From: Dominika Phillips
To: Hornsea Project Three; KJ Johansson; Kay Sully
Cc: Andrew Guyton; Stuart Livesey
Subject: Hornsea Project Three (UK) Ltd response to Deadline 4 (Part 6)
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D4_HOW03_Appendix 19_Lawson et al 2016.pdf
D4_HOW03_Appendix 20_Masden 2015.pdf
D4_HOW03_Appendix 21_Wade et al 2016.pdf
D4_HOW03_Appendix 22_Desholm 2005.pdf
D4_HOW03_Appendix 23_Welcker et al 2016.pdf
D4_HOW03_Appendix 24_Cook et al 2018.pdf
D4_HOW03_Appendix 25_Parry 2015.pdf

Dear Kay, K-J

Please find attached the 6th instalment of documents.

Best regards,
Dr Dominika Chalder PIEMA
Environment and Consent Manager

[redacted]

Environmental Management UK│ Wind Power
5 Howick Place │ London │ SW1P 1WG

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Hornsea Project Three
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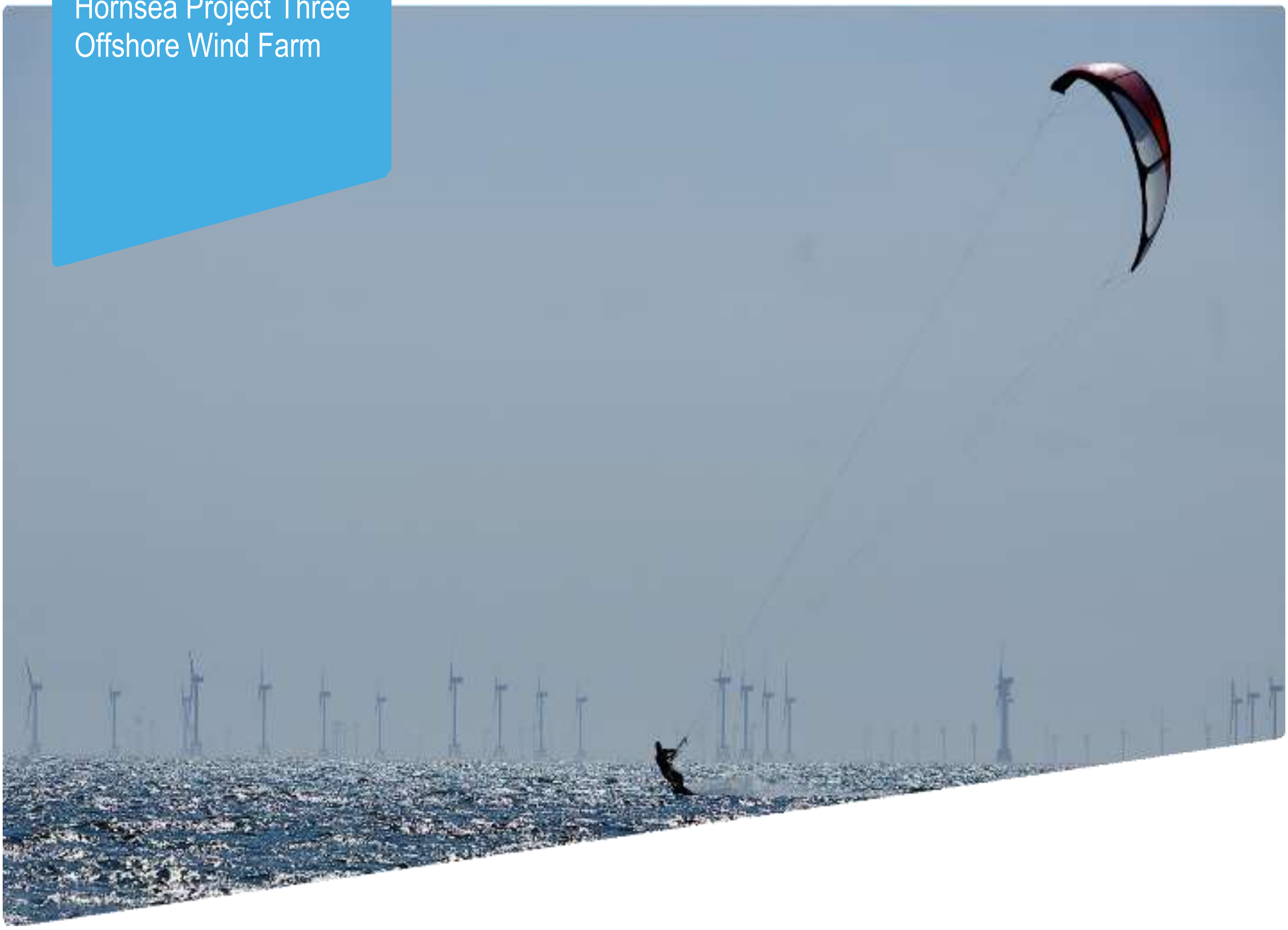

Hornsea Project Three

Offshore Wind Farm

Appendix 22 to Deadline 4 Submission – Desholm 2005

Date: 15th January 2019

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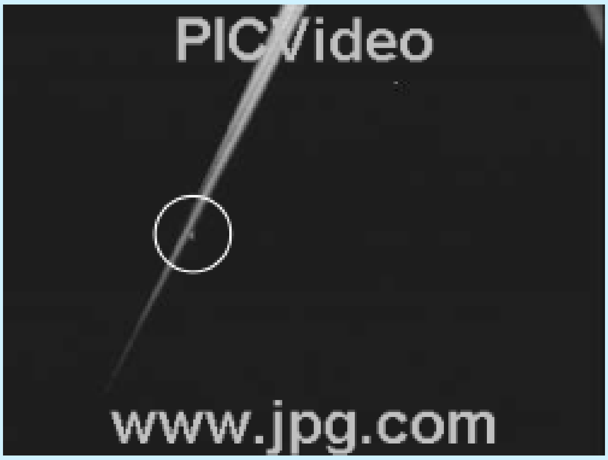
National Environmental Research Institute
Ministry of the Environment · Denmark

TADS investigations of avian collision risk at Nysted offshore wind farm, autumn 2004

Report commissioned by Energi E2
2005



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National Environmental Research Institute
Ministry of the Environment · Denmark

TADS investigations of avian collision risk at Nysted offshore wind farm, autumn 2004

Report commissioned by Energi E2
2005

Mark Desholm

Data Sheet

Title:	TADS investigations of avian collision risk at Nysted offshore wind farm, autumn 2004
Author:	Mark Desholm
Department:	Department of Wildlife Ecology and Biodiversity
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Contents

Synopsis

This report presents data on infrared monitoring investigations by use of Thermal Animal Detection System (TADS) on autumn migrating waterbirds at the Nysted offshore wind farm, Denmark in 2004.

The aims of the report were twofold:

1) to collect data on the number of waterbird collisions and on the near rotor evasive behaviour using TADS, and
2) to compile information (data collected by TADS and radar) to develop a deterministic predictive collision model in order to estimate the number of Common Eiders *Somateria mollissima* which collide with the sweeping rotor-blades of the 72 wind turbines.

The results from the collision monitoring study confirm the findings from the same site in spring 2004, when a relatively low migration volume around the near vicinity of the turbines was also documented. During autumn operation, the TADS recorded 1,944 thermal video sequences automatically at one turbine, of which five were triggered by birds passing the field of view. No birds were recorded as passing the sweep area of the rotor-blades nor colliding with any part of the turbine during the 28,571 minutes (equivalent to 476 hours) of monitoring.

A single passerine was observed approaching the rotor-blades, and ceased its onward flight hovering on its wings before it returned in the direction it came from. The remaining five sequences showed three flocks of passerines and two flocks of waterbirds passing within the near vicinity of the turbine but beyond the reach of the rotor-blades.

Hence, out of six events four were passerines passing the field of view of the TADS, and this despite the fact, that the present monitoring scheme was designed for measuring waterbird collisions. This demonstrates that the TADS can evenly well be used for monitoring passerines as waterbirds, especially if a larger telephoto lens is applied.

The values, which were imputed in a collision model, were obtained partly from the conclusions of the present study and from the literature. The model estimated that on average 68 Common Eiders would collide with the turbines in one autumn season, with a range of 3 to 484 individuals. The estimated average number of collisions of 68 individuals lie within range of the published estimates from the literature.

The model in its present form, as a deterministic model, must be characterised as a preliminary solution. Before the preferred stochastic approach can be applied, enabling the variance of the data of the input parameters to be incorporated in the final collision estimate, the last radar data collected in 2005 will have to be included.

1 Introduction

Millions of birds migrate annually between their breeding and wintering areas. During these flights they often make use of the lowest 150 metres of air space above ground level, and hence, risk colliding with human obstacles such as buildings, bridges, towers, power lines and wind turbines (Karlsson 1977, Brown & Drewien 1995, Bevanger 1998, Kerlinger & Kerlinger 2000, Wiese et al. 2001, Nilsson & Green 2002). It is well documented world wide that birds collide with such constructions, and in theory these mortality events are most likely to occur in periods of poor visibility (e.g. in dark, rain, snow and foggy conditions; Desholm et al. 2003, Desholm 2003). The highest number of casualties has been reported as discrete events, occurring especially when sudden weather changes have reduced the visibility during periods of high migration intensity (Nilsson & Green 2002).

