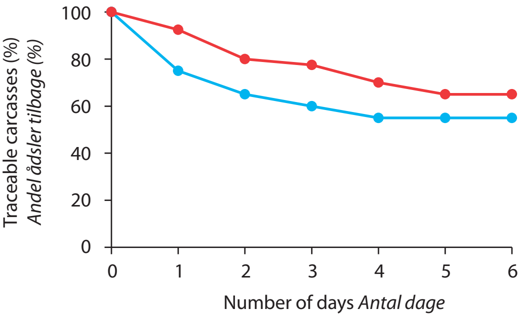

Fig 4. Proportion of carcasses still traceable after being placed in the experimental study area (blue line) and the wind farm area (red line) in December 2017.
Andelen af ådsler, der stadig kunne spores, efter at de var udlagt i ådselforsøgsområdet (blå streg) og vindmølleområdet (rød streg) i december 2017.

mental area (Kaplan-Meier survival analysis: Chi$^2 = 11.5$, $df = 1$, $P < 0.001$). This indicated that the scavenging rate within the wind farm area was not higher than in the surrounding area, and hence the estimated persistence time of carcasses, based on data from the experimental area, did not underestimate scavenger activity within the wind farm area.

Searcher efficiency

The three carcass experiments conducted within the wind farm area to test searcher efficiency showed that the searchers found five out of nine carcasses (56%) during the experiment in September, eight out of nine (89%) in January, and eight out of nine placed carcasses (89%) during the experiment in April.

Searcher 1 conducted the searches during the first experiment in September, while searcher 2 conducted the searches during the test experiments in January and April. During the searches in September, the vegetation cover within the carcass-search areas was higher (20-50 cm) at four turbines than during the searches in January and April. The two factors, searcher and vegetation height, could explain the lower searcher efficiency during the first experiment in September.

One carcass placed at turbine 20 was removed by scavengers before searcher 2 searched the area during the third experiment in April. In total, searcher 2 therefore found 16 out of 17 placed carcasses (94%) during the last two experiments. The probability of searchers finding collision fatalities was therefore estimated as $S_{o\text{-}min} = 0.56$ and $S_{o\text{-}max} = 0.94$.

Estimation of the number of fatal collisions

All carcasses and remains of geese recorded during the standardised searches were assumed to have been killed by collision with the turbines, i.e. N (in the Kahlert *et al.* 2010 formula) was equal to the number of recorded carcasses and remains of *Anser* geese. However, the cause of death could not be determined because all geese encountered only consisted of feathers or other remains of dead birds (Tab. 1). Additionally, most carcasses of geese recorded could only be identified as species belonging to the genus *Anser*.

In year 1, where searches were conducted every three days, Sp-1 = 0.83 was used as a correction factor for persistence time of carcasses. In year 3, Sp-3 = 0.84 was used, because searches were conducted every other day during the periods when carcasses of geese were recorded during the searches (Tab. 1). To correct for search efficiency of the searchers (S_o), two different correction factors were used because S_o varied from 0.56 to 0.94 (see above).

Based on the formula by Kahlert *et al.* (2010), the annual number of fatal collisions of Pink-footed Goose at Klim Fjordholme was estimated at 10-17 individuals in year 1 and 35-38 individuals in year 3 (Tab. 2).

Common Crane often flew in-between the turbines (see below) and carcasses of this species would be difficult to miss during the carcass surveys due to their large size. Therefore, the fact that no carcasses or remains of Common Crane were recorded during the searches in year 1 and 3, indicates that Common Cranes rarely collide with wind turbines in the study area. Recorded tracks (see below) and visual observations of movements of Common Crane within the wind farm also showed that they were good at manoeuvring in-between the turbines.

