National Environmental Research Institute
Ministry of the Environment · Denmark

Preliminary investigations of bird-turbine collisions at Nysted offshore wind farm and final quality control of Thermal Animal Detection System (TADS)

Autumn 2003 and spring 2004

Report commissioned by Energi E2

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Data Sheet

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Synopsis

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

Information presented covers the autumn period of 2003 and spring period of 2004.

The aims of the report were threefold:

1) to present preliminary data on the number of avian collisions using infrared video recording (TADS),
2) to assess the performance of the TADS during prolonged operation in an offshore environment,
3) to compile information (data collected by radar) to model the probability of birds passing the sweep area of offshore wind turbines (Appendix I) in order to present recommendations for the development of a future TADS-study to be conducted from autumn 2004 onwards.

During operation the thermal trigger software saved 1,223 thermal video sequences on hard disc (see Table 1), of which only three were triggered by birds passing the field of view all in a 45° viewing mode. No birds were recorded as passing the sweep area of the rotating turbine blades nor colliding with any part of the turbine during the 11,284 minutes of monitoring.

The final quality control of the offshore utility of the TADS produced excellent results. It can be concluded that TADS can be considered as a fully developed monitoring set-up capable of detecting migrating birds flying over offshore areas and passing at the range of distances planned for the equipment.

The fact that no birds were recorded as passing the sweep area of the A2-turbine could give rise to some doubt as to whether the TADS actually functioned properly during the trial. However, comparison with data gathered from other sources confirm the extremely low intensity of waterbird migration in the near vicinity of the turbines:

A the 5-min long manual sequences of horizontal view successfully detected 52 birds despite the very restricted number of operation hours,
B) the radar data on bird flocks migrating within the wind farm show significant avoidance responses towards individual turbines, resulting in a higher probability of flying more than 50 m from the turbines than expected by chance alone.

Given the maximum coverage of c. 30% of the sweep area per TADS and the monitoring efficiency of 63.7% during the study period, it is considered highly unlikely that the single TADS used in the present study would have detected the single theoretically estimated flock of Common Eiders forecast by the probability model (Appendix I) to be crossing the sweep area of a single turbine.

As a consequence of the extremely low estimated probability of Common Eiders passing the sweep area of the turbines (Appendix I), the level of coverage required to adequately monitor all 72 turbines would be extremely high, if a realistic and reliable measure of the daily number of avian collisions are to be registered by use of TADS only. Hence, it is considered that using TADS as the only method to measure actual collision rates of Common Eiders at the Nysted Wind farm is neither an economical nor practical option when it comes to estimation of the daily low number of collisions.

NERI therefore proposes future collision studies to include a combination of data collected by radar and TADS for use as input to a more accurate and statistically robust model of the probability of daily number of avian collisions.

Finally, a monitoring programme with TADS at a relatively low intensity (i.e. one TADS) could, besides collecting data for the probability model, function as a background monitoring scheme, aiming at detecting periods with high number of collision casualties under rare and unusual situations, which in contrast to the low daily collision frequency do not need any intensive coverage.

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 of collision with human obstacles such as buildings, bridges, towers, power lines and wind turbines exist. 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, rainy, snowy 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. The attraction of birds to stationary lights has been reported for both small passerines and for larger waterfowl. Hence, the combination of illuminated obstacles (for recreational purposes or for air/ship traffic navigation warning) and poor visibility constitutes the greatest collision risk to migrating birds.

During the past decade, several studies have focused on the topic of collisions between birds and wind turbines (Pedersen & Poulsen 1991, Winkelman 1992), as numbers of wind farms have increased significantly during this period. However, up to 2002 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 to obtain 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 at land, knowledge of avoidance response of the generally large and presumably less manoeuvrable waterfowl species to offshore turbines is almost non-existent. Lack of data combined with the fact that these species are long-lived and therefore sensitive to additional adult mortality have resulted in concerns for possible negative cumulative impacts on their populations (Kahlert et al. 2000). Placement in offshore locations makes it difficult to conduct investigations as described above, and hence, novel methods needed to be developed.

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 resulting Thermal Animal Detection System (TADS) was ready for use by the end of 2003 (Desholm 2003), and together with surveillance radar it has formed the basis for data collection for the present report. This report presents the first results of offshore data collection by the TADS and covers studies conducted during November 2003 - April 2004.

The aims of the report were threefold:

1) to present preliminary data on the number of avian collisions using infrared video recording (TADS),
2) to assess the performance of the TADS during prolonged operation in an offshore environment,
3) to compile information (data collected with radar) to model the probability of birds passing the sweep area of offshore wind turbines (Appendix I) in order to present recommendations for the development of a future TADS-study.

In the longer term, experience from several seasons with 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/or flock size? Insight into this subject will be very useful in the future 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?
3) Given the impossibility of identifying all radar tracks to species - which species or species groups are represented in radar data collected within the wind farm area?
4) Do the TADS and radar data confirm each others conclusions?

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 NERI office.

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 TADS was mounted on the second most southern turbine (H8) in the eastern row during autumn 2003 and on the second most northern turbine (A2) of the western row during spring 2004 (Fig. 2). These positions represent the high volume sectors with regard to bird migration in autumn and spring, and were chosen to potentially register as many passing birds as possible in the vicinity of the monitored turbines.

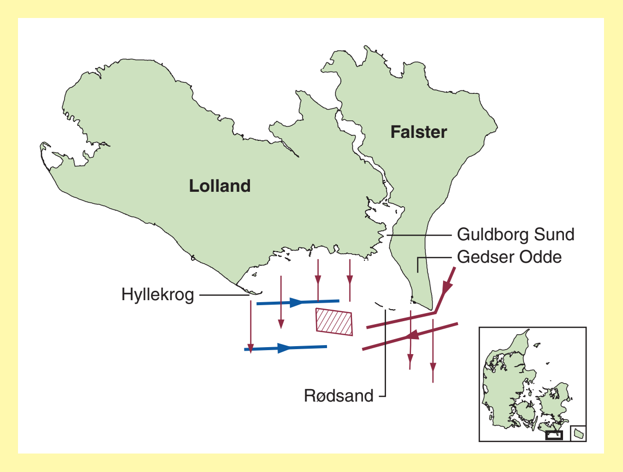

Figure 1. The wind farm and study area south of Lolland and Falster in south-eastern Denmark. Names of locations are indicated. The hatched area represents the wind farm area, thin and thick arrows indicate the schematic direction of terrestrial and waterfowl migration, respectively. Blue arrows indicate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

2.2 Thermal Animal Detection System (TADS)

2.2.1 Technical data

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).

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.

