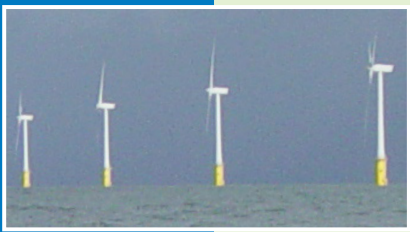
A review of methods to monitor collisions or micro-avoidance of birds with offshore wind turbines

Part 1: Review

Strategic Ornithological Support Services Project

SOSS-03A



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Preface

As part of the Strategic Ornithological Support Services (SOSS), which has been established in order to identify key ornithological issues relating to the expansion of the UK wind industry and to determine programmes to address these issues and inform the consenting process for offshore wind projects, Bureau Waardenburg was sub-contracted by the British Trust for Ornithology (BTO) to carry out part of Task 1 under Scope SOSS-03A 'Developing methods to monitor collisions of birds with offshore wind farms'.

This work consisted of compiling a summary review of the problem of monitoring collisions of birds with wind turbines offshore, the methods that can be applied to date and their limitations, recent advances in methodologies and potential deployment options.

The SOSS is funded by The Crown Estate.

Scope and acknowledgements
The idea and scope for this project was developed by the Strategic Ornithological Support Services (SOSS) steering group. Work was overseen by a project working group comprising Alan Gibson (MMO), Matty Murphy (CCW), Richard Walls (Natural Power, nominated by E.ON) and Gero Vella (RES, nominated by Centrica). We thank the project working group and other members of the SOSS steering group for many useful comments which helped to improve this report. SOSS work is funded by The Crown Estate and coordinated via a secretariat based at the British Trust for Ornithology. More information is available on the SOSS website www.bto.org/soss.

The SOSS steering group includes representatives of regulators, advisory bodies, NGOs and offshore wind developers (or their consultants). All SOSS reports have had contributions from various members of the steering group. However the report is not officially endorsed by any of these organisations and does not constitute guidance from statutory bodies. The following organisations are represented in the SOSS steering group:

SOSS Secretariat Partners:	The Crown Estate
	British Trust for Ornithology
	Bureau Waardenburg
	Centre for Research into Ecological and Environmental Modelling, University of St. Andrews
Regulators:	Marine Management Organisation
	Marine Scotland
Statutory advisory bodies:	Joint Nature Conservation Committee
	Countryside Council for Wales
	Natural England
	Northern Ireland Environment Agency

	Scottish Natural Heritage
Other advisors:	Royal Society for the Protection of Birds
Offshore wind developers:	Centrica (nominated consultant RES)
	Dong Energy
	Eon (nominated consultant Natural Power)
	EdF Energy Renewables
	Eneco (nominated consultant PMSS)
	Forewind
	Mainstream Renewable Power (nominated consultant Pelagica)
	RWE npower renewables (nominated consultant GoBe)
	Scottish Power Renewables
	SeaEnergy/MORL/Repsol (nominated consultant Natural Power)
	SSE Renewables (nominated consultant AMEC or ECON)
	Vattenfall
	Warwick Energy

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1 Introduction

Large numbers of wind farms are currently being planned in the offshore environment, and the first offshore wind farms have been erected. Notwithstanding the benefits of this development, collision victims among birds are considered one of the major ecological drawbacks of wind energy. Establishing the collision risks of birds with offshore wind turbines therefore has a high priority. Measuring collisions is however not an easy task, because in contrast to onshore locations, birds that collide with turbines fall down and disappear in the sea.

In this report we review the systems that have been and are being developed to date to monitor bird collisions with turbines offshore. We also considered methods and techniques used in studies of bird collisions with other man-made objects such as power lines and aircraft. We discuss the requirements that have to be met by these systems to adequately measure collisions in the offshore environment. We discuss to what extent the various systems meet these requirements, and what their limitations are, as well as recent advances in methodologies and potential deployment options.

The project was carried out for the British Trust for Ornithology, as part of the Strategic Ornithological Support Services (SOSS) of the Crown Estate.

1.1 Birds and wind turbines

Collision victims among birds are considered one of the major ecological drawbacks of wind energy. Unlike other effects of wind turbines on birds, such as disturbance, barrier effects and habitat loss, the consequences of bird collisions are directly evident in the population within a short space of time and, in most cases, are likely to bring about the highest levels of mortality. Depending on the level of this mortality the effects may noticeable at the population level. This may result in: reduced numbers of breeding birds, lowered breeding success and lowered survival, all of which may result in a decline in the population.