Flight activity and bird occupancy

A total of 206 and 213 radar tracks of Pink-footed Goose were recorded in year 1 and 3, respectively (Fig. 5). Most of the recorded movements of Pink-footed Geese were between their night roost area on Bygholm Vejle and foraging areas utilised during the day. The foraging areas were mainly located north and east of the wind farm area but varied according to seasonal variation in the availability of food resources in the area. The majority of Pink-footed Geese avoided the wind turbines

Tab. 2. The annual number of fatal collisions of Pink-footed Goose estimated by the formula $F = (N / Sp * S_o) / T$ (see text) after turbines were searched for collision-killed geese for 108 days and geese were present at Klim Fjordholme for 212 days according to our surveys.
Årlige antal kollisioner af Kortnæbbet Gås estimeret ud fra formlen $F = (N / Sp * S_o) / T$ (se tekst), når der blev søgt efter kollisionsdræbte gæs i 108 dage og de Kortnæbbede Gæs opholdt sig ved Klim Fjordholme i 212 dage om året.

Year *År*	**N**	**T**	**F_{min}**	**F_{max}**	**Estimated fatal collisions/turbine/day** *Estimeret antal kollisioner/mølle/dag*	**Fatal collisions/year** *Antal kollisioner/år*
1	2	11	0.2330	0.3912	0.0022-0.0036	10-17
3	7	11	0.8059	1.3528	0.0075-0.0125	35-58

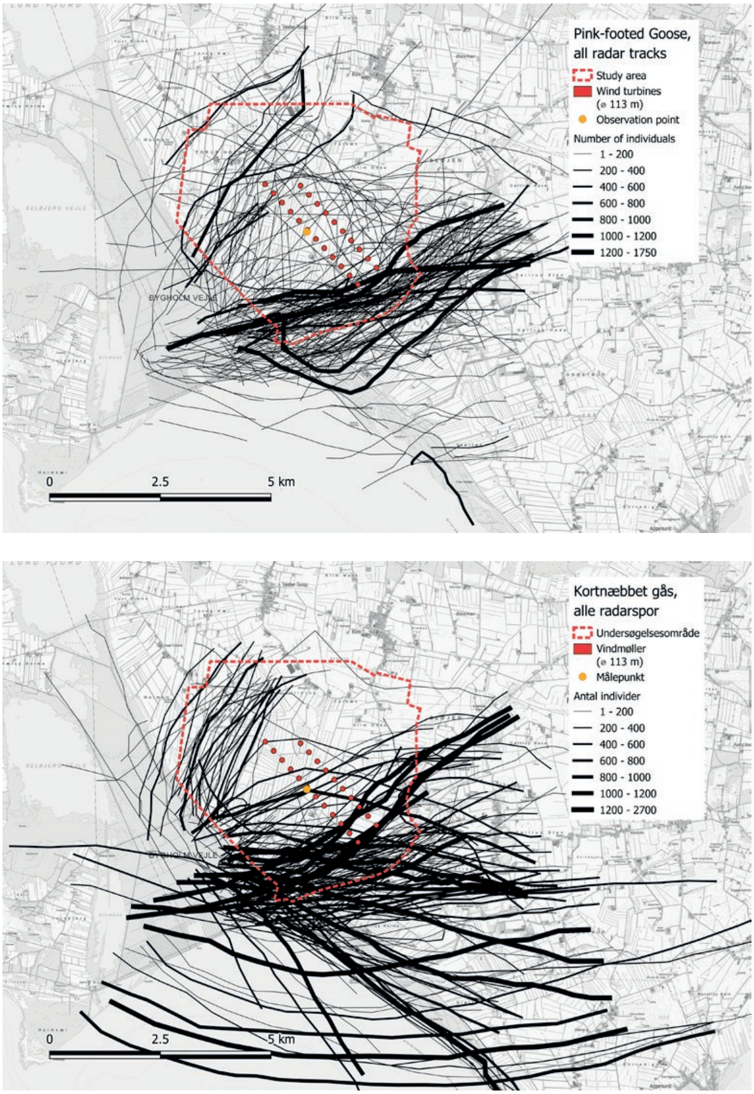

Fig. 5. Radar tracks of Pink-footed Goose in the two study years, with year 1 shown at the top.
Flyveruter af Kortnæbbet Gås registreret med radar i de to undersøgelsesår, hvor år 1 er øverst.