Using a 24° lens, the maximum coverage (32.4%)

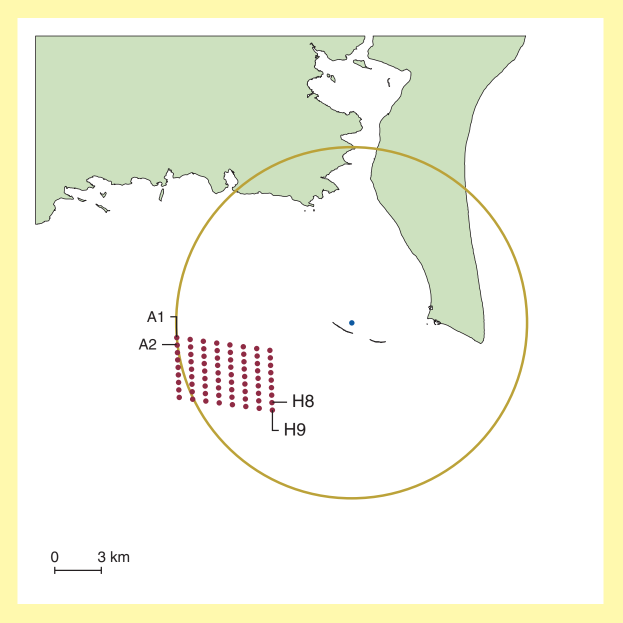

Figure 2. Placement of the observation tower (blue dot) and extent of radar range (yellow circle) for mapping the migration trajectories of waterbirds. Names are indicated for te turbines (red dots) mentioned in the text.

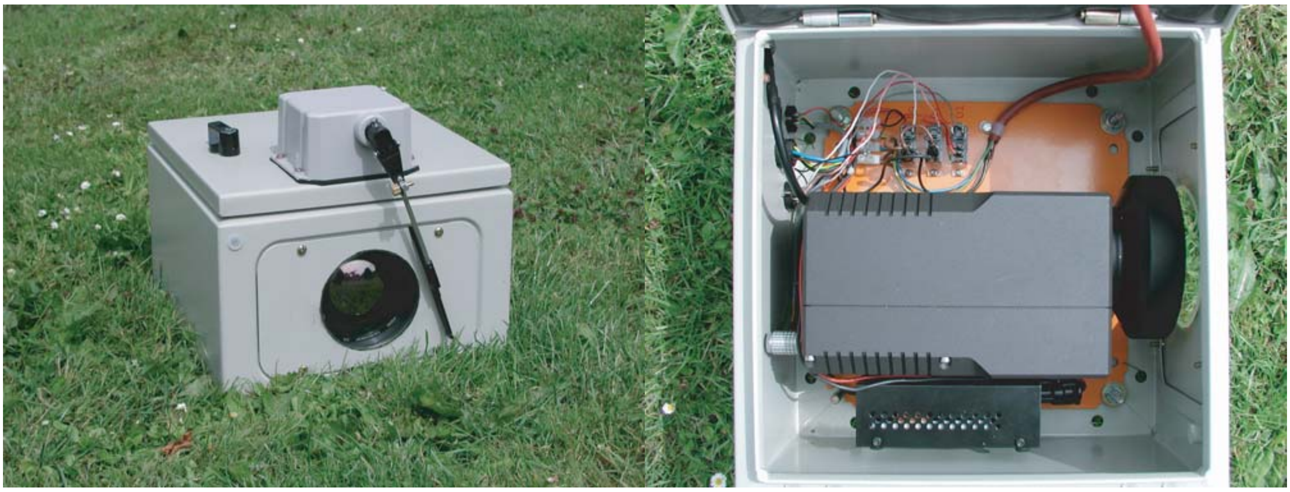

Figure 3. The thermal camera (right) and the camera housing for environmental protection with windscreen wiper (left).

of the disk area swept by the blades of a wind turbine rotor was achieved (hereafter referred to as the sweep area). For a detailed description of the TADS, see Desholm (2003). 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 in to account. However, as the distance between the bird and camera increases the possibilities of identification will decrease.

The main features of the TADS (Fig. 3 & 4) are as follow:

1) the 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) the thermal trigger software which starts downloading video sequences to the hard disc 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) the environmental sealed metal box for camera protection against weather and salt from sea water spray,
4) a computer sited inside the turbine tower for necessary software and video sequence storage,
5) network connection from the turbine computer at sea to the NERI office at land,
6) windscreen wiper and sprinkler system.

Since the final TADS-development report (Desholm 2003) some new features have been added successfully to the system:

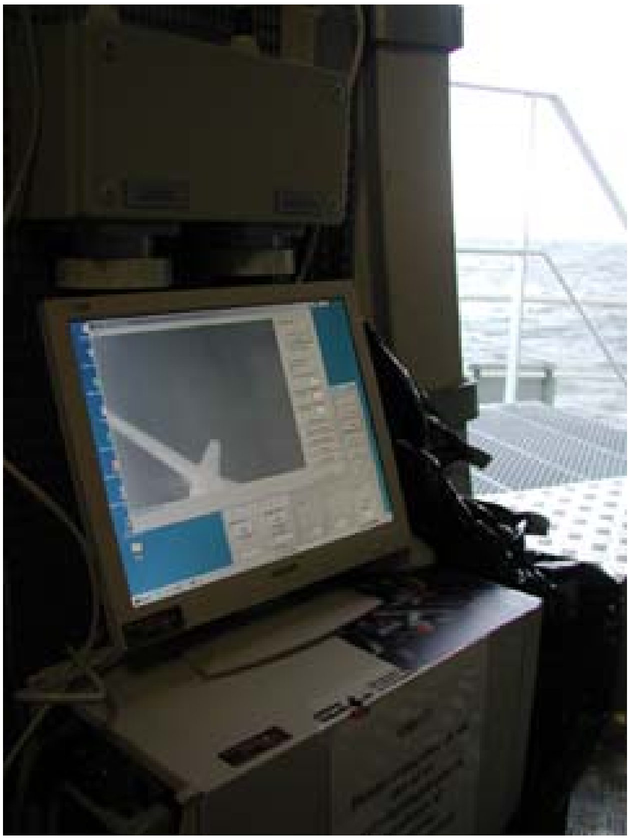

Figure 4. The TADS-computer inside the turbine tower showing the vertical view of the camera and the software interface.

Figure 5. Thermal camera mounted with a pan/tilt head on the A2 offshore turbine at Nysted wind farm.

7) a pan/tilt head enabling the operator to change the heading and vertical angle of the field of view (Fig. 5),
8) a small water valve for removal of condensing water inside the camera housing.