During the past decade, several studies have focused on the topic of collisions between birds and wind turbines (Pedersen & Poulsen 1991, Winkelman 1992, Tucker 1996, Garthe & Hüppop 2004, Band et al. in press), as numbers of wind farms have increased significantly during this period. However, to date the vast majority of the operating wind turbines have been constructed on land where searching for casualties and controlling for the removal by predators have been the preferred and straightforward way of obtaining data on collision frequency. The European wind power industry plans to exploit the offshore potential for power production in the future and in Denmark the first two large offshore wind farms are already in operation. Since most assessments of turbine-related collision risk among birds have been conducted on land, knowledge of the avoidance response of the generally large and presumably less manoeuvrable waterfowl species to offshore turbines has been almost non non-existent until recently. Lack of data combined with the fact that these species are long-lived and therefore relatively sensitive to additional adult mortality have resulted in concerns for possible negative cumulative impacts on their populations. The placement in offshore locations makes it difficult to conduct investigations as described above, and hence, novel methods needed to be developed and used.

To determine the impact of collision mortality on populations, it is essential to determine the number and species involved (or at least identify casualties to species group). This is important because a similar collision frequency may have a significantly different impact on two different populations, dependent on their population dynamics. Given that the numbers of birds colliding with offshore turbines were expected to be few and the events rare, any method to count the number of bird collisions will need to be automatic, cost-effective and remotely controlled, whilst providing information on the species involved in each collision. The thermal infrared video technology was judged to meet these requirements since it is capable of detecting moving birds in all light conditions including total darkness. A project was therefore initiated in 2001 to develop a system for use in an offshore environment and to be operated from land. The system was named Thermal Animal Detection System (TADS) and was ready for use by the end of 2003 (Desholm 2003), and together with surveillance radar since 2000 (Kahlert et al. 2000, Desholm et al. 2003, Kahlert et al. 2004) it has formed the basis for data collection for the present report. This report presents the second season of offshore data collection by TADS and covers studies conducted during autumn 2004. The project is a part of the Danish Demonstration Project running at the Nysted wind farm and is initiated by the Miljøgruppen.

The aims of this study are two fold:

1) to collect data on the number of waterbird collisions and on the near rotor evasive behaviour using TADS, and
2) to compile information (data collected by TADS and radar) to build a deterministic predictive collision model (DPCM) for estimating the number of Common Eiders, the most common species in the area, colliding with the sweeping turbine blades at the Nysted offshore wind farm, Baltic Sea, Denmark.

In the longer term, experience from several seasons of surveillance of turbines by TADS can be compiled into a library of sequences. Hence, the long-term objectives of future TADS-studies aim at answering the following questions:

1) How do different bird species or groups of species react when approaching single turbines, and is the reaction pattern related to weather conditions, flight speed, flight altitude and flock size? Insight into this subject will be very useful in future management programmes if actions are to be taken to lower the frequency of bird collisions at offshore wind farms.
2) What is the species-specific probability of collision for birds approaching the turbines, and is the probability related to weather conditions, flight speed, flight altitude or flock size?

Henrik Quist, PræcisionsTeknik A/S is thanked for technical assistance, the staff of Energi E2 and Ebbe Bøgebjerg from NERI for their practical assistance during offshore installation of the TADS and for help with establishing the data connection from Nysted wind farm through the optic fibres to land and through the Internet to the office at the National Environmental Research Institute (NERI). Finally, thanks to Hans Erik Dylmer for patiently looking through the many hours of manual horizontal recordings of the H9-turbine and the following data extraction.

2 Methods

2.1 Study area

The Nysted wind farm is situated south of Rødsand, ca 10.5 km west-southwest of Gedser Odde and ca 11.5 km south of Lolland in water depths of 6-9.5 m (Fig. 1). The wind farm consists of 72 2.3 MW turbines arranged in 8 north-south orientated rows each with 9 turbines. For a detailed description of the wind farm see Kahlert et al. (2000). The study area is known to be passed by more than 250,000 Common Eiders each spring and autumn on their migration over the Baltic Sea (Alerstam et al. 1974, Christensen & Grell 1989).

The TADS was mounted on the second most southern turbine (H8) in the eastern row during autumn 2004 (Fig. 2). This position represent a sector with high migration volume of waterbirds during the autumn, and was chosen to potentially register as many passing birds as possible in the vicinity of a monitored turbine.

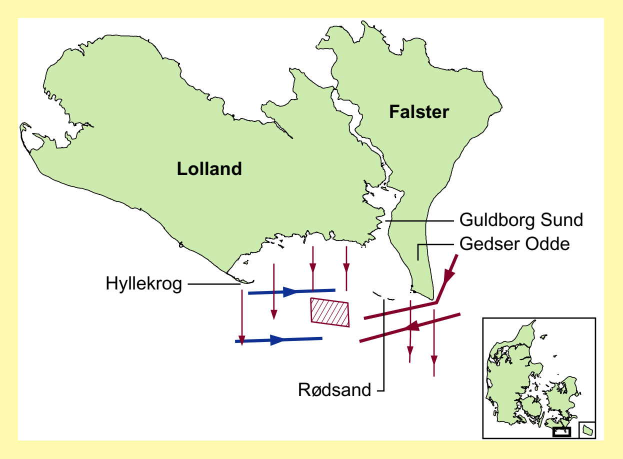

Figure 1. The wind farm and study area south of Lolland and Falster in south-eastern Denmark. Names of locations are indicated. The hatched area represents the wind farm area, thin and thick arrows indicate the schematic direction of terrestrial and waterfowl migration, respectively. Blue arrows indicate spring migration and red arrows autumn migration (from Kahlert et al. 2004).

2.2 Thermal Animal Detection System (TADS)

The TADS is an infrared based detection system that can monitor the behaviour of animals in total darkness and in an automated way so thermal video sequences are stored only if relatively hot animals enter the field of view. TADS has been developed for use in the severe and saline conditions of offshore areas (Desholm 2003).

All objects with a temperature above absolute zero, i.e. -273°C, radiate heat. Thermal imaging is a method of obtaining images of objects by measuring their own, and the reflected heat radiation detectable within the infrared spectrum of wave lengths of 2-15 m, and contrasts the ordinary photographic image which results from the reflection of visible light. For a more detailed description of the theory behind the thermal imaging technique see Desholm (2003).

Using a 24° lens, the maximum coverage (32.4%) of the disk area swept by the blades of a wind turbine rotor was achieved (hereafter referred to

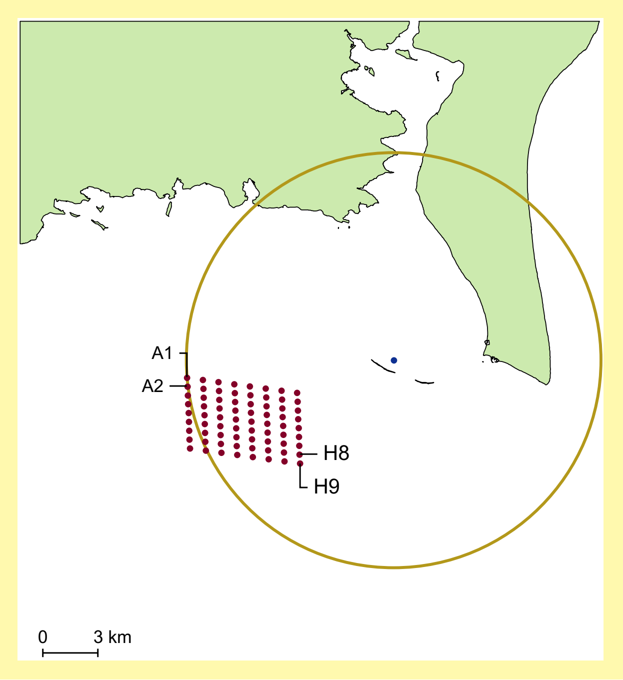

Figure 2. Placement of the observation tower (blue dot), the turbines (red dots) and extent of radar range (yellow circle) for mapping the migration trajectories of waterbirds. The TADS was mounted on the H8 turbine.

as the sweep area). For more details on the camera model Thermovision IRMV 320V from FLIR see specifications at the Internet site: http://www.flirthermography.com/media/320V.pdf

In order to identify birds appearing on the imagery to species level, a combination of body shape, the movements of the flying bird and the wing beat frequency has to be taken into account. However, as the distance between the bird and camera increases the possibilities of identification will decrease.