by passing either south or west of the wind farm area. Relatively few and smaller flocks of inbound and outbound Pink-footed Geese were recorded to pass directly over the wind farm during both survey years (Fig. 5). The duration of the inbound periods was from before sunrise to until 15 minutes to three hours after sunrise. The outbound periods occurred after sunset during eight of the 13 days of radar surveys. During the remaining five survey days, the outbound period lasted from between 15 and 60 minutes before sunset until after sunset. The calculated total annual bird occupancy in the flight risk volume for Pink-footed Goose was 303.8 and 480.6 million (M) bird seconds for year 1 and 3, respectively. The relative importance of the inbound, outbound, and foraging birds differed between the years. In year 1, 26.7% of the bird occupancy were inbound birds, 52.3% were outbound birds and 21.0% were foraging birds. The equivalent numbers for year 3 were 24.4%, 26.7% and 49.0%, respectively.

The movements of Common Cranes were difficult to record by radar because they mainly consisted of low-flying small flocks, and radar echoes from hedgerows often obscured the movements of this species in the area. Only 29 and nine radar tracks of Common Crane

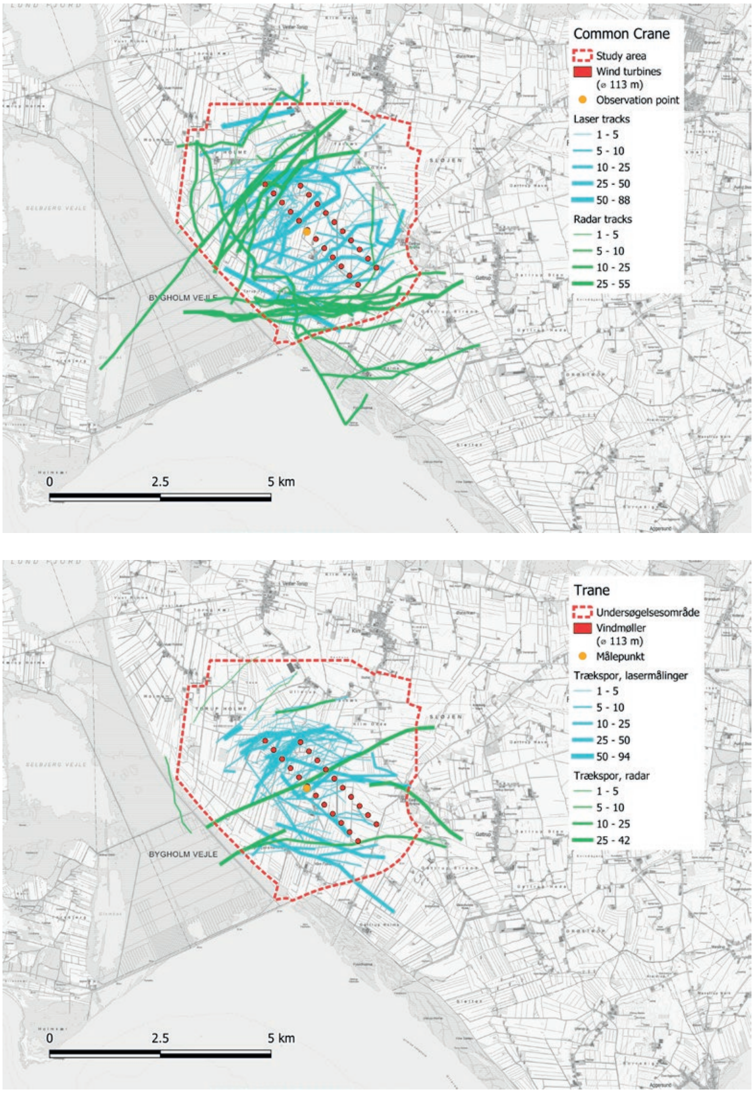

Fig. 6. Radar and laser tracks of Common Crane in the two study years, with year 1 shown at the top. *Flyveruter af Trane registreret med radar og laserkikkert i de to undersøgelsesår, hvor år 1 er øverst.*