Estimates of the number of birds killed by collisions with wind turbines on land vary between studies, most likely reflecting the differences between areas and species, however, numbers of between 0.05-28 birds per turbine per year are commonly given although figures of over 60 birds per turbine per year have also been stated (Johnson *et al.* 2002; Barrios & Rodríguez 2004; Hötker *et al.* 2004; Everaert & Stienen 2007; de Lucas *et al.* 2008; Drewitt & Langston 2008; Krijgsveld *et al.* 2009). This variation is strongly related to the flux or flight intensity through a wind farm area. The higher the flux, the more collision victims can be expected (Krijgsveld *et al.* 2009; collision rate = collision risk * flux).

In the offshore environment, collision rates may be different from those on land, because different species (with different behaviour) are involved, and because vertical structures are uncommon at sea. Virtually no data are available at present on actual collisions with offshore turbines, but see Desholm & Kahlert (2005) and Pettersson (2005). Although collisions surely do occur offshore, it is unknown whether the collision rates observed onshore also apply for the offshore situation; thus the magnitude at which collisions occur is unknown.

Information on flight activity offshore is also limited. Observations are mostly restricted to ship surveys, carried out during daytime. Flight activity at night of local birds or migrants flying through the area is largely unknown. That nocturnal flight activity over the North Sea can be considerable, was first shown using radar during the middle of last century (Lack 1959), and more recently in the effect study for the Offshore Wind Farm Egmond aan Zee in the Netherlands (Krijgsveld *et al.* 2009; Krijgsveld *et al.* 2011).

With the relatively infrequent occurrence of a bird collision with a single turbine (based on figures above, a collision occurs at a turbine every two weeks to every 20 years, although possibly more frequently at certain times of the year) and the difficulties with observations in remote locations and during low visibility (when collisions are thought to be more likely), the need for a technique to monitor collisions remotely becomes clear. No systematic attempts to manually monitor collisions offshore are known and ideas along the lines of nets or booms to capture corpses are likely to be confronted by practical difficulties and biases associated with the disappearance of corpses. Drewitt & Langston (2006) highlighted the urgent need to improve the methods of measuring collisions and avoidance offshore, highlighting radar, thermal imagery and acoustic detection as techniques under development.

The number of wind turbines planned in offshore areas, along with the uncertainty of the level of collisions and the potential effect this may have on bird populations urges the need for an increase the knowledge on the rate of collisions with turbines in the offshore environment. This knowledge is needed to better inform consent procedures, more accurately assess potential effects on bird populations and to construct appropriate mitigation measures.

1.2 Monitoring collisions and avoidance rates offshore

For wind farms onshore, the numbers and species of birds colliding with wind turbines can be estimated through the number of corpses found; correcting for search effort, probability of finding and removal by predators. Offshore, searches for collision victims are unfeasible. In such areas the numbers of collisions must either be measured directly or be estimated using collision risk models.

For existing wind farms, the direct recording of bird collisions is preferable over modelled estimates, because it reduces the uncertainty of the estimates of numbers of collisions. Development of tools to carry out such direct measurements have however been hampered by the physical nature of the environment (e.g. remote, strong winds, salt water) and of the turbines themselves (e.g. continuous movement or noises that have to be filtered out from recorded data, rotor structures, safety demands).

An alternative to the direct measurement of bird collisions is the use of collision risk models (Band *et al.* 2007; Troost 2008; Mateos *et al.* 2011). Because the number of birds colliding with turbines is largely dependent on the level of flight activity of birds through the rotor area, the level of avoidance that is assumed has a large influence on the outcome of the models (Chamberlain *et al.* 2006). In addition, data on the number of birds passing the area (flux) is needed for a range of temporal, ecological and environmental circumstances.

The sensitivity of current collision risk models to avoidance creates a need for the better understanding of the avoidance behaviour of birds close to individual turbines (micro-avoidance) as well as of the level of macro-avoidance (*i.e*. avoidance behaviour around the entire wind farm) under a range of conditions. In contrast, direct measurement of the numbers of collisions of birds with wind turbines will provide information on the number of bird casualties resulting from collisions with wind turbines under a range of conditions without the uncertainty associated with modelling collision risk in the absence of known levels of avoidance.