The main features of the TADS are as follow:

1) A thermal video camera with a 24° lens that can detect birds in total darkness and, to a greater degree than the human eye, in dense fog also.
2) A thermal trigger software which start downloading video sequences to the hard disc of a computer when at least one pixel in the field of view exceeds an operator-defined threshold temperature level ensuring an automated way of saving mainly sequences when birds are either passing or colliding with the turbines.
3) A sealed metal box for camera protection against precipitation and salty seawater spray (Fig. 3).
4) A pan/tilt head enabling the operator to change the heading and vertical angle of the field of view (Fig. 3).
5) A computer sited inside the turbine tower for the necessary software and video sequence storage.
6) A network connection from the turbine computer at sea to the NERI office on land.
7) A windscreen wiper and a sprinkler system.
8) A water valve for removal of condensing water inside the camera housing.

Figure 3. Thermal camera mounted with a pan/tilt head on an offshore turbine at Nysted wind farm.

2.3 Measuring avian collisions

During autumn 2004, a single TADS was used to monitor bird collisions at the H8-turbine at the Nysted offshore wind farm in the Danish part of the Baltic Sea (Fig. 2).

The camera was mounted on the eastern side of the turbine tower at c. 7.5 m a.s.l.

Data were collected during both day and night from 10 September to 7 November 2004. Only one operator performed camera adjustment settings and data collection, ensuring as high continuity and as low variance in the data collection process as possible. Two different views were used during data collection:

1) the preferred vertical view for monitoring the birds passing or colliding with the turbine tower and the turbine blades,
2) the 45° angle view for monitoring the near vicinity of the turbine towards the north.

View 1 was the primary view usable in westerly winds only when the blades were rotating on the opposite side (western) of the tower in relation to the camera, and the aim using this viewing mode was to measure collisions directly. View 2 was the secondary view usable during all possible wind directions. The aim using this viewing mode was to collect data on the migrants flying in the very close proximity of the turbine.

In total, 72,677 minutes of TADS-operation was conducted during spring 2004, representing a total of 50.5 days out of a study period of 59 days, resulting in an operation efficiency (OE) throughout the entire study period of:

$$OE = \frac{72,677}{84,960} \times 100\% = 85.5\% \qquad \text{Eq. 1}$$

Monitoring was conducted in approximately equal proportions of the two viewing modes (Table 1).

From the recorded thermal video sequences, the following data were derived:

Table 1. The operation time (when the camera is running), monitoring time (when the camera was able to detect birds) and the number of recorded thermal sequences separated in accordance to the two different viewing modes. The two viewing modes are listed as they were prioritised during operation of the TADS. View 1 equals the vertical view and View 2 equals the 45 degree view.

	Operation time (minutes)	Monitoring time (minutes)	Number of sequences
View 1	37879	28571	1396
View 2	34798	31499	548
Total	72677	60070	1944

1) number of birds colliding with the turbine or passing in the near vicinity of it,
2) number of sequences triggered,
3) sequence length (seconds),
4) view type,
5) wind conditions during data collection (obtained from a meteorology mast within the wind farm area),
6) numbers of and reasons for false (i.e. non-bird) triggered sequences (when other things than birds triggered the recording).

2.4 Collision model parameterisation

Not only can TADS be used to monitor the avian collisions with wind turbines, moreover it is capable of collecting data for model parameterisation. Since it will never be economical feasible to monitor all turbines within a large offshore wind farm a modelling approach will always be necessary. A framework for a predictive collision model will be presented in chapter 2.5 and below is described those input that were collected by the TADS during autumn 2004. The remaining input data for the model originate from visual and radar data collected over the past five years and will be presented in the chapter on modelling.

2.4.1 Near rotor-blade avoidance response

The ability of birds to perform a last-second evasive manoeuvre in order to pass safely the area swept by the rotor-blades is an important factor to be incorporated into any future predictive collision models. Such information will be obtained both from all three viewing modes. Ideally, this information should be plentiful and species specific, but it must be emphasised here that this study using one TADS only during one autumn migration season will not provide all the necessary data, and thus, more data collection will be needed in the future if this topic has to be understood.

2.4.2 Flight altitude

Knowing the flight altitude of the migrants is essential for the process of predicting the number of future collisions through modelling. The height data will be derived from manually recorded thermal video sequences of birds passing between the turbine at which the TADS is mounted (H8) and the neighbouring turbine towards south (H9; Fig. 2). Each sequence was five minutes long and processed by a human observer. Looking through all these hours of recordings and finding the passages where birds were passing the field of view was very time consuming. The speed of the process can be enhanced by using the fast moving forward feature which increase the frame rate. This not only reduces the time for processing but also increase the contrast between the often blur background and the moving bird flock, and hence, makes the processing work a lot easier.

In order to estimate the flight altitudes of migrants using TADS, the distance and angle to each individual/flock has to be estimated. The distance (A) to the recorded Common Eider flocks was estimated by trigonometry:

$$A = \frac{C}{\tan V_h} \qquad \text{Eq. 2}$$

where C represents half the distance the flock flew when passing the field of view (on the east-west direction) and V_h is half the horizontal angle of the applied camera lens which was a 24° lens. C was calculated for each flock by multiplying the time it took to pass half of the field of view with the ground speed (the mean air speed for Common Eiders corrected for the wind assistance experienced by the birds recorded by the TADS). The mean air speed for Common Eiders was estimated from five years of radar data on the species ground speed corrected for the wind assistance.

From the visually obtained line of sight the vertical angle to each bird can be estimated by trigonometry:

$$V_v = inv\tan\frac{a}{b} \qquad \text{Eq. 3}$$

where a denotes the projected height of the bird at the neighbour turbine and b denotes the distance between the two turbines (Fig. 4).

Knowing the distance and angle to the bird, the flight altitude (T) of the recorded flocks of Common Eiders was estimated by trigonometry:

$$T = (\sin(V_v)\times A) + H \qquad \text{Eq. 4}$$

where V_v is derived from equation 3 and A from equation 2 and H denotes the mounting height of the TADS (Fig. 4).

Measuring flight altitude by means of TADS is constrained by the relative small vertical opening angle of the camera lens (18°), which result in a limited field of view. This will exclude bird flocks flying high and close to the TADS from being detected. The view direction was set towards the south in order to obtain data from both inside and outside the wind farm. Consequently, the number of flocks flying at the same height as the sweeping rotor-blades will be underestimated inside the wind farm but not outside. This must be kept in mind when analysing the frequency distributions of flying altitudes.

2.4.3 Flock size and species composition

From the 5-minute horizontal recordings the number of individuals in each flock was estimated visually by a single experience observer. From the same sequences species composition was determined by a combined assessment based on flight pattern, flock structure, migration speed, wing beat frequency and the general appearance of the individuals (known as the 'jizz').

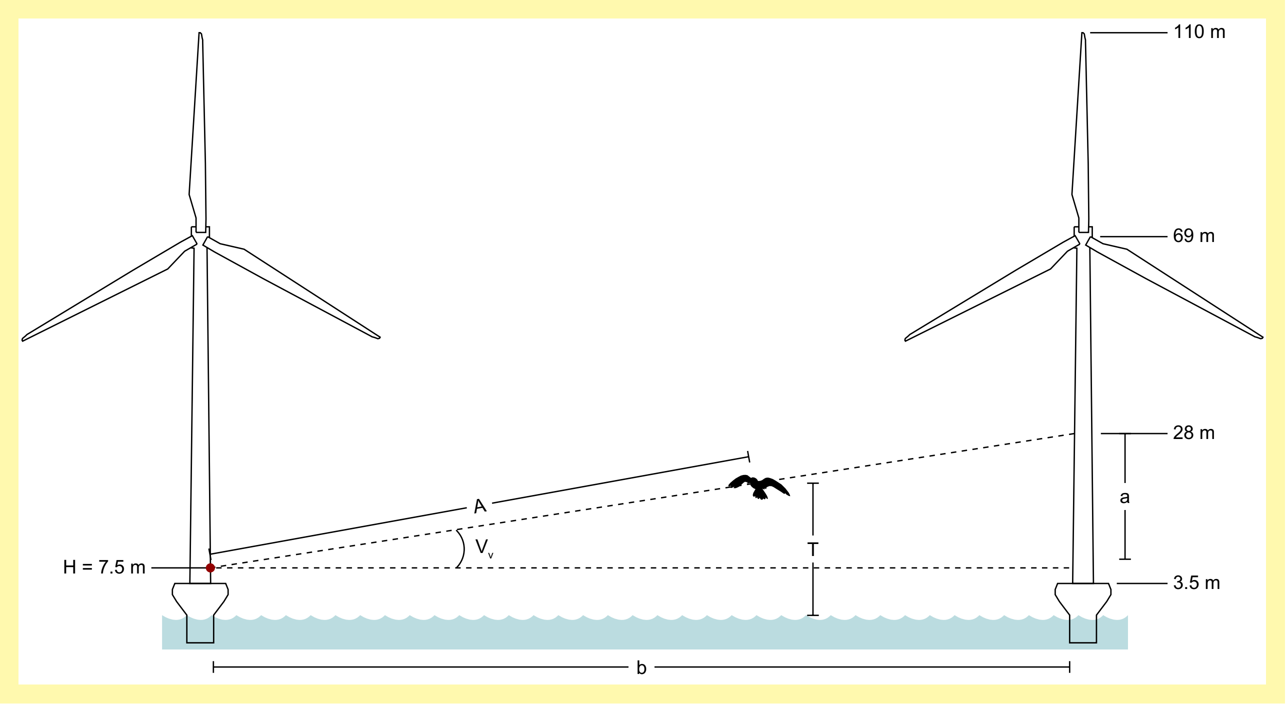

Figure 4. Schematic presentation of the trigonometry features used for estimating the flight altitude (T) of the migrating waterbirds. A denotes the distance (m) between the TADS and the bird flock (depicted as a single bird), V_v the vertical angle of flock, b the distance between the two turbines (480m), a the projected height on the neighbour turbine of the flock, and H the mounting height of the TADS.