were thus recorded in year 1 and 3, respectively. Therefore, recorded laser tracks of Common Crane (N = 84 in year 1 and N = 70 in year 3) were also used in addition to the obtained radar tracks to describe the movements of Common Crane in the wind farm area (Fig. 6). Common Cranes did not actively avoid entering the wind farm, but often flew in-between the turbines during movements in the area, where they were observed to be able to avoid individual turbines. This was supported by the fact that no carcasses or remains of Common Crane were encountered during the standardised carcass searches. The calculated total annual bird occupancy in the flight risk volume within the survey area for Common Crane was 15.6 and 7.8 M bird seconds for year 1 and 3, respectively. Due to limitations of the radar method, the bird occupancy of Common Crane was calculated using only data from the transect crossing counts.

Flight altitude

The altitudinal distribution in 10 m intervals was calculated (Fig. 7). Relatively large proportions were observed within the intervals 181-190 m and 170-180 m in year 1 and 3, respectively, which were above the turbines that spanned the altitude interval of 36 to 149.5 m. Sev-

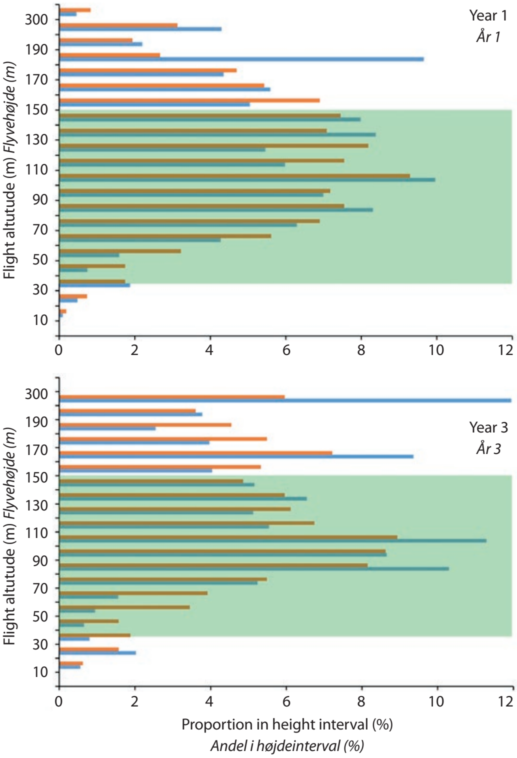

Fig. 7. Flight altitudes of Pink-footed Goose within the study area in year 1 (N = 1087) and 3 (N = 638) shown as a proportion of all recordings (orange) and as a proportion weighted for the number of individuals in measured flocks of geese (blue). Rotor height of the turbines (36-149.5 m) is indicated by the green field.
Højdemålinger af Kortnæbbet Gås inden for undersøgelsesområdet i år 1 (N = 1087) og 3 (N = 638). Angivet som hhv. procentdel af alle målinger (orange) og procentdel vægtet for antal individer (blå). Rotorhøjden i intervallet 36-149,5 m er indtegnet med grønt.

eral times during the field work, flocks of Pink-footed Goose were observed to cross the lines of turbines in the altitude intervals above turbine height. Of the 1725 flight altitude measurements of Pink-footed Goose, 486 were performed on geese that occurred within 100 m distance to, or between, the two rows of turbines. Of these, 16.7% were within the interval 170-190 m. The equivalent percentage was 4.7% for the 1239 altitude measurements performed on Pink-footed Goose that occurred at greater distances to the rows of turbines, indicating that flocks actively flew above the rotors to avoid collision.

During year 1, a large number of small flocks of Common Crane was recorded to fly below the rotors, which was not an apparent trend in year 3 (Fig. 8). In both years, a majority of the measured individuals of Common Crane was observed to occur at rotor swept altitudes. The observed altitude distributions were assumed to reflect the altitudinal distribution of the two target species during flight within the study area.