2.2.2 Monitoring set-up

Study of autumn 2003

During autumn 2003 it was planned to collect data from a single infrared test system, but due to delayed mounting of the TADS at the offshore H8-turbine, only one out of two project aims was achieved. This was the offshore test of the hardware, whereas the second aim of collecting information for a preliminary assessment of avian collision risk, could not be accomplished as the majority of the waterfowl had already passed the study area on their autumn migration.

The test of the level of physical stress of the thermal camera, when operating outside in an offshore environment and under real vibration conditions at the 2.3 MW turbine at Rødbyhavn, was conducted to see how well the waterproof metal box, pan/tilt head, windscreen wiper and sprinkler system, water valve and rubber vibration absorbers performed. The criterion for success was to achieve successful recordings during the test period, and to determine whether environmental conditions were likely to reduce image quality under most operating conditions.

Study of spring 2004

During spring 2004, preliminary data collection using one TADS was carried out at the A2-turbine at the Nysted offshore wind farm (Fig. 2). The camera was mounted on the western side of the turbine tower at c. 6 m a.s.l.

Data were collected as continuously as possible during both day and night from 17 March to 12 April 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. Three different views were used during data collection:

View 1) the preferred vertical view for monitoring the birds passing or colliding with the turbine tower and the turbine blades (Fig. 6),

View 2) the 45° angle view for monitoring the near vicinity of the turbine towards the north (Fig. 7),

View 3) the horizontal view of the neighbour turbine A1 to the north (Fig. 8).

View 1 was the primary view usable in eastern winds only when the blades were rotating on the opposite side (eastern) of the tower in relation to the camera. View 2 was the secondary view usable during all possible wind directions. View 3 was only used to a very limited degree for manual recording of the prolonged sequences of the lowest part of the air space in the direction of the turbine A1 (see Fig. 2). In case, for some reason, automatic monitoring of the sweep area failed to

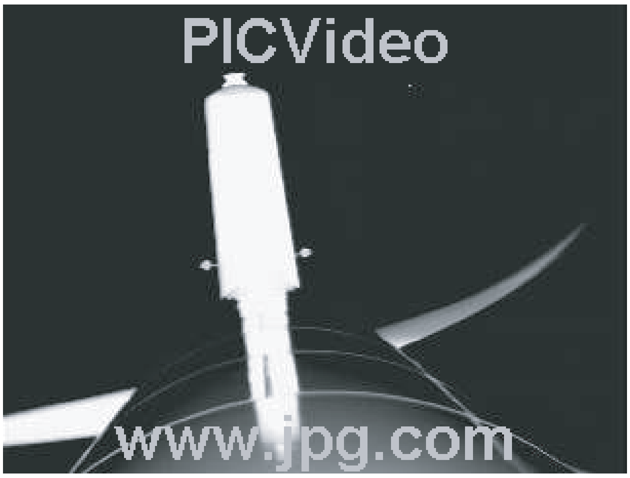

Figure 6. Single frame of a thermal video sequence showing the vertical view for monitoring the birds passing or colliding with the turbine tower and the turbine blades.

Figure 7. Single frame of a thermal video sequence showing the 45° view for monitoring the birds passing the near vicinity of the turbine. A relatively warm cloud is visible as a light blotch at the lower right corner of the frame.

detect birds in the field of view, a control-monitoring scheme using manual recordings were set up, in order to verify the results obtained by TADS, recording sequences of c. 5 minutes' duration especially of views 1 and 3.

Furthermore, the utility of the TADS (using the 5 min. long sequences of view 3) for estimating the height distribution of the migrating waterfowl was assessed. Knowing the flight height of the migrants is essential for the process of modelling the estimated number of future collisions. In order to estimate the flight heights of migrants using TADS, the distance and angle to each bird has to be estimated. The body length of an individual bird measured in number of pixels (measured from a single frame of the sequence) can be used to calculate the distance to the bird given the specific lens used (see Desholm 2003). From the visually obtained line of sight the angle to each bird can be estimated following the schematic presentation in Fig. 9. Knowing the distance and angle to the bird, its approximate flight height can be assessed by simple trigonometry. This method of measuring flight heights is necessarily rather coarse but can at least be used to determine whether a flock of birds is flying below or within the risk zone of the sweeping turbine blades, which is the most relevant aspect.

Figure 8. Single frame of a thermal video sequence showing the horizontal view towards north for monitoring the birds passing between the camera and the neighbour turbine A1.

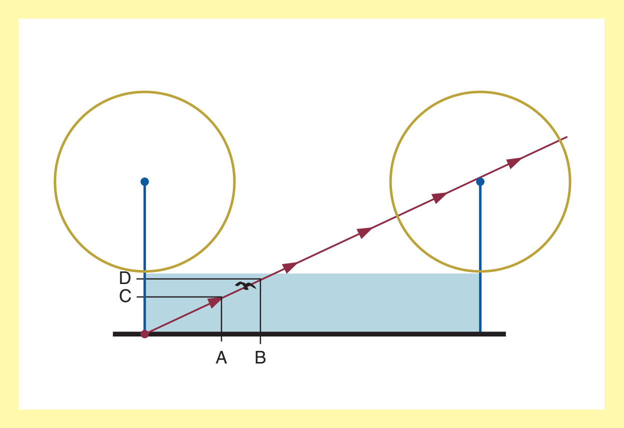

Figure 9. Schematic diagram showing principles of assessing whether birds are flying under, within or over the sweeping area by use of the line of sight (line with arrows) from a thermal frame and the estimated distance between camera and bird (see chapter 2.2.2). Red dot indicate camera position, light blue area the collision free zone under the sweeping turbine blades and yellow circles the sweeping areas of the turbines. The intersections between the line of sight and the vertical lines from the estimated minimum distance (A) and maximum distance (B) between camera and birds will indicate range of flight height (C-D). Visually, the depicted bird will appear to be flying within the sweeping area since the line of sight intersects with the sweeping circle. However, the estimated true flight interval (C-D), in which the bird is actually flying lie below the sweeping turbine blades.

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

1) number of birds colliding with the turbine or passing in the near vicinity of it,
2) number of sequences triggered and recorded,
3) sequence length (seconds),
4) view type,
5) wind conditions during data collection,
6) visibility during data collection,
7) numbers of and reasons for the false (i.e. non-

bird) triggered sequences (when other things than birds triggered the recording).

2.3 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 TADS study, autumn 2003

As mentioned in chapter 2.2.2, the delay in the mounting of the TADS until November 2003 was long after the main autumn migration period of waterbirds. Hence, investigating the avoidance response of birds using TADS was not possible in that season and therefore only the aim of testing the offshore performance of the hardware was accomplished.

The 20% alcohol sprinkler solution proved effective under frosty conditions (-10ºC), but its necessity was not demonstrated since the images showed no reduction in quality due to either dirt or precipitation.