2.5 Avian collision model

When constructing collision prediction models it is necessary to discriminate between models for EIA studies (pre-construction) and models for effect studies (pre- and post-construction) since only the latter offers the opportunity of including the avian evasive actions towards wind turbines. This is because data on species specific evasive manoeuvring are very scarce. Consequently, data on evasive manoeuvre capabilities need to be collected at the study site of interest before proper estimates of the number of collisions (including avoidance behaviour) can be estimated through quantitative predictive modelling. Nevertheless, it is recommended to build non-evasive-types models as part of the EIA studies, as a first crude assessment of the potential risk of collision for any proposed wind farm.

2.5.1 Framework for a collision model

In the present report focus have been at the development of the model framework, and hence, only the deterministic model for autumn migrating waterbirds (Common Eiders) colliding with the rotor-blades during one season will be presented.

Risk of collision is defined as the proportion of birds/flocks exposing themselves to a collision by crossing a scale-specific collision conflict window (e.g. a wind farm or the area swept by the rotor-blades). The risk of collision (r_i) is assessed at four levels of conflict windows: Level 1 relates to the study area, level 2 the wind farm, level 3 the horizontal reach of rotor-blades, and level 4 the vertical reach of rotor-blade (Fig. 5). The value of r_i can be measured directly for each level post-construction as an average transition probability, or be estimated pre-construction by multiplying the pre-construction proportion of birds/flocks (p_i) passing the level specific conflict window with the assumed (published estimates) proportion of birds (a_i) not showing any evasive manoeuvres at the given level. After level 4, a factor describing the by-chance-prob-

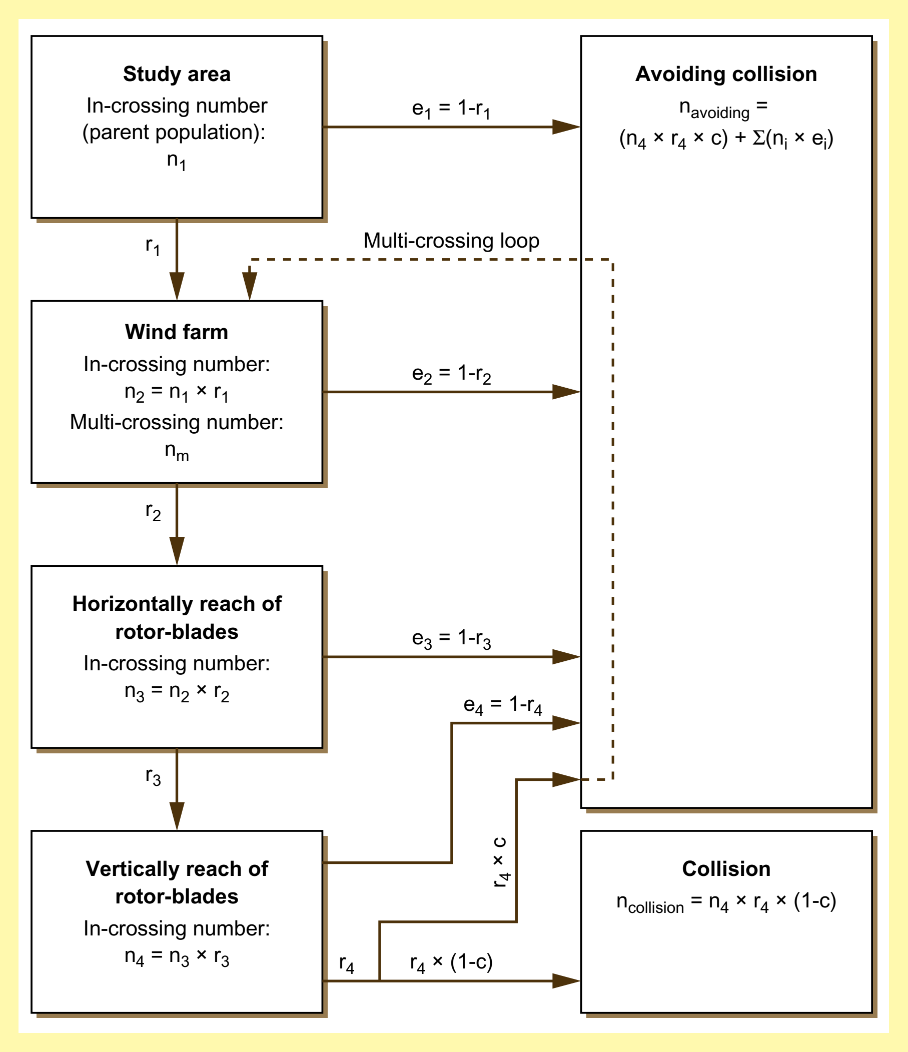

Figure 5. Schematic presentation of the collision prediction model where the boxes to the left represent the four scale-specific conflict windows and the boxes to the right the non-colliding and colliding segments of the migrants. The six values of n_i denotes the number of birds/flocks which enter each box and can be calculated in accordance to the equations presented in the boxes. The migration volume in study area is represented by n_1 and n_m is the number of north-south orientated rows of turbines that a given flock of birds passes on its way through the wind farm. Risk of collision is denoted r_i and is defined as the proportion of birds/flocks exposing them self to a collision by crossing a collision conflict window (e.g. wind farm or area swept by the rotor-blades). The evasive transition rates are denoted as e_i and c is a factor describing the by-chance-probability (c) of not colliding with the rotor-blades when crossing the area swept by the rotor-blades.

ability (c) of not colliding with the rotor-blades must be incorporated to account for those birds passing safely the area swept by the rotor-blades by chance (Fig. 5; Tucker 1996, Band et al. in press). An overall risk of collision (R) can be obtained by multiplying the four probability risk values:

$$R = r_1 \times r_2 \times r_3 \times (r_4 \times (1-c)) \qquad \text{Eq. 5}$$

In the present report, the simple deterministic way of estimating the overall number of collisions at the wind farm ($n_{collision}$) will be applied. Average values for all the input parameters will be used in this (Fig. 5) predictive collision model. In practice, R must be multiplied with n_1 using average values for all transition probabilities and for the c and n_1-values. The more profound way of estimating $n_{collision}$ would be by simulating the migration event from n_1 through $n_{collision}$ in accordance to the collision prediction model (Fig. 5) by resampling transition probabilities and c-values and n_1-values from probability distributions collected in the field post-construction.

This model covers one row of turbines only, and hence, the model has to be repeated several times (equal to n_m) re-starting at level 2 (wind farm) with $n_4 \times r_4 \times c$ individuals from the previous simulation (see the Multi-crossing loop at figure 5). This approach implies that only birds passing the area swept by the rotor-blades at the first row of turbines will have the possibility of passing the area swept by the rotor-blades of the second row of turbines and likewise for any next rows. This assumption will result in a relatively small estimated number of collisions at row 2-9 compared to row 1, but intuitively this makes sense. This is because birds avoiding the turbines in the first row most properly will have the same perception of risk when passing the turbines at the next row of turbines, and hence, most probably perform an evasive response again.

The average number of rows the flocks of waterbirds were passing when crossing the wind farm area was estimated from the autumn base-line data collected at the study site from 2000-2002. Only tracks entering the wind farm through the eastern gate was used. Each track was followed through the wind farm area and the number of north-south orientated turbine rows passed was counted. If a track terminated inside the wind farm area its last node was prolonged until it left the wind farm area.

The modelling process at this early stage of the before-and-after study at the Nysted offshore wind farm should be considered as preliminary, since a more detailed modelling will be performed after the final season of data collection (2005). At this point, model input values is intended to be resampled from the full and final data set collected on site, and thus, the very important variance estimates of the output values (e.g. $n_{collision}$ and $n_{avoiding}$) will be produced.

When the data collection (both in planned radar studies and possible future TADS studies) is terminated the model will be applied for the following scenarios:

a) day and night,
b) tail-, head- and cross-wind (especially r1, r3 and c may be affected significantly by the wind direction and speed), and
c) rotor-blades, foundation and turbine tower.

The results from these partial scenarios will finally be combined in an overall estimate of the number of collisions at the wind farm under study.