Nocturnal movements

A single flock consisting of a few Pink-footed Geese was the only observation of the two target species recorded during the six nights of nocturnal radar monitoring in year 1. Based on this result, the two target species were assessed not to fly at night in the study area in any significant numbers, which was expected because the two species prefer to rest at night roosts away from the foraging localities during night to avoid predation.

Inferred avoidance rates estimated by the Band model

When assuming no avoidance, the number of annual collisions was calculated as the theoretical numbers of birds flying through the turbine rotor sweep areas (see Scottish Natural Heritage 2000) multiplied by the risk of a bird colliding with the rotors when flying through the swept area (see NatureScot 2021b). The number of annual collisions of Pink-footed Goose, assuming no avoidance, was estimated at 20 250 and 30 228 individuals for year 1 and 3, respectively. The equivalent numbers for Common Crane were 1382 and 824 individuals for year 1 and 3, respectively.

The inferred avoidance rates for Pink-footed Goose were 99.92-99.95% and 99.81-99.88% for year 1 and 3, respectively, based on the actual numbers of collisions (Table 2).

The inferred avoidance rate for Common Crane was 100%, because no collision fatalities were recorded during the carcass searches. The species was, however, present at relatively large numbers in the study area during both survey years, and possible annual collisions could therefore not be entirely ruled out. To infer a more probable avoidance rate, the calculations were made assuming zero to one annual fatal collision in the survey area. The resulting intervals for the inferred avoidance rates for Common Crane were therefore estimated at 99.93-100% and 99.88-100% for year 1 and 3, respectively.

Discussion

Numbers of fatal collisions

Skilled scent-detection dogs have been shown to be more efficient than human observers in finding bats and small bird species below turbines (Smallwood *et*

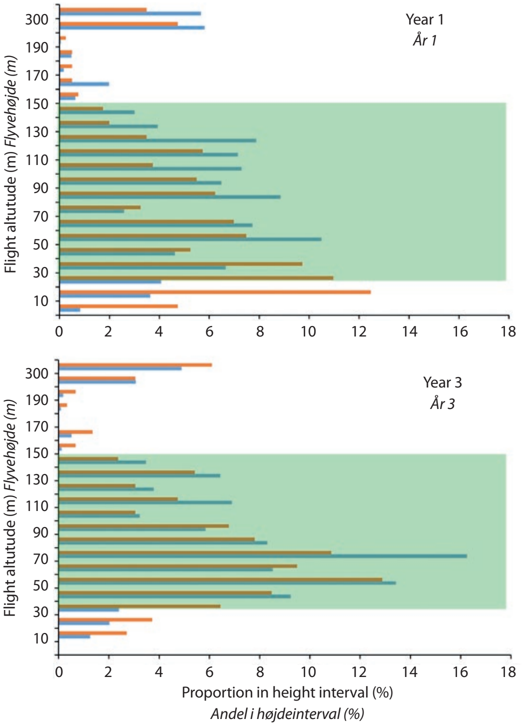

Fig. 8. Flight altitudes of Common Crane within the study area in year 1 (N = 401) and 3 (N = 295), shown as a proportion of all recordings (orange) and as a proportion weighted for the number of individuals in measured flocks of Common Crane (blue). Rotor height of the turbines (36-149.5 m) indicated by the green field.
Højdemålinger af Trane inden for undersøgelsesområdet i år 1 (N = 401) og 3 (N = 295). Angivet som hhv. procentdel af alle målinger (orange) og procentdel vægtet for antal individer (blå). Rotorhøjden i intervallet 36-149,5 m er indtegnet med grønt.

al. 2020). However, the two target species in our study, Pink-footed Goose and Common Crane, were both large species that were easily found by human searchers within the carcass-search areas (Peters *et al.* 2014). At Dun Law wind farm in Scotland, Gill (2001) searched for carcasses of Pink-Footed Goose and estimated search efficiency for this species to be at least 83% in their study. Our field experiments of searcher efficiency showed that searcher efficiency was between 56% (searcher 1 in high vegetation) and 94% (searcher 2 in low vegetation). Compared with other studies, our calculated probability of searcher detection was therefore not extremely high, and hence the searcher's detection ability did not lead to a huge underestimation of the actual casualties.