1.3 Requirements for monitoring collisions offshore

Systems developed to monitor bird collisions with offshore wind turbines should overcome the problem that corpses disappear in the water and cannot be quantified accurately by manual counts, in contrast to onshore situations. This means that a mechanism should be incorporated that
1) can verify that a collision actually occurred and
2) will allow determination of the species (group) involved.
In addition, during migratory periods, flight activity through the wind farm may well be higher at night than during the day. Birds may also be more prone to collisions during periods with poor visibility (night-time, fog, rain). The system should therefore also
3) operate under circumstances both with and without daylight.

Collision rate is not equal for all turbines within a wind farm or at all times of the year (e.g. Bevanger *et al.* 2010; Muñoz-Gallego *et al.* 2011). Also, collision rate may vary at different distances from the hub, through differences in fluxes or collision risk across the rotor-sweep area. To avoid biased results, data on collision rate should therefore be collected
4) from multiple turbines throughout the wind farm array and throughout the year, and
5) across the entire rotor area.

The offshore environment imposes a number of difficulties for the use of technical equipment for the monitoring of collisions and activity of birds offshore. Strong winds,

storms (under which conditions collision risk for birds may be higher due to changes in flight behaviour), high waves and tidal currents usually result in continuous vibration in offshore constructions, and can result in excessive forces working on any equipment installed on these constructions. Also the salty environment can damage equipment through corrosion and salt accumulation, and can reduce effectiveness of sensors such as microphones and lenses. Equipment must therefore be
6) suitably protected from weather conditions and salt water.

Furthermore, weather and sea conditions may severely limit access to offshore wind farms. Visits to offshore locations are also costly. This suggests benefits for the remote access of systems located offshore.

To be able to relate the number of collisions to the number of birds flying through the wind farm, and thus establish the collision risk of species offshore rather than only the collision rate, it is necessary to not only measure the rate of collisions, but also the flight intensity of species through the wind farm.

2 Methods

2.1 Literature review

A review of available literature was carried out in order to identify the available and potential methods for monitoring collisions or avoidance rates offshore. Both peer-reviewed and non-peer-reviewed literature was searched as well as general publications and websites. To provide a comprehensive review on this topic, information on the recording of collisions of birds other than with wind turbines (i.e. power lines and aircraft) was also considered.

2.2 Conference

From the 2nd to the 5th of May 2011, an international ‘Conference on Wind energy and Wildlife impacts’ was held in Trondheim, Norway. The conference was attended by almost 300 delegates from more than 30 countries (NINA 2011; CEDREN 2011). During the conference information on the available and potential techniques to monitor collisions or avoidance rates at offshore wind turbines was gathered. Information was obtained from oral presentations, posters and stands, as well as during discussions with delegates.

3 Techniques and background

Offshore wind turbines present a unique challenge in the recording of bird collisions. Their remote location and large size means that collisions go largely unnoticed, unless resulting in damage to the turbines or corpses of birds showing clear signs of collision with a turbine happen to be found washed up along the coast. In contrast, bird collisions with aircraft (bird strikes) are often immediately apparent, allowing collision events to be well studied. Techniques used in the study of bird strikes, such as the analysis of bird remains, are unrealistic for offshore wind turbines due to the difficulties associated with finding and ultimately recovering any remains. Here we focus on remote technologies, which reduce the need for the manual detection of collision events.

Below we describe the main sensing technologies suitable for use in collision detection systems. Each of the systems reviewed in chapter 4 and 5 incorporate one or more sensing technologies. The terms by which these technologies are described differ between systems, although the basic principles, for the purposes of detecting collisions with wind turbines or flying birds, remain the same.

3.1 Limitations of sensors for the detection of collisions

Sensors can be separated into contact and non-contact sensors. Contact sensors are sensors such as accelerometers and fibre-optic sensors. Non-contact sensors are mostly acoustic sensors or microphones. Pandey *et al.* (2006) concluded, in a review of the suitability of sensing devices to detect collisions at wind turbines, that in general non-contact sensors, in particular acoustic sensors, were more suitable than contact sensors. Limitations of contact sensors were identified as being:

- sensitivity to vibrations (accelerometers and piezoelectric sensors),
- the need for hardware to be mounted on rotors (accelerometers and fibre-optic sensors),
- associated hardware (accelerometers and fibre-optic sensors),
- relative cost (fibre-optic sensors) and
- the level of development needed (accelerometers and fibre-optic sensors).