Parameterisation of the collision prediction model can be done by applying both radar, TADS and visual observations in the data collection protocol as follows for each of the four spatial levels (Fig. 5):

Level 1. This level relates to the study area and specify its in-crossing number n_1 representing the overall number of birds/flocks passing the study area during a migration event (i.e. spring or autumn migration season).

Level 2. For this part of the analysis radar data defining the probability of migrants passing the wind farm is needed (r_1).

Level 3. For this part of the analysis radar data defining the distance to nearest turbine is needed for those flocks that pass through the wind farm. From the compiled frequency distribution of distance to nearest turbine, the proportion (r_2) of the migrating flocks that pass within the horizontal risk distance (equal to the length of the rotor-blades) of the turbines can be calculated for day and night. Desholm & Kahlert (in press) has recently recorded a diurnal difference in mean distance to turbines for waterbirds.

Level 4. In order to estimate the proportion (r_3) of birds flying within vertically reach of rotor-blades, a height distribution is needed. Depending on the level of information on migration altitudes the height distribution can either be based on theoretical calculations or preferable on directly measured altitude data collected at the study site. Altitude data on migrating birds can be collected by operating a surveillance radar vertically or by applying the height data collection protocol by TADS (see paragraph 2.4.2).

At this stage, n_4 (number of birds/flocks passing the area swept by the rotor-blades) was estimated and the final transitions to birds colliding ($r_4 \times (1-c)$) and avoiding the rotor-blades ($e_4 + (r_4 \times c)$) must hereafter be executed. For inclusion of the near rotor-blade evasive manoeuvres (e_4) which must be collected during both day and night, infrared detection systems (e.g. TADS) must be applied to collect data on ability of the different species of birds to perform evasive actions when crossing the sweeping rotor-blades. So far, such evasive factors have only been reported in the study by Winkelman (1992) using a thermal camera. In total, 92% of the birds (all species combined) approached the rotor-blades without any hesitation at day time whereas this figure was 43% at night time. It is assumed that birds showing evasive action (e_4) when crossing the area swept by the rotor-blades are passing safely.

Finally, an avoiding-by-chance factor (c) must be incorporated after level 4 for those birds crossing the area swept by the rotor-blades safely without performing any evasive actions. Procedures for calculation of 'c' can be found in Tucker (1996) & Band et al. (in press) and can be directly incorporated in the collision prediction model.

The end product of the collision prediction model will be the predicted number of birds colliding with the turbines:

$$n_{collision} = n_4 \times r_4 \times (1-c) \qquad \text{Eq. 6}$$

and the predicted number of birds that avoid (either by chance or by evasive actions) colliding with the turbines:

$$n_{avoiding} = (n_4 \times r_4 \times c) + (n_i \times e_i) \qquad \text{Eq. 7}$$

where n_1 (overall number of birds passing the study area) equals the sum of $n_{collision}$ and $n_{avoiding}$.

2.6 Data handling

All data were stored in databases. Unusual data were tagged and commented to enable a later exclusion of erroneous data. After having stored data in databases, the original data were checked once again.

The following quality control procedures were imposed throughout the production of this report:

- Internal scientific review by a senior researcher
- Internal editorial and linguistic revision
- Internal proof-reading
- Layout followed by proof-reading
- Approval by project managers.

3 Results

3.1 Measuring avian collisions

Wind conditions during the study period affected the choice of viewing mode to a very high degree, since the preferred vertical view required a wind direction from the opposite side of the turbine tower to the placement of the camera. Otherwise the turbine blades would continuously sweep through the field of view of the camera and facilitate a false triggering. In autumn 2004, the optimal wind for the vertical viewing mode was from westerly directions (180°-360°) as the camera was mounted on the eastern side of the turbine tower (90°). In 54.7% of the study period winds were from westerly directions and consequently it came from easterly direction in the remaining 45.3% (Fig. 6).

During operation the thermal trigger software saved 1,944 thermal video sequences (see Table 1), of which five were triggered by birds passing the field of view in the 45° viewing mode and one was triggered by the rotor blades showing a bird in the vertical view mode. No birds were recorded as colliding with the rotating turbine blades (vertical view only) nor colliding with any part of the turbine during the 28,571 minutes of vertical monitoring (Table 1).

Event number 1 was recorded on 4 October 2004 at 21:19 PM (in the dark) in the 45° viewing mode. The resulting thermal video sequence showed 15 large passerines (size of thrushes) passing the field of view from the middle of the field of view and up towards the right corner (Fig. 7). The distance from the birds to the camera was c. 50 meters. No evasive behaviour could be detected.

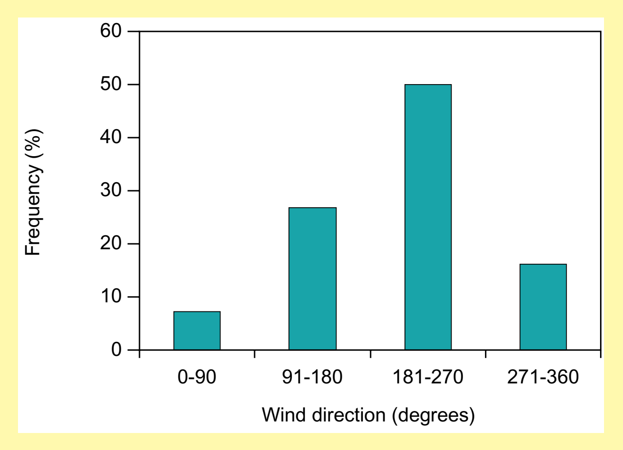

Figure 6. Frequency distribution of the wind direction divided into four sectors (0-90° = north-east, 91-180° = east-south, 181-270° = south-west, 271-360° = west-north) and experienced in the study area from 10 September to 7 November 2004.

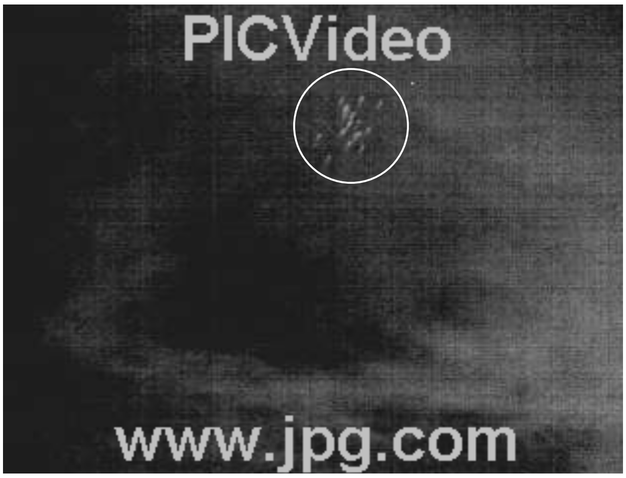

Figure 7. A single frame from the sequence recorded at event no. 1 showing 15 larger passerines passing the field of view upwards.

Event number 2 was recorded on 6 October 2004 at 06:50 AM (in the dark) and showed a single passerine approaching the rotor-blades, standing still hovering on its wings before it returned to the direction it came from (Fig. 8). The distance from the bird to the camera was c. 30 meters and it was recorded in the vertical viewing mode. This

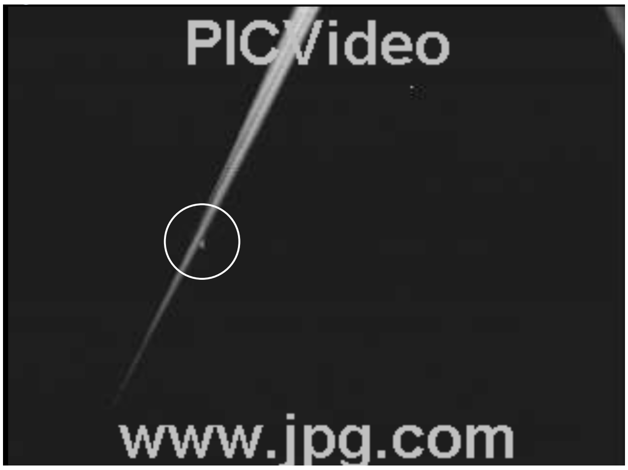

Figure 8. A single frame from the sequence recorded at event no. 2 showing a single passerine approaching the rotor-blades, standing still hovering on its wings before it returned to the direction it came from.

Figure 9. A single frame from the sequence recorded at event no. 3 showing 25 waterbirds, looking very much like Common Eiders, passing the field of view towards right (west).

must be characterised as an evasive behaviour that eliminated the collision risk.

Event number 3 was recorded on 6 October 2004 21:19 PM (in the dark) and shows 25 waterbirds looking very much like Common Eiders. They were passing the field of view from the left (east) to right (west) and were recorded in the 45° viewing mode (Fig. 9). The distance from the birds to the camera was c. 120 meters. No evasive behaviour could be detected.

Event number 4 was recorded on 6 October 2004 21:22 PM (in the dark) and shows a single passerine (Fig. 10) passing from left to right (towards southwest) at a distance of c. 20 meters. The event was recorded in the 45° viewing mode and no evasive behaviour could be detected.