The waterproof box was heated inside by the power supply of the camera, and because the ambient temperature was lower, condensed water accumulated within the box during a preliminary study in 2002 (Desholm 2003). It was attempted to solve this problem by applying a small water valve in the bottom of the metal box to permit draining during the 2003 autumn study. Despite the valve, condensed water continued to accumulate within the metal box that once resulted in electrical short circuit when the camera was tilted from a vertical to a horizontal viewing position exposing the electrical contacts to the water. The condensation problem remained unsolved throughout the autumn 2003 study, but was solved during the spring 2004 study (see below).

3.2 TADS-study, spring 2004

In total, 28,861 minutes of TADS-monitoring was conducted during spring 2004, representing a total of 20 days out of a study period of 27 days, resulting in an operation efficiency (OE) of 74.2% (Equation 1) throughout the entire study period.

$$OE = \frac{28{,}861}{38{,}880} \times 100\% = 74.2\% \qquad \text{Eq. 1}$$

Most monitoring was in vertical and 45° viewing modes (Table 1).

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 will continuously sweep through the field of view of the camera and facilitate a false triggering. In the 2004 spring study, the optimal wind directions for the vertical viewing mode was from easterly directions (0°-180°) since the camera were mounted on the western side of the turbine tower (270°). In 40.5% of the study period winds were from easterly directions and consequently it came from westerly direction in the remaining 59.5% (Fig. 10).

During operation the thermal trigger software saved 1,223 thermal video sequences on the hard disc (see Table 1), of which only three were triggered by birds passing the field of view all in the 45° viewing mode. No birds were recorded as passing the sweep area of the rotating turbine blades (vertical view only) nor colliding with any part of the turbine during the 11,284 hours of monitoring (Table 1).

Event number 1 was recorded 7 April 2004 at 01:14 PM and the resulting thermal video sequence

Table 1. The operation time, monitoring time and the number of recorded thermal sequences separated in accordance to the three different viewing modes. The three viewing modes are listed from top to bottom as they were prioritised during operation of the TADS.

	Operation time (minutes)	Monitoring time (minutes)	Number of sequences
Vertical view	12,281	11,284	730
45° view	15,872	12,932	478
Horizontal view	708	533	15
Total	28,861	24,749	1,223

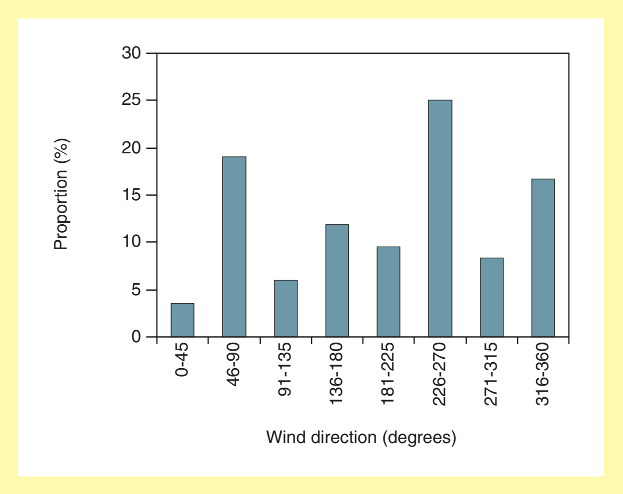

Figure 10. Wind conditions during operation of the TADS in spring 2004. Wind direction denotes the direction in degrees from where the wind is blowing.

Figure 11. Three frames from the sequence recorded at event no. 1 showing a large gull passing the field of view from left to right.

Figure 12. Three frames from the sequence recorded at event no. 2 showing a gull passing the field of view from left to right.

Figure 13. Three frames from the sequence recorded at event no. 3 showing a large gull passing the field of view from right to left.

showed one large gull passing the field of view from left to right (Fig. 11), most likely a Herring Gull *Larus argentatus*, a numerous species in the study area. The wing beat frequency was estimated to 2.7 Hz (wing beats per second), which fits well with that of a large sized gull species.

Event number 2 was recorded on 7 April 2004 at 01:43 PM and showed one bird performing a descending flight path in the lower left corner of the field of view (Fig. 12). Based on the single frames of the sequence it can be identified as a gull sp., although the body size was difficult to determine. The wing beat frequency was estimated at 2.3 Hz, which given a descending flight path could fit for a large sized gull species (e.g. also a Herring Gull).

Event number 3 was recorded on 12 April 2004 11:55 AM and shows one large gull passing the field of view from right to left (Fig. 13), and again it is likely to be a Herring Gull. The wing beat frequency could not be estimated due to the relatively long distance between bird and camera (> 100 m), which made it difficult to distinguish wings from the body of the bird.

The remaining 1,220 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 (31.8%), sun heating of the atmosphere especially after sunrise (28.4%) or by the blades of the turbines turning into the field of view (37.5%) because of changing wind conditions (see Fig. 14).

However, such false triggered sequences were

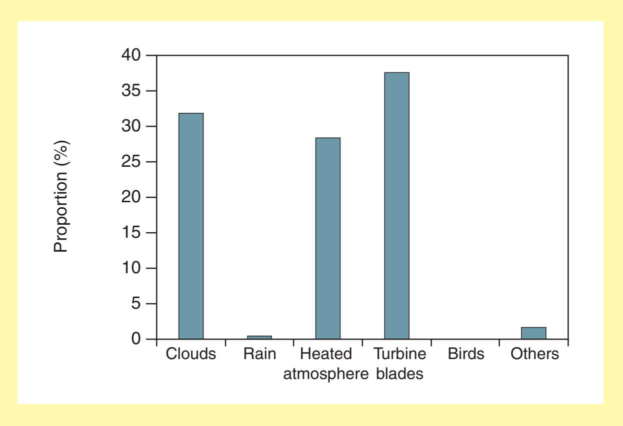

Figure 14. Reasons for the 1,220 fault triggered thermal video sequences as a result of changing temperature pattern of the background of the field of view.

Table 2. The number of sequences (N), elapsed time (minutes) and information on the recorded birds from the manually recorded long thermal sequences. Data is separated in accordance to the three different viewing modes.

View	N	Elapsed time	Number of birds (flocks)
Vertical view	11	60.5	0 (0)
45° view	2	10.1	0 (0)
Horizontal view	28	119.2	52 (8)

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. To ensure further development of the system, 97 of the non-bird sequences have been stored digitally to represent the range of variety of different reasons for false triggering of the system.