The sensors used in collision detection systems are often specific for their purpose, such as the Bird Strike Indicator (EDM, 2011) that uses accelerometers to detect vibrations from bird collisions with power lines. The variety in contact sensors is very large however, and therefore should not be ruled out entirely beforehand. Contact sensors are used together with non-contact sensors in the WT-bird system (section 4.1.1), but in none of the other systems encountered in this review.

3.2 Acoustic sensors

Acoustic sensors (microphones) have been identified as the most suitable means of detecting collisions at wind turbines (Pandey *et al.* 2006). During field tests microphones, mounted on and within the wind turbine, were able to detect the majority of impacts of a 50 g, 7 cm object with the moving rotor blades (Verhoef *et al.* 2003; Verhoef *et al.* 2004; Wiggelinkhuizen *et al.* 2006a) This level of sensitivity would include the detection of species around the size of Little Tern (*Sternula albifrons*) and Redwing (*Turdus iliacus*) but may not detect smaller species such as Sky Lark (*Alauda arvensis*) or Leach's Petrel (*Oceanodroma leucohoa*). False detections, such as from mechanical noise and weather, were detected at a rate of 5-10 false triggers per day, although the sensitivity of individual systems could be tuned to the specific circumstances and the flagging of false triggers may be possible through analysis to screen for such events (Wiggelinkhuizen *et al.* 2006a; Wiggelinkhuizen *et al.* 2006b). Although microphones are relatively inexpensive compared to alternative detection sensors (Pandey *et al.* 2006), Verhoef *et al.* (2004) suggested that good quality microphones would detect more collisions than those of a lower quality.

3.3 Imaging

Cameras have the potential to record images that can later be analysed or used for validation, such as to confirm bird collisions with wind turbines. Cameras can record either still images or video sequences, with modern cameras typically recording images digitally. Cameras typically record visual light, although specialist cameras can record the longer wavelengths of infrared, which is not visible to the human eye.

Infrared cameras can be broadly divided into two types, active infrared cameras (also called image intensification) and thermal imaging cameras (also called passive infrared or thermographic cameras). Active infrared cameras detect near-infrared (shorter infrared wavelengths), whereas thermal imaging detects thermal infrared or heat (longer infrared wavelengths). Active infrared requires ambient shortwave infrared to light the subject; therefore, additional infrared illumination is often required. Thermal imaging cameras detect heat emitted from an object and as such do not require an additional illumination source.

In general, active infrared cameras are less expensive and have higher resolution than thermal imaging cameras; both are more expensive and have poorer resolution than visible light cameras. Desholm (2003) showed that during periods of poor visibility, such as in a snowstorm, large birds (30cm in length) were visible with an infrared (thermal imaging) camera over a greater distance than with visible light alone. Detection of birds in fog was less than in snow, perhaps due to cooling of the bird (Desholm 2003), although this effect may be less of an issue for flying birds.

3.4 Radar

Although radar can be used to assess the numbers, densities and movements of flying birds at large spatial scales, such as in relation to bird activity around entire wind farms (Desholm *et al.* 2006; Krijgsveld *et al.* 2010), in this review we only consider the use of radar in monitoring collisions and bird movements close to wind turbines offshore.

Of the various types of radar used in bird studies (surveillance, Doppler, tracking radar) surveillance radar has most commonly been used for studies at offshore wind farms (Kalhert *et al.* 2004; Desholm *et al.* 2006; Krijgsveld *et al.* 2010; Coppack *et al.* 2011a; Coppack *et al.* 2011b). These radar systems vary in their power, format (scanning or fixed beam) and software settings, although in general low powered radars can detect flying birds at a range of up to 10 km whilst for high-powered radars this range can be over 200 km (Desholm *et al.* 2006; Walls *et al.* 2009). Radars are not dependent on visible light and can therefore operate during periods of darkness. Detection can, however, vary depending on environmental conditions such as atmospheric moisture from rain or fog.

Due to the spatial and temporal scale of operation, radar has the potential to collect a vast amount of data. Expertise in the interpretation and analysis of radar data is required to interpret data gathered through this method, particularly in relation to the interpretation of false echoes (clutter). Two limitations of radar are that tracks cannot be identified to species, or sometimes species-group, and that the number of individuals within a track can often not be assessed, although these can be aided by visual observations, experience of the operator and type of radar (through recording of wing-beat frequency and target size).