Figure 10. A single frame from the sequence recorded at event no. 4 showing a single passerine passing from left to right (towards south-west).

Figure 11. A single frame from the sequence recorded at event no. 5 showing a single passerine passing the field of view from left to right downwards.

Event number 5 was recorded on 10 October 2004 22:12 PM (in the dark) and shows a single passerine (Fig. 11) passing the field of view from left to right downwards in the 45° viewing mode and at a distance of c 15 meters. No evasive behaviour could be detected.

Event number 6 was recorded on 20 October 2004 17:31 PM (in the twilight) and shows c. 30 medium sized birds (probably waterbirds; Fig. 12) approaching the turbine from the south and performing an evasive manoeuvre towards the west before disappearing out of the field of view. The event was recorded in the 45° viewing mode and at a distance of c. 80 meters.

Figure 12. A single frame from the sequence recorded at event no. 6 showing c. 30 medium sized birds (probably waterbirds) approaching the turbine form the south and performing an evasive manoeuvre towards the west (right) before disappearing out of the field of view.

The remaining 1,938 non-bird sequences can be characterised as false triggered sequences, and was the result of changing temperature patterns in the background of the camera view. Such temperature changes in the field of view were mainly caused by drifting clouds (45.5%), sun heating of the atmosphere especially just after sunrise (21.1%) by the blades of the turbines turning into the field of view (32.0%) because of changing wind conditions, or due to other reasons (the sun entering the field of view (1.5%).

However, such false triggered sequences were easily identified as being non-bird sequences, since a series of similar (showing similar picture in the first frame) sequences were saved during a restricted period of time which could be processed and removed within a few minutes in a single operation, and these periods were then excluded from the monitoring time. In order to estimate the monitoring efficiency, such unusable periods, which comprised many false-triggered sequences, were excluded from the operation time. Of the total operation time, 12,607 minutes (17.3%) could be characterised as unusable where the trigger software was constrained in operating properly. Thereby, the monitoring efficiency (ME) amounted to:

$$ME = \frac{72{,}677 - 12{,}607}{84{,}960} \times 100\% = 70.7\% \quad \text{Eq. 8}$$

3.2 Collision model parameterisation

3.2.1 Near rotor-blade avoidance response

During the study period of 50.5 days, no waterbirds, which was the target species in this study, were detected as approaching the rotor-blades at a short distance. One passerine was observed flying towards the rotor-blades and eventually performed a 180° horizontal turn and returned in the direction it came from. At a longer distance from the turbines (100-200 m), three flocks of waterbirds (probably Common Eiders) performed horizontal evasive manoeuvres to individual turbines (manual recordings in horizontal viewing mode). One of these flocks also showed a downward vertical movement that was interpreted as an evasive action.

3.2.2 Flight altitude

Mean air speed for Common Eiders was estimated to 17.34 m/sec (SD = 2.4; n = 352) for all flocks detected by radar in the study area during 1999-2004 and visually determined to species.

The flight altitude was estimated on the basis of 514 5-minute horizontal TADS-recordings (42.8 hours) in accordance to equation 2-4. In total, 12 flocks of waterfowl were recorded inside the wind farm and 90 flocks outside. On average, each 5-minute sequence contained 0.2 flocks, and hence, five sequences are needed to obtain on average one flock passing the field of view. The biased representation of data towards a small proportion of flocks, which was recorded inside the wind farm, is a consequence of the relatively low migration volume inside the wind farm (Desholm 2005) and to the geometric constrains described in the end of paragraph 2.4.2. Due to the low number of flocks detected inside the wind farm, a correction of the altitude data cannot be performed. When more data are collected in the future, such a correction procedure can be performed and a statistical comparison between flocks inside and outside the wind farm can be conducted.

The mean (±SD) flight altitude was 13.7 m (±15.0) and 28.9 m (±19.6) for flocks of waterbirds flying inside and outside the wind farm, respectively. Figure 13 shows the frequency distribution of flight altitudes for waterbird (probably Common Eiders) flocks inside and outside the wind farm.

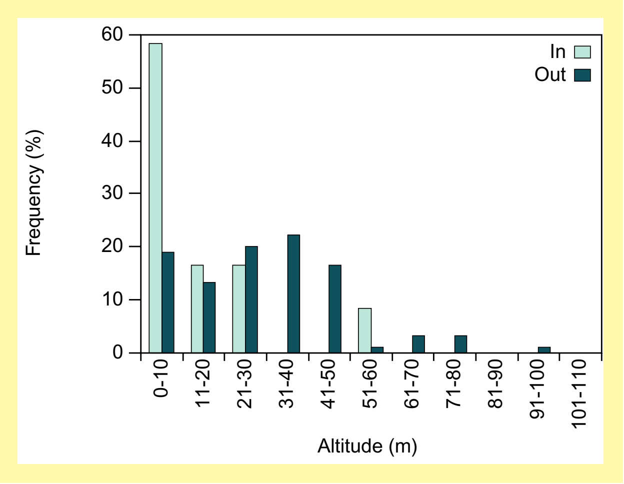

Figure 13. Frequency distribution of the flight altitude for flocks of migrating waterbirds passing the view of the TADS. "In" means flocks flying within the wind farm and "Out" flocks flying just outside the wind farm to the south.

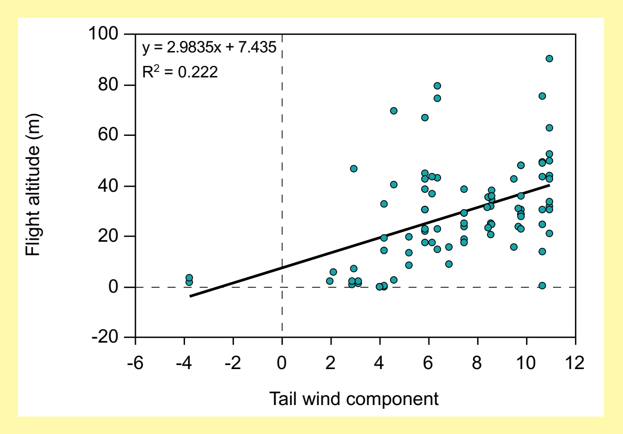

Figure 14. Relationship between the tail wind component and flight altitude of waterbirds and its linear regression. Positive tail wind component means tail wind whereas negative component values means head winds.

No flocks were observed flying higher than the upper reach of the rotor-blades (110 m) and the percentages of flocks flying below the rotor-blades were 91.7% and 52.2% for flocks inside and outside the wind farm, respectively.

A tendency to increasing flight altitude with increasing tail-wind component was discovered (Fig. 14), but the explanatory power was relatively low. As can be seen from figure 14, only very few data have been collected in periods with head winds since these are known to result in low migration volume (Pettersson 2005).

Unfortunately, only three flocks of waterbirds were detected during darkness in the 514 sequences, and hence, a proper day vs. night comparison can not be made, at present.

3.2.3 Flock size and species composition

From the horizontal TADS-recordings (from both inside and outside the wind farm) 15 flocks of larger gulls (i.e. Herring Gull *Larus argentatus*) and 101 flocks of waterfowl (probably Common Eiders) could be assessed with regard to flock size. Of the 15 gull observations 13 was of single individuals and two of two individuals, which resulted in an average flock size of 1.13 (SD = 0.35). Waterfowl/ Common Eiders was presented by 101 flocks for flock size estimation with an average of 25.45 (SD = 18.54) individuals per flock. The frequency distribution of the waterfowl flock sizes (Fig. 15) was skewed towards smaller flocks with values for skewness and kurtosis of 1.6 and 1.8, respectively. Again the number of flocks detected in darkness was not sufficient for a proper statistical analysis between day and night, but further data collection in the future will overcome this. In this study, the mean flock size values will not be included in the collision model. However, the data will be presented here and used in the fully developed version of the model were model parameters will be resampled from the collected data.

3.3 Collision model

3.3.1 Parameterisation of model input values

In the following, procedures for parameterisation of the average of each input value for the deterministic predictive collision model (DPCM; see figure 5) will be outlined and used in the average scenario. Furthermore, for each parameter an alternative pair of values will be applied using standardised or published values that respectively maximise and minimise $n_{collision}$. These maximum and minimum values were then used for two alternative scenarios (Maximum scenario and Minimum scenario). For a description of the abbreviations used for transitions rates and in-crossing numbers, see chapter 2.5.