The searcher efficiency experiments were conducted by placing labelled carcasses of geese that were easily recognised by the searchers. It could therefore be argued that the searchers would be keener to search for victims after finding the first labelled goose, since they then knew that they were part of a test. However, due to the large size of geese carcasses, they were very easy to find in the low vegetation that prevailed at the majority of the searched turbines (see methods). Therefore, a keener search for victims after finding the first labelled goose would not lead to a markedly higher detection rate during the experiments.

High (20-50 cm) vegetation occurred at four of the searched turbines during the autumn searches, and therefore a more intensive search effort (see methods) was conducted at these turbines during autumn. Additionally, by utilising a different searcher efficiency for high vegetation (56%), differences in vegetation height and its influence on detection probability were taken into account in the fatality estimates.

The conducted scavenger experiments showed that many carcasses were removed by scavengers, especially red fox, but the majority of scavenged carcasses could still be discerned more than a week after scavenger removal due to mainly feather remains. The scavenger experiments also showed that scavenger rates varied during the season, which may have reflected the seasonal activity patterns of the scavengers, e.g. larger food demands of red foxes during spring when they were raising cubs. The scavenger rate also varied between sites because when we simultaneously compared the scavenging rates between the two areas in December 2017, carcass survival rate was significantly higher in the wind farm area than in the experimental area. Using the scavenger rate estimated from the experimental area may thus have resulted in an overestimate of the scavenging rate at the wind farm area and may therefore have led to an inflated estimate of the number of fatal collisions of Pink-footed Goose. The difference in scavenging rates between the two areas could be due to differences in scavenger community, topography, vegetation, or light conditions (Wobeser & Wobeser 1992, Philibert *et al.* 1993, Morrison 2002).

By conducting the scavenger experiments away from the wind farm area, we avoided increased attraction of scavengers to the wind farm due to artificially increased prey availability for scavengers. Our scavenger experiments in year 1 thus did not result in increased scavenger activity within the wind farm in year 3. However, natural fluctuations in prey availability and other environmental factors influencing scavenger densities within the wind farm may have varied between year 1 and year 2. The scavenger experiments should therefore have been replicated in year 3, but unfortunately these experiments could not be conducted due to lack of suitable carcasses.

During the scavenger experiments, we did not take special precautions to disguise the scent and tracks of the field workers. Mammalian scavengers could be attracted to human scent on the trial carcasses and by tracks leading to the carcasses. However, they could just as well be repulsed by human scents and tracks if they perceive humans as a 'super-predator' (Smith *et al.* 2017). Therefore, it is unclear whether human scent and tracks could have influenced the results of our scavenger experiments. In general, red foxes and other scavengers will naturally be attracted to wind farm areas if these constitute a constant food source in the form of collision-killed birds.

The majority of the recorded remains of geese during the standardised searches could not be identified to species, but just as unidentified *Anser* geese. This could also have resulted in an overestimation of collision-killed Pink-footed Geese at the wind farm if some of the remains were from other *Anser* species. The lack of carcass experiments to estimate the correction factors for persistence time of carcasses (S_p) and searcher efficiency (S_o) in year 3 could also have influenced the estimated number of fatal collisions because both S_p and S_o may vary annually (Morrison 2002, Smallwood 2007, Flint *et al.* 2010, Santos *et al.* 2011).

Inferred avoidance rates

The survey area of 23.16 km² was relatively large and encompassed the wind farm and at least 765 m between the turbines and the border of the area. For most turbines, the distance was much larger, with distances up to 1.8 km to the border. Based on the relatively large areas around the turbines, during planning of the project, it was assumed that the observed flight activity in the study area would be comparable to flight activity before construction of the new turbines.