In order to estimate the monitoring efficiency, such unusable periods comprising many false-triggered sequences were excluded from the operation time. Of the total operation time, 4,112 minutes (14.2%) could be characterised as unusable where the trigger software had no chance of operating properly. Thereby, the monitoring efficiency (ME) amounts to:

$$ME = \frac{28{,}861 - 4{,}112}{38{,}880} \times 100\% = 63.7\% \qquad \text{Eq. 2}$$

A total of 41 long sequences was recorded manually (i.e. without the use of the trigger software), representing a total recording time of 190.2 minutes. These control sequences apply fully to the findings using the trigger software where no birds were detected as passing the sweep area of the turbine. From these manual recorded sequences, no birds were detected in the two vertical viewing modes whereas 52 birds (50 waterfowl and 2 large gulls) were registered flying just above sea level between the two turbines A1 and A2 (Table 2).

The recorded birds from the manually triggered sequences were two single individuals of large gulls, one flock of 6 geese and five flocks of Common Eiders of c. 4, 5, 10, 10 and 15 individuals, respectively. Although the identification of the geese and Common Eiders represent a best guess, they can certainly be ascribed to the group waterfowl.

The spring 2004 study made it possible to extend the long-term offshore testing of the TADS and its related devices. A new valve for removing the condensed water within the camera metal box was tested. It consisted of a simple hole with a diameter of 20 mm and stuffed with a small piece of foam rubber and proved effective both in removing condensed water and in hindering rain and sea spray from entering the camera box.

The TADS was used at wind speeds of up to 13 m/sec. during spring 2004. The video sequences showed some degree of vibration at wind speeds above c. 9 m/sec., due to the looseness of the pan/tilt head. However, this did not reduce the ability of the operator of the TADS to obtain the necessary data. It is concluded that the mounted rubber vibration absorbers (Desholm 2003) fulfilled their purpose of damping the wind induced vibrations of the camera, and this holds at wind speeds of at least up to 13 m/sec.

4 Discussion and conclusions

As described in chapter 3, the final quality control of the offshore utility of the TADS produced excellent results. It can be concluded that TADS can be considered as a fully developed monitoring set-up capable of detecting migrating birds flying over offshore areas over the range of distances planned for the equipment.

The fact that no birds were recorded as passing the sweep area of the A2-turbine could give rise to some doubt as to whether the TADS actually functioned properly during the test period. However, the results from data available from other sources confirm the extremely low intensity of waterbird migration in the near vicinity of the turbines:

1) the 5-min. long manual sequences of view 3 (horizontal) successfully detected 52 birds despite the very restricted number of operation hours,
2) the radar data on bird flocks migrating within the wind farm shows significant avoidance responses towards individual turbines, resulting in a higher probability of flying more than 50 m from the turbines than expected by chance alone (see Appendix I).

Given the maximum coverage of c. 30% of the sweep area per TADS and the monitoring efficiency of 63.7% during the study period, it is considered highly unlikely that the single TADS used in the present study would have detected the single theoretically estimated flock of Common Eiders forecast by the probability model (Appendix I) to be crossing the sweep area of the H8-turbine.

At least six TADS need to be mounted on the H8-turbine to be certain of securing the detection of such one flock irrespective of wind direction. Three TADS would be required to cover the whole sweep area each on both eastern and western sides of the turbine.

5 Recommendations for future use of TADS

As a consequence of the extremely low estimated probability of Common Eiders passing the sweep area of the turbines (Appendix I), the level of coverage required to adequately monitor all 72 turbines would be extremely high, if a realistic and reliable measure of the daily number of avian collisions are to be registered by the use of TADS only. Hence, it is considered that using TADS as the only method to measure actual collision rates of Common Eiders at the Nysted Wind farm is neither an economical nor practical option when it comes to estimation of the daily low number of collisions.

NERI therefore proposes that future TADS-studies should include a combination of data collected by radar and TADS for use as input to a more accurate and statistically robust model of the probability of daily number of avian collisions.

Specific factors that define the future collision risk for which data are needed for the probability model include:

1) spatial migration pattern and avoidance responses both in relation to the wind farm as one unit, to individual turbines and to the rotating turbine blades,
2) species specific flock sizes during day and night,
3) general species composition,
4) species specific migration heights,
5) rotor specific collision risk (Tucker 1996),
6) influence of weather on each of the factors 1-5.

It is expected that collisions are most likely to occur during dark nights, and hence, it is very important that the data on the factors listed above (1-6) are collected throughout the diurnal cycle. Both radar and TADS are fully operationally during night time as well as during day time and therefore comply fully with these requirements, but species identification at night is only possible with TADS.

Radar studies of the migration and avoidance pattern of birds at offshore wind farms will fulfil the need for such model input data on larger scales, whereas small scale avoidance responses to the rotating turbine blades needs adoption of other methods. The latter could be obtained by visual observations during day time and by TADS throughout the diurnal circle.

At present, NERI has collected a substantial amount of data on flock size and species composition during the day time by visual observations. However, TADS could contribute significantly with important night-time data parameterisation for the modelling work.

The migration height profiles are best studied by use of a vertical operating radar with TADS as a verifying tool collecting more small scale data on flight heights. However, TADS can provide essential back-up by adding species identification of radar data collected during night observations.

The rotor specific collision risk and the influence of weather do not need further data collection as these data will automatically be available for further analyses in the future (Tucker 1996).

Finally, a continued monitoring programme with TADS at a relatively low intensity (i.e. one TADS) could, besides collecting data for the probability model, function as an low level background monitoring scheme, aiming at detecting periods with high number of collision casualties under rare and unusual situations, which in contrast to the low daily collision frequency do not need any intensive coverage. Such mass casualty events have been reported in studies of land-based turbines and of illuminated super-structures such as lighthouses, bridges and oil-platforms. These could occur under conditions where either the weather, factors that attract birds (e.g. light or food) or some other factors or a combination of factors result in high collision events.

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Appendix I

Framework for the probability model

This section defines the data which are required to estimate by day and night the number of autumn migrating Common Eiders that pass:

Level 1) the study area,
Level 2) the wind farm,
Level 3) within the collision risk distance to the turbines,
Level 4) the sweep area of the turbine blades.

Based on the logic above, a probability model can be constructed consisting of a series of consecutive probability calculations to estimate the number of Common Eider flocks that passes the sweep area of the H8-turbine at the Nysted wind farm. This model starts by defining the total number of birds passing the study area and defines each level of risk as a probability at each spatial scale as follows:

Level 1. For this first part of the analysis data collected visually of the number of migrants in the study area are needed. As reported by Christensen & Grell (1989) and Kahlert et al. (2000), each autumn c. 300,000 waterfowl pass the study area at Gedser Odde during day time, of which c. 260,000 are Common Eiders. The remaining c. 40,000 individuals can mainly be ascribed to other diving ducks, dabbling ducks and geese. For assessing the migration volume during night time radar data on the ratio of night to day waterfowl migration intensity was used. Data on the night-day intensity of waterfowl migration passing the eastern edge of the wind farm (3.85 km transect) was compiled from the base-line studies of 1999-2001. Data from autumn 2002 was excluded due to the temporary suspension of the study (Desholm et al. 2003) before the main Common Eider migration period, and the autumn 2003 data was excluded due to the presence of turbines which may have affected the relative intensities of migration during day vs. night. Only autumn data from periods showing north-easterly winds (the preferred wind directions for autumn migrating Common Eiders; Kahlert et al. 2000) were used excluding any wind induced effects on the migration volume.