Parameterisation of n_1

The estimated migration volume (n_1) for Com-

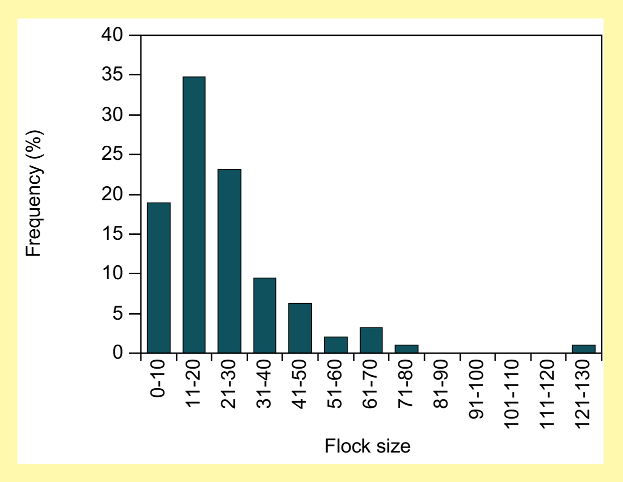

Figure 15. Frequency distribution of the flock size of waterbirds (mainly Common Eiders) as observed by the horizontal TADS recordings (n = 101).

mon Eiders in the study area is adopted from Desholm (2005) with 343,461 individuals for one autumn season used in the average scenario. The two alternative values for the maximum scenario and minimum scenario is defined respectively as 25% more than n_1 and 25% less than n_1 (see Table 2).

Parameterisation of r_1

Values presented in this paragraph is adopted from Desholm & Kahlert (In press). The overall proportion of flocks (r_1) crossing the eastern row of turbines decreased significantly from 40.4% (n = 1,406) during pre-construction (2000-2002) to 8.9% (n = 779) during initial operation (2003; $\chi^2 = 239.9$, $P < 0.001$). The data on r_1 for the post-construction year of 2004 are still being analysed but lye also between 8% and 9% (NERI unpublished data). In contrast to the analyses by Desholm et al. (2003) and Kahlert et al. (2004), the present analysis has defined night as the period from 2 hours after sunset to 2 hours before sunrise, and day as the period from sunrise to sunset. This procedure was adopted for comparing the situation of full light with total darkness. During initial operation r_1 was significantly higher at night compared to daytime (13.8%; n = 289 and 4.5%; n = 378, respectively; $\chi^2 = 17.1$, $P< 0.001$). The average value from autumn 2003 will be used in the average scenario, the night value for the maximum scenario and the day value for the minimum scenario (Table 2).

Parameterisation of r_2

The procedure for estimating the transition rate from study area to wind farm follows the approach by Desholm (2005), and hence, data from autumn 2003 were used. The cumulative frequency distribution of distances to nearest turbine, when birds passed the north-south orientated rows of turbines, was significantly different from an evenly distributed migration pattern both during day and night (Kolmogorov-Smirnov one-sample test; D = 0.0846, n = 260, $p < 0.05$ and D = 0.1775, n = 400, $p < 0.01$ for day and night, respectively; Fig. 16). Hence, the waterfowl flocks tended to fly between individual turbines instead of crossing the wind farm irrespective of the place-

Table 2. Input and output values for the three scenarios of the deterministic predictive collision model (see Fig. 5). The average scenario is run using average values for each parameter as described in paragraph 3.3.1. The two alternative scenarios (maximum and minimum) aim at determining the maximum and minimum number of collisions (see definition in text).

	Parameters	Average scenario	Maximum scenario	Minimum scenario
Model input	n_1	343,461	429,326	257,595
	c	0.849	0.821	0.877
	r_1	0.089	0.138	0.045
	r_2	0.074	0.100	0.056
	r_3	0.289	0.478	0.100
	r_4	0.675	0.920	0.430
	n_m	5.9	8.4	3.4
Model output	e_1	0.911	0.862	0.955
	e_2	0.926	0.900	0.944
	e_3	0.711	0.522	0.900
	e_4	0.325	0.080	0.570
	n_2	30,568	59,247	11,592
	n_3	2,262	5,925	649
	n_4	654	2,832	65
	$n_{avoiding}$ (first row)	343,394	428,860	257,592
	$n_{collision}$ (first row)	67	466	3
	$n_{collision}$ (wind farm)	68	484	3
	Probability of collision (%)	0.020	0.113	0.001

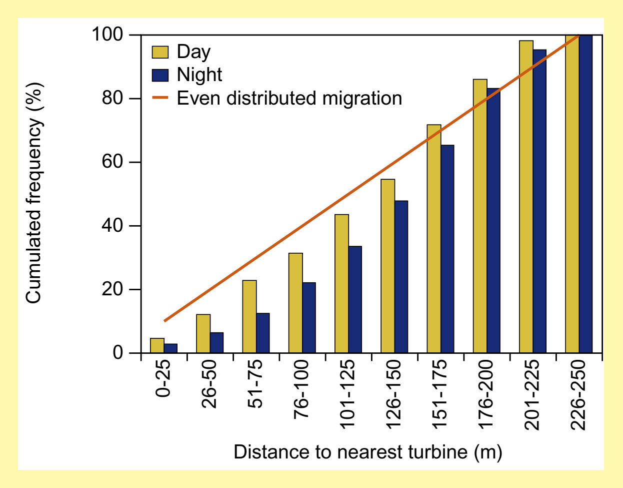

Figure 16. The cumulated frequency distribution of distances between flocks of waterbirds and nearest turbine when passing the north-south orientated rows of turbines. Adopted from Desholm & Kahlert (in press).

ment of the turbines. Likewise, the cumulative frequency distribution differed significantly between day and night (Kolmogorov-Smirnow two-sample two-tailed test, D=0.1273, n_{day} = 260, n_{night} = 400, d.f. = 2, $p<0.05$, adopted from Desholm & Kahlert (in press)), as the night-distribution was displaced further away from individual turbines (Fig. 16). The overall proportion of flocks flying closer than 41 m (length of rotor-blades) to the turbines were 7.4% (n = 660). During night and day this proportion was 5.6% (n = 400) and 10.0% (n = 260), respectively. The average value of r_2 (7.4%) will be used when modelling the average scenario and the time-of-day specific values will be used as the maximum (10.0%) and minimum (5.6%) values for the maximum and minimum scenario, respectively (Table 2).

Parameterisation of r_3

Measurements of the migration height of Common Eiders migrating in head winds have been adopted from Kahlert et al. (2000) where the proportion (r_3) of eiders flying at the altitudes swept by the rotor-blades (30-110m) was 10%. The flight altitude estimations from the present TADS study was used for the tail wind situation (see paragraph 3.2.2) where 47.8% (100%-52.2%) were flying in the area swept by the rotor-blades (Fig. 13). For modelling the average scenario the r_3-value (28.9%) lying in between the values for head and tail wind was used, for the maximum and minimum scenarios the values for respectively tail wind and head wind will be adopted (Table 2).

Parameterisation of r_4

Parameterisation of the proportion (r_4) of birds trying to pass the area swept by the rotor-blades without performing any evasive actions was significantly constrained by the general large proportion of birds which avoided flying in the collision risk zone of the blades. Therefore, it is not possible to estimate an r_4-value based on the data collected for this report. However, Winkelman (1992) reported that 92% of the birds approached the rotor without any hesitation at day time but only 43% at night time. These two figures were adopted as the r_4-values for maximum and minimum scenarios respectively, and the value lying in between (67.5%) will be used for the average scenario (Table 2). It must be stressed here that these values have not been collected for common eiders, but they are the only available estimates at present.

Parameterisation of c

The probability of passing safely the rotor-blades by chance was adopted from Band et al. (in press). The theoretic estimation of c by Band et al. (in press) for Greylag Goose was 0.877 and 0.821 for Harrier sp. *Circus* sp. The value for Greylag Goose *Anser anser* was used in the minimum scenario and the Harrier c-value in the maximum scenario. The value (0.849) centred between these two values was used as the c-value in the average scenario. These values are in close agreement with the mean values calculated by Tucker (1996) for a

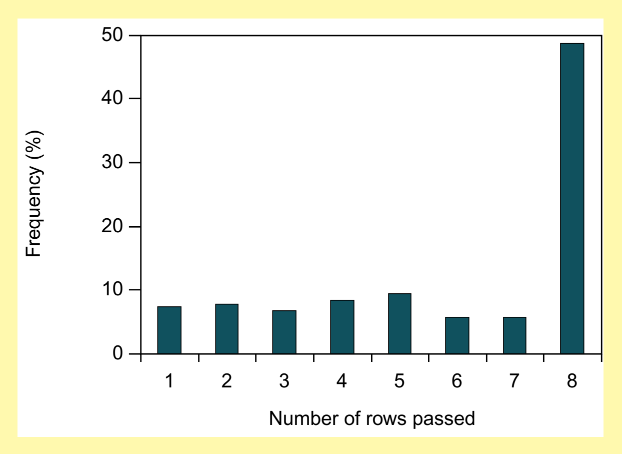

Figure 17. Frequency distribution of the number of north-south orientated rows of turbines passed by the autumn migrating flocks of waterbirds passing the wind farm area in the pre-construction period (2000-2002).

tailwind situation, and since the vast majority of the migration volume of Common Eiders passes the study area in tailwinds it seems reasonable to adopt those c-values.