Contrary to most other baseline or post-construction studies of birds at wind farms, our field surveys used a number of different methods and a considerable field effort, which was targeted specifically at gathering data for applying the Band model. It was therefore assessed that the quality of the gathered data resulted in highly reliable, inferred avoidance rates for the two target species.

A noteworthy finding was that the flight activity of Pink-footed Goose during the foraging period was as low as 21% and 49% in year 1 and 3, respectively, and that much of the flight activity occurred before sunrise and after sunset. Therefore, it was important that the field work also covered about one hour before sunrise and one hour after sunset. This finding should be taken into consideration in future studies of flight activity of geese at wind farms.

Our inferred avoidance rates for Pink-footed Goose and Common Crane were at least 99.81% and were thus higher than the avoidance rates recommended by NatureScot (2021a) for use of the Band model. The recommended, and internationally recognised, avoidance rate for geese was 99.0% for several years (Scottish Natural Heritage 2014). Recently, the recommended avoidance rate has been increased to 99.8% based on accumulated international experience (Scottish Natural Heritage 2018).

In the present study, the inferred avoidance rates for year 3 (99.81-99.88%) was relatively close to the above-mentioned recommendation. However, the estimated avoidance rate for year 1 (99.92-99.95%) was much higher.

Avoidance rates for Common Crane have not been reported before.

Environmental impact assessments of wind farms often rely on calculations of the expected number of annual collisions of birds based on baseline studies and use of the Band model. The expected number of annual collisions is directly correlated to the avoidance rate used in the Band model. Small adjustments of avoidance rates that are close to 100% will result in large changes in the calculated number of expected annual collisions. When applied in the Band model, the current recommendation of 99.8% would thus result in four times more expected collisions than the inferred avoidance rate of 99.95% at the high end of the interval for Pink-footed Goose in year 1 in our study.

During calculations of the inferred avoidance rates, it was assumed that the observed flight activity within the study area was not affected by the presence of the wind turbines within the area. The results of the radar surveys (see Fig. 5) do, however, indicate that a proportion of Pink-footed Geese were diverted and flew south or west outside the survey area due to avoidance responses to the wind farm. The observed flight activity during year 1 and 3 may thus have been lower in the wind farm area than it would have been during a baseline study conducted before construction of the turbines. If that is the case, the inferred avoidance rates in the present study are lower than inferred avoidance rates based on baseline data from the study site before construction of the turbines. That is because the calculations were based on both the observed number of fatal collisions and the observed flight activity. During the calculations, higher flight activity will result in higher inferred avoidance rates.

In addition, the radar surveys and transect crossing counts were primarily performed during periods with high visibility. It is conceivable that the flight activity in the study area was greater during periods with heavy mist or fog if, under such conditions of low visibility, the birds did not avoid entering the wind farm because they were not able to see the turbines. Carcass searches were performed regularly regardless of the weather conditions and therefore did cover collisions during periods of low visibility. The inferred avoidance rates for Pink-footed Goose were therefore probably low estimates.

Conclusion

The great majority of Pink-footed Geese avoided the wind turbines by passing either south or west of the wind farm area (see Fig. 5). Common Cranes on the other hand were observed to be able to avoid individual turbines during their movements within the wind farm area.

This study confirms that the avoidance behaviour of birds is species-specific (Drewitt & Langston 2006). Even small adjustments of the avoidance rate of a given species can result in large changes in the calculated number of estimated fatal collisions. Therefore, in order to evaluate possible mortality risks associated with a given wind farm, avoidance rates should be derived for relevant species and for localities as similar as possible to the location under consideration.

In view of the important role avoidance plays in estimating the impact of wind farms on birds, there is a need for more studies of the avoidance process. It is crucial in this context to identify the underlying mechanisms of behavioural responses by birds to wind farms and to individual turbines.