For converting between number of flocks and number of individuals, data on mean flock size are needed, and hence, data were compiled from the autumn studies conducted by NERI at Rødsand (1999-2001 and 2003). The reason for excluding the 2002 data from the analysis of flock sizes, was the temporary suspension of the study in September that year. The autumn study of 2002 was suspended before the peak migration period of Common Eiders, and therefore, the data would not be representative since flock size is known to be highly correlated with the migration volume (i.e. more migrants adds up to larger flock sizes; Alerstam et al. 1974).

Level 2. For this part of the analysis radar data defining the proportion of the migrants that actually pass the wind farm is needed (Fig. 15a and 15b).

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. The distance from each bird flock to nearest turbine was measured in the GIS and was performed on those flocks passing the north-south orientated rows of turbines. This kind of data has not been compiled before in reports produced by NERI describing the bird studies at the Nysted wind farm.

Level 4. To estimate the proportion of the birds flying closer than 50 m to turbines that actually cross the sweep area, a theoretical calculation will be conducted. Here, the assumption is made that the waterfowl flocks distribute themselves randomly on the horizontal axis within the area up to 110 m a.s.l. In Fig. 16, a schematic presentation of the 2.3 MW wind turbine from the Nysted wind farm is depicted, and the horizontal hatched area indicate the 50 m near vicinity area and vertical hatched area the risk zone of the sweeping blades. The sweep area covers 2,640 m^2 (48%) of the 5,500 m^2 near vicinity area and 64.4% of the part of the near vicinity zone which is above 28 m (i.e. the lowest level of the sweep zone), and the half part of the turbine tower occupies 116 m^2 (2.1%) of the near vicinity zone.

Measurements of the migration height of Common Eiders have been adopted from Kahlert et al. (2000), and were conducted 22 September - 3 November 1999 at Gedser Odde c. 10 km east of

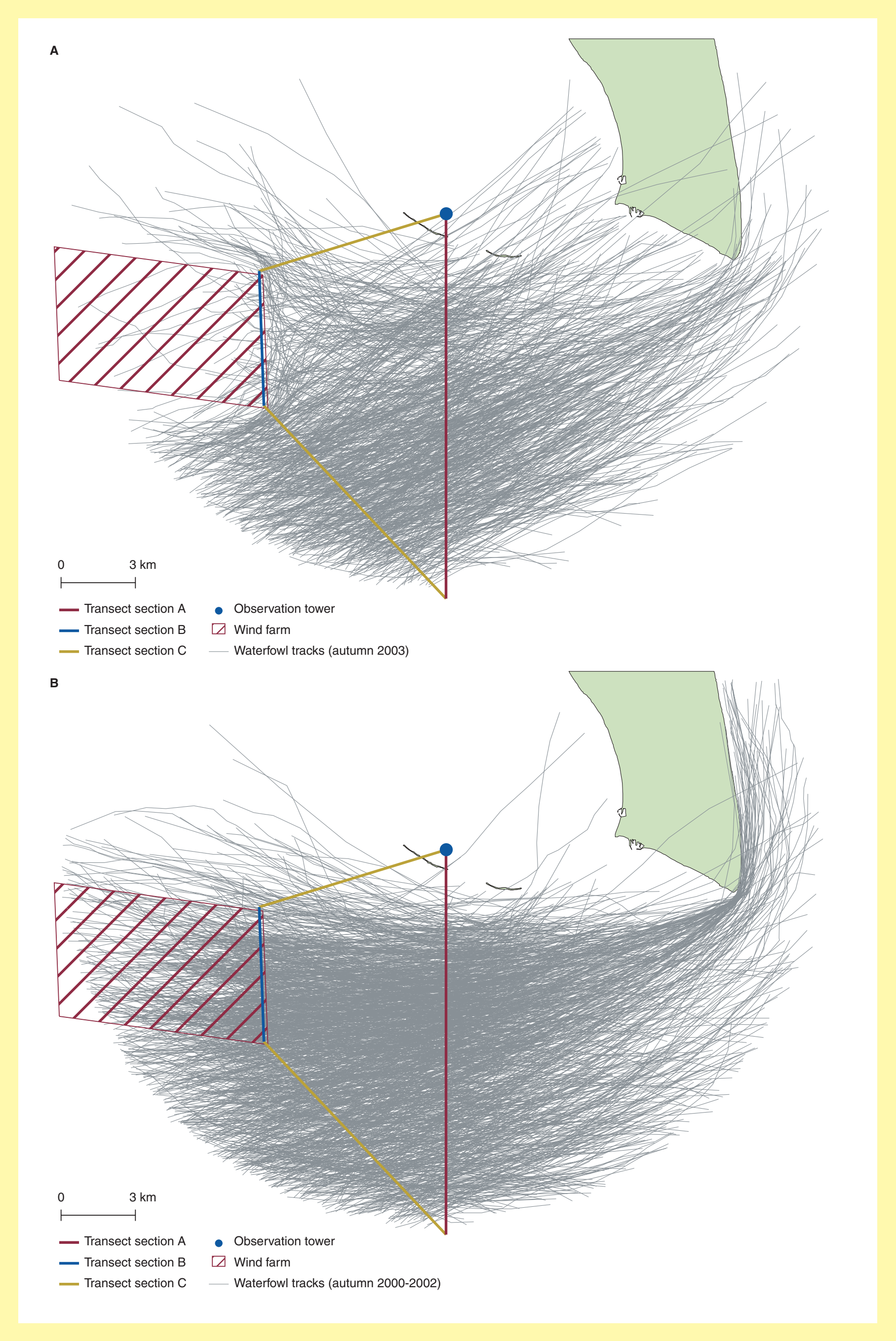

Figure 15. The waterfowl autumn migration tracks selected for the analysis of the proportion of flocks that entered the wind farm area. Only those flocks passing the red line were used in the analysis. Of these bird flocks, those that passed the blue line were regarded as entering the wind farm and those that passed one of the two yellow lines were regarded as not entering the wind farm. **a**: the situation after the turbines have been erected (2003). **b**: the situation before the turbines were erected (2000-2002).

the wind farm area. Angle and range finder were used on flocks at a maximum distance of 1,500 m. For more detailed information on methodology, see Kahlert et al. 2000. It should be stressed that the amount of data is rather limited, and furthermore, that it at present is unknown to which degree these near land data (0-1,500 m from the coast) collected during day light can be extrapolated to the area of the offshore wind farm and to the night time situation.