Parameterisation of n_m

On average, each flock entering the wind farm from the east pre-construction passed 5.9 (SD = 2.5) north-south orientated rows of turbines. The majority of all trajectories (48.7%) passed 8 rows whereas the remaining flocks were more or less evenly distributed with between 1 to 7 row passages (Fig. 17). These data were incorporated into the model to take into account that most of the waterbird flocks passing the wind farm area passed more than one of the north-south orientated rows of wind turbines. In figure 5 this aspect is depicted schematically as the Multi-crossing loop. The average value of 5.9 row passages was used for modelling the average scenario and for the maximum and minimum scenario one SD (2.5) will be added (n_m = 8.4) and subtracted (n_m = 3.4) from the average, respectively (Table 2).

3.3.2 Running the model

Using the input values described above in the average scenario of the deterministic predictive collision model (Fig. 5) for the Nysted offshore wind farm resulted in an average number of 68 Common Eiders colliding during an autumn season (Table 2). The range in which the number of colliding Common Eiders most probably lies, is modelled through the minimum and maximum scenarios, and turned out to be between 3 and 484 individuals (Table 2). Hence, the general risk of collision for waterbirds passing the study area at Nysted is estimated to 0.001% - 0.113% with an average of 0.020%.

4 Discussion and conclusions

4.1 Monitoring

The results from the present collision monitoring study confirmed the conclusions in spring 2004 obtained at the same wind farm (Desholm 2005). The present study period was about twice as long as the spring study (59 compared to 27 days), and equally, the present programme resulted in approximately twice the number of events during which birds triggered the TADS (6 compared to 3 events). This may indicate that what the TADS is measuring in terms of migration volume in the close proximity of the wind turbines is fairly constant between seasons in the same study area. Due to the relatively low sample size and only two seasons of study further investigations must be performed before firm conclusions can be made about the year to year variation.

Out of six events at least four showed passerines passing the field of view of the TADS, and this despite the fact, that the present monitoring scheme was designed for measuring waterbird collisions. This demonstrates that the TADS can also be used for monitoring passerines especially if a larger telephoto lens is applied.

In between the study by Desholm (2005) and the present study, improvement has been achieved with regard to operator skills resulting in a 7% higher monitoring efficiency and in a decrease in the number of false triggered sequences from 45.2/day to 32.8/day. This just reflects the fact that the complex skills of operating a TADS are likely to be improved and therefore the efficiency by which the system is collecting data may potentially be enhanced as experience is gained.

In conclusion, the risk of collision for Common Eiders at the Nysted offshore wind farm is too low to be measured directly by one TADS only. We know that only a very little fraction of the migrating Common Eiders fly close enough to the turbines to be at risk of colliding with rotor-blades or tower construction, but we can not measure the exact number of annual casualties with the available hardware.

4.2 Modelling

The applied values for the model input parameters were obtained partly from the conclusions of the present study and partly from the literature. Four out of seven parameters have been derived from the data of this study (n_1, r_1, r_2, and n_m), two parameters originate solely from other publications (r_4 and c), and one is base in part on both (r_3). To improve the predictive model and make it more site specific the c values could be calculated on the basis of resampled data collected in the study. Furthermore, species specific values for r_4 would be more appropriate to improve the model. At present, such data do not exists, however, in future this might change if international collaborative programmes regarding this issue have been established.

The interesting question whether there is a difference in the behaviour of the waterbirds between day and night can not be dealt with at this early stage of the study since only very few observations of birds have been recorded during night-time. This can be explained by the relatively low number of waterbirds migrating at night compared to day-time and because the main focus of this study was to maximise the number of recording of flocks. Further investigations need to be conducted to collate more data on the night-time behaviour before firm conclusions on diurnal differences in behaviour can be made, and before day/night values for different model input parameters can be applied.

The estimated average number of collisions of 68 Common Eiders during one autumn migration period equals 1.9 individuals per turbine per year, which lie within the published estimates at a coastal wind farm (Winkelman 1992). Caution should be taken though when using estimates which are not site-specific, since for obvious reasons local conditions like migration volume, species composition and topography most likely will play a significant role for the number of collisions. Therefore it is advised to compile and publish species specific behavioural data, which can be applied in future studies at other locations experiencing different local conditions. In the past, a tendency to publish estimates of the number of collisions per turbine per year only, have been very common. Unfortunately, such site specific data is not of much value at other sites unless the local conditions are very alike. But since this rarely happens, the data on the number of collisions per turbine per year from one study will never be used in others, and this is unfortunate considering the relatively resource demanding nature of this kind of investigations.

If a realistic maximum number of collisions can be estimated and this turns out to be at an acceptable level, obtaining the exact true value becomes less important. This is not to say that we should not try to estimate or preferably count the true number of collisions, but if the maximum estimated number of collisions is acceptable, from an ecological point of view, then resources might be used better at other wind farms or on other species.

As a validation of the presented results the likely number of collisions at the H8-turbine (at which the TADS was mounted) will be estimated and compared to the obtained results of no Common Eiders passing the field of view of the TADS. In order to estimate the likely number of collisions at the H8-turbine, a series of simple consecutive probability calculations must be performed. From Desholm (2005) we know that c. 25% of the waterbirds entering the wind farm through the eastern row do this between the two north-south neighbour turbines of H8, and if an equal migration pattern is assumed, 50% of those birds colliding at these three turbines will do so at H8. Only 33% of the area swept by the rotor-blades of H8 is covered by the single TADS and from Table 1 a collision monitoring efficiency of 39% can be calculated ((28,571 hours / 72,677 hours) x 100). If these probabilities are multiplied (0.25 x 0.50 x 0.33 x 0.39), a H8-correction factor (F) of 0.0161 can be estimated. Multiplying F with the estimated number of collisions at the first row of turbines from the DPCM will lead to an estimated number of collisions at H8. Multiplying the estimated F-value and the $n_{collision}$ from the average scenario of the DPCM results in a predicted annual number of collisions at H8 of a single Common Eider. In conclusion, it is therefore judged that the two partial results of this report, that no collisions were detected by the single TADS and the estimated annual 68 colliding Common Eiders, tend to be in agreement with each other. There seems to be too few collisions at the Nysted offshore wind farm to be recorded by a single TADS. However, it must be stressed here, that although one TADS may not be enough for direct measurement of the number of collisions at this wind farm, but the value of a single TADS as a tool for model parameterisation has proven very high. So, even though neither the monitoring or modelling part of the present study claim to have produce an exact estimate of the collision rate, they both suggest it to be relatively low, and by agreeing in this they strengthen the credibility of the overall conclusion.

The model in its present form as a deterministic model must be characterised as a preliminary solution. Before the preferred stochastic approach can be applied, enabling to incorporate the variance of the data into the final collision estimate the last radar data collected in 2005 will have to be included.

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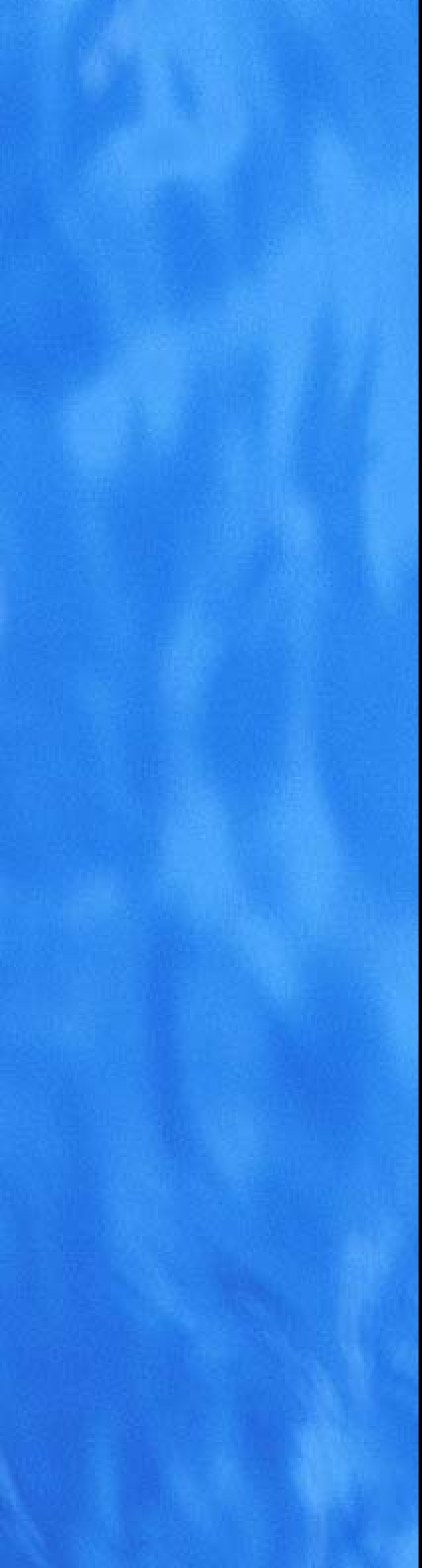
Publications:
NERI publishes professional reports, technical instructions, and an annual report (in Danish). Databases containing reference to all publications and current projects are available on the World Wide Web.



TADS investigations of avian collision risk at Nysted offshore wind farm,
autumn 2004