Acknowledgements

Vattenfall Vindkraft A/S financed the study and facilitated access to the study area. Besides some of the authors, Jens Frimer took part in the carcass searches. Additionally, we are grateful for the comments from two anonymous referees and from D.P. Whitfield and David Boertmann, and Nick Nathaniels Quist corrected the English text, which all greatly improved the manuscript.

Resumé

Kortnæbbet Gås og Trane udviser stor evne til at undvige kollision med vindmøller i en dansk vindmøllepark

Mange forskellige fuglearter er registreret at kollidere med vindmøller i drift, og deres risiko for at kollidere med møllerne afhænger blandt andet af møllernes placering samt fugleartens morfologi og adfærd. Et meget vigtigt adfærdsmæssigt træk for at undgå kollision med vindmøller er fuglenes evne til at aktivt at undvige møllerne. I dette studie undersøgte vi kollisionsrisikoen for Kortnæbbet Gås *Anser brachyrhynchus* og Trane *Grus grus* ved vindmølleparken ved Klim Fjordholme nær Vejlerne i Nordjylland. Et og tre år efter konstruktionen af vindmøllerne estimerede vi antallet af kollisionsdræbte Kortnæbbede Gæs og Traner i vindmølleparken, og undersøgte de to arters evne til at undgå kollision med møllerne. Det årlige antal kollisionsdræbte Kortnæbbede Gæs blev estimeret til henholdsvis 10-17 og 35-58 individer i de to undersøgelsesår, mens der ikke blev fundet kollisionsdræbte traner i vindmølleparken. De to arters undvigerater i forhold til vindmøllerne blev estimeret ved hjælp af Band-modellen, som viste, at Kortnæbbet Gås havde en undvigerate på henholdsvis 99,92-99,95 % og 99,81-99,88 % i de to undersøgte år. Undvigeraterne for Trane i de to år blev estimeret til henholdsvis 99,93-100 % og 99,88-100 %. Begge arter udviste således stor evne for at undgå kollision med vindmøllerne ved Klim Fjordholme, men de to arter benyttede forskellige adfærdsmønstre for at undgå kollisioner. Langt de fleste Kortnæbbede Gæs fløj helt udenom vindmølleparken, når de fløj til og fra deres overnatningsplads på Bygholm Vejle og ud til deres foretrukne fourageringsområder. Tranerne fløj derimod ofte direkte gennem vindmølleparken, hvor de aktivt fløj udenom de enkelte vindmøller for at undgå kollisioner.

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Det er tydeligt, at ornitologi og naturforskning på Færøerne gennem tiderne har nydt godt af besøgende forskere og ornitologer. Dette er britiske Kenneth Williamson et særlig godt eksempel på. Kenneth blev som officer stationeret på Færøerne under Anden Verdenskrig, og i sin tid på øerne var han en meget aktiv ornitolog og ringmærker. Den forskning, som han udførte på Færøerne, var med til at skaffe den første viden om Sulens færden. På denne måde var naturforskning med til at sætte Færøerne og dets rige natur på verdenskortet. Til hans minde har den færøske ornitologiske forening, Føroya Fuglafrøðifelag, grundlagt en ny rejsefond ved navn Kenneth Williamson fuglefonden. Formålet med fonden er at gøre det muligt for udenlandske fugleforskere at komme til Færøerne i forskningsøjemed i en begrænset periode, samt for færøske forskere at udvikle deres kompetencer i eksempelvis ringmærkning i udlandet. Kenneth Williamson fuglefondens hovedsag er således en styrket viden og forskning indenfor færøsk fugleliv. Forskere, der får tildelt støtte fra fonden, vil derudover få mulighed for at benytte organisationens lokaliteter i hjertet af hovedstaden, Tórshavn. Alle med interesse i færøsk fugleliv eller fugleforskning opfordres til at søge støtten.

Vejledning til ansøgere kan findes på foreningens hjemmeside: http://fuglar.fo/kwf. Ansøgningsfristen er den 15. februar og 15. september hvert år.