These rough estimates of the number of flocks of Common Eiders passing the sweep area of a single turbine can be used to assess the future coverage needs with regard to monitoring volume and how to design such a collision monitoring program. It must be stressed though, that these estimates are based on data collected in one year with operating turbines only, and hence, cannot take into account any year to year variation or possible habituation behaviour of the birds.

The following data collected by radar are used for the probability model:

1) The proportion of those waterfowl flocks passing the transect due south of the observation tower that enter the wind farm,

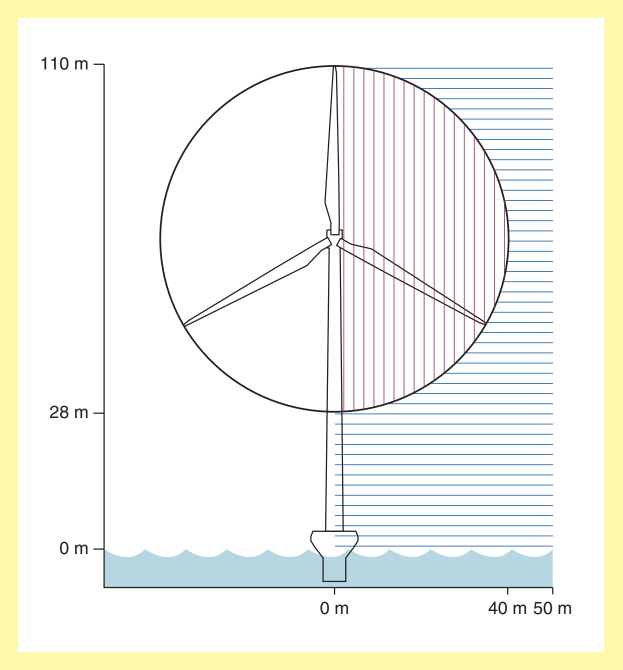

Figure 16. Schematic presentation of a 2.3 MW turbine showing the safe zone (hatched horizontally) and the sweep zone (hatched vertically) of the near 50 m vicinity of the turbine.

2) the distance between migrating flocks of waterfowl and individual turbines,
3) the day/night proportion of migration intensity at the eastern row of turbines.

Only autumn data were used to calculate the above described proportions since these are the most likely to produce good information on avoidance responses by use of radar (Kahlert at al. 2004).

By combined analyses of the above listed radar data, it will be possible to assess the future migration pattern and volume within the wind farm.

Radar data

Since autumn 1999, NERI has conducted radar and visual observations of migrating birds during spring and autumn. These investigations were performed from an observation tower placed 5 km north-east of the wind farm area. Registration of bird flocks by radar was performed within a circular area of 388 km^2 around the observation tower (Fig. 2).

The spatial migration pattern has been studied at the Nysted wind farm since 2000. From spring 2000 to spring 2003 investigations were performed before the wind farm was erected and during autumn 2003 radar studies was conducted during initial operation of the wind turbines. To compile data on bird migration at long distance and during periods of poor visibility due to fog or darkness a ship-radar (Furuno FR2125) was operated from an observation tower situated c. 5 km from the wind farm (Fig. 17). The distance from the observation tower to the periphery of the study area covered by the radar was 11 km (see Fig. 2). Each echo on the radar monitor corresponded to a flock of birds, and in this way the spatial migration pattern could be described both during day and night. The migration routes were mapped by tracing the course of bird flocks from

Figure 17. Observation tower with the mounted radar and the Nysted wind farm (c. 5 km mutual distance) in the background of the picture.

Table 3. Probability model consisting of a series of consecutive probability calculations leading to the estimated number of Common Eiders passing the sweep area of the H8-turbine during day time and night time throughout an autumn migration period. a: Number of Common Eiders passing Gedser Odde annually as observed visually for day time and as calculated for night time (see under Level 1 in this chapter), b: Number of flocks (based on a mean flock sizes of 17.99 from Rødsand), c: Number of flocks entering the eastern gate of the wind farm (night = 13.8%; day = 4.5%), d: Number of flocks passing between H7-H9 = 25.4% of the flocks entering the eastern gate, e: Number of flocks passing closer than 50m to individual turbines (night = 6.5%; day = 12.3%), f: Number of flocks passing to either of the two sides of H8 = 50%, g: Number of flocks passing the sweep area (theoretical estimate) with 10% of the Common Eider flocks flying above 30 m over which 64.4% of the near vicinity area are covered by the sweep area (see Fig. 16), h: Number of flocks passing the air space occupied by the turbine tower which is 2.1% of the near vicinity area (assumed that the birds distribute themselves randomly both horizontally and vertically).

Common Eiders	a	b	c	d	e	f	g	h
Day time migration	260,000	14,452	650	165	20	10	1	0.2
Night time migration	83,461	4,639	640	163	11	5	0.3	0.1
Diurnal migration	343,461	19,092	1,291	328	31	15	1.3	0.3

the radar monitor on to a transparency. Only tracks longer than 5 km were included in the analyses, thereby excluding short tracks of local movements. When possible, species and flock size were visually verified. Afterwards, the transparencies were digitised and entered into a GIS-database. Further details on the radar studies and methods see Desholm et al. (2003) and Kahlert et al. (2004).

The appropriate monitoring coverage of the wind farm in a future collision study depends on the expected number of casualties, which again depend on the number of birds that pass the sweeping area. Hence, an analysis of the radar data will constitute the basis for assessing the number of birds passing the sweep area and the air space occupied by the tower of the H8-turbine. This knowledge will then together with the preliminary TADS-investigations presented in the present report form the basis for the recommendations for a future collision study (Chapter 5).

Probability model

In the following several references are made to the data numbered Level 1-4 (see above) for the probability model.

Level 1. In a flyway perspective, the 260,000 Common Eiders migrating annually at Gedser Odde during day time amounts to c. 34% of the total Baltic/Wadden Sea population of c. 760,000 individuals (Desholm et al. 2002).

The distribution of night-day migration intensity data lies far from a normal distribution with 52% of the 15-minute period showing less than two flocks, and hence, average number of flocks per 15-minute period (without any variance estimate) are used rather than the mean. Average number of waterfowl flocks per 15-minutes period were 5.11 and 1.24 for day and night periods, respectively. Hence, the average proportion of night migration could be calculated to 24.3%. This lies close to an estimate for Common Eiders in southern Scandinavia (Alerstam et al. 1974), and thus, this Rødsand estimate is used for Common Eiders when calculating the number of migrants during night time in Table 3.

Based on the above described proportion of night migrants, the total number of migrating Common Eiders is estimated at c. 343,000 individuals (see Table 3) constituting 45% of the entire Baltic/Wadden Sea population.

The estimated mean flock size of Common Eiders at Rødsand ranged between 14.6 and 21.6 individuals with an overall mean of 18.0 individuals. As the species specific distributions of flock sizes differed markedly from normal distributions, log-transformation of data was undertaken when calculating the mean flock size of Common Eiders. This approach is generally less sensitive to extreme observations of very large flocks, which may occur at very low frequency, compared to calculation of simple averages. Dividing the number of 343,000 Common Eiders with this mean flock size results in a number of 19,092 flocks (see Table 3).

Level 2. The probability that bird flocks would pass the eastern gate in autumn 2003 was reduced considerably compared to the base-line years (2000-2002). This result was obtained under all combinations of cross wind regimes and time of the day when controlling for their latitudinal position as the bird flocks approached the wind farm (Kahlert et al. 2004). Overall, the probabilities were in 2000: 48.1%, 2001: 35.2%, 2002: 23.9% and 2003: 8.9%.

The overall proportion of flocks (P) 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; $\chi^2 = 239.9$, $P < 0.001$). Visually, the spatial avoidance response by migrating waterfowl flocks can be seen in Fig. 15a + b. In contrast to the analyses by Desholm et al. (2003) and Kahlert et al. (2004), the present analysis have 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, the two situation which have been hypothesised to show different risks of collisions (Winkelman 1992, Wiese et al. 2001, Desholm et al. 2003, Kahlert et al. 2004, Garthe & Hüppop 2004). During initial operation P_{night} was significantly higher compared to P_{day} (13.8%; n = 289 and 4.5%; n = 378, respectively; $\chi^2 = 17.1$, $P< 0.001$; Table 3).

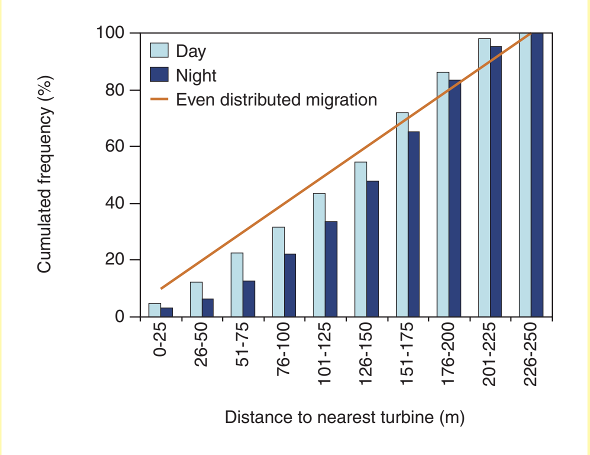

Figure 18. Cumulated frequency distribution of the distance to nearest turbine for waterfowl flocks passing the north-south orientated rows of turbines within the Nysted wind farm. The theoretical even distributed migration is compared to the observed migration pattern during day and night.

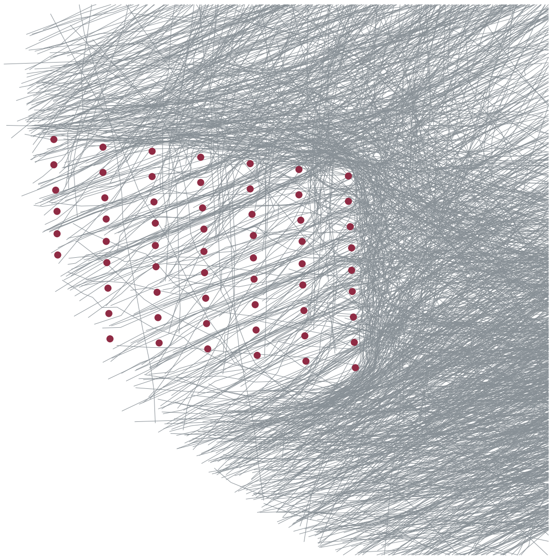

Figure 19. Small-scale map showing the turbines (red dots) within the radar range and the migration trajectories of the autumn waterfowl migration (flying from right to left) after the erection of turbines.

Level 3. The cumulative frequency distribution $F_N(X)$ of distances to nearest turbine when passing the north-south orientated rows of turbines was significantly different from an even 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. 18). Hence, the waterfowl flocks tend to fly in between the individual turbines instead of crossing the wind farm irrespective of the placement of the turbines (Fig. 19). Likewise, $F_N(X)$ differed significantly between day and night ($\chi^2 = 69.85$, df = 8, $P< 0.001$) with the night-distribution skewed further away from individual turbines (Fig. 18). The proportions of flocks flying closer than 50 m to the turbines were 6.5% and 12.3% during night and day, respectively (see Table 3).

Level 4. In general, all flocks of Common Eiders were observed flying below the maximum height of the 110 m high turbines, with 90 % of the Common Eiders migrating below the turbine blades (< 30 m; N = 71 flocks), although this value changed depending on prevailing head or tail winds. In tail winds and head winds 73% and 90%, respectively, flew below 30 m (i.e. below the turbine blades).

The theoretical value (used in Table 3) for the proportion of those Common Eider flocks which are flying within the near vicinity zone of the turbines that actually cross the sweep area were estimated to be 6.44% (10% flying at blade height and 64.4% flying within the risk zone above 28m ((0.1*0.644)* 100% = 6.44%).

Given the data listed (see this chapter), the series of consecutive probability calculations starts at 343,461 individuals or 19,092 flocks of Common Eiders and ends with an estimated number of 1 flock passing the sweep area and zero flocks passing the air space occupied by the tower of the H8-turbine during a single autumn migration period (see Table 3).

Discussion and conclusions

The probability model leads to the estimate that one flock of Common Eiders will pass the sweep area of the H8-turbine during a single autumn migration period and zero flocks will pass the air space of the turbine tower. However, it must be emphasised, that this coarse estimate of migration volume near the turbine should not be used directly to assess the avian collision risk at the Nysted wind farm, due to the:

1) preliminary character of the data set including only one year of avoidance radar studies,
2) rather simple data on flight height distribution,
3) the lack of probability calculations concerning risk of collision with turbine blades.

Furthermore, the H8-turbine was chosen because of a higher than average expected migration volume in its mediate vicinity, it can not be expected that the other turbines within the wind farm will be passed by the same relatively high number of birds.

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Preliminary investigations of bird-turbine collisions at Nysted offshore wind farm and final quality control of Thermal Animal Detection System (TADS)

National Environmental Research Institute
Ministry of the Environment