4 Systems in existence or under testing

The following systems are known to have been tested under field conditions or have been used in wind farms. These have been divided into two groups: those that allow the direct detection of collision events (section 4.1) and those that monitor bird activity close to the turbine (section 4.2). The former are suitable for the detection of collisions only, whereas the latter may be suitable for the assessment of micro-avoidance and may also be suitable or adapted for the monitoring of collisions.

4.1 Systems for direct detection of collisions

The following systems allow direct detection of bird collisions with wind turbines. These systems incorporate a trigger mechanism that is activated during a collision event with the wind turbine. These systems are suitable for the detection of collisions and may also include a component for the validation and identification of detected collisions.

4.1.1 WT-Bird

WT-Bird, a system for detecting and registering bird collisions at wind turbines, was developed at the Energy research Centre of the Netherlands (ECN) during the early 2000s (ECN, 2011). This system uses a combination of accelerometers and microphones to detect collision incidents, and infrared (active infrared) video cameras to record video footage of the event (figure 1). (Wiggelinkhuizen *et al.* 2004; Wiggelinkhuizen *et al.* 2006).

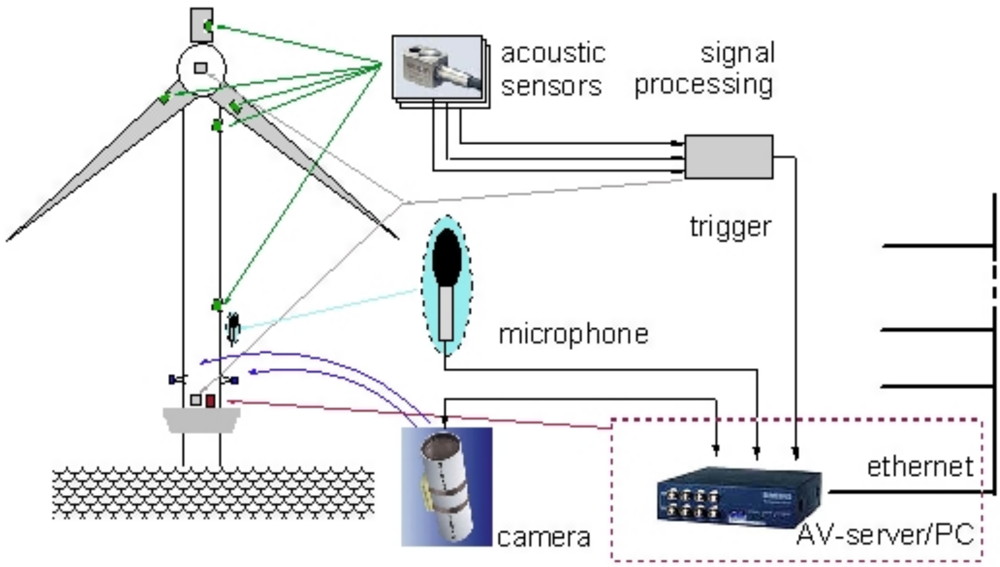

Figure 1. Schematic overview of the WT-Bird system (from Wiggelinkhuizen et al. 2006b).

The sensors that are located within the rotors and turbine towers, detect potential collisions. The signal is analysed by software to filter out background and operating noise. The software can be adjusted to account for use on different types of turbines and under various weather conditions, such as rain. The two infrared (active infrared) cameras are mounted along with illumination on the lower part of the turbine tower and capture images of the area swept by the rotors.

Images are continuously captured but are only recorded and stored once a potential collision has been detected. During such cases images of the period prior to until after the detection event are recorded and stored, for example for 30 seconds prior until 30 seconds after. Following a detection event both the sound and images are stored and a message can be sent to the user, such as by e-mail. Depending on the exact local set up, records may be accessed remotely.

The system has been calibrated for Nordex 2.5 MW turbines. In these trials dummies were used of around 50 g in mass and 7 cm in length. The majority of the collisions of dummies with the rotors were detected. This system has proven successful on terrestrial turbines. The resolution of the infrared (active infrared) cameras that were used in onshore trials in 2006 was not sufficient to allow identification to the species-level during periods of darkness, however, it has been commented that the quality of cameras is continually increasing.

Trials on offshore turbines are ongoing in the Dutch Offshore Wind farm Egmond aan Zee (OWEZ). These tests aim to establish whether the WT-Bird system can be made operational offshore on Vestas V90 / 3 MW turbines. Results from these tests are expected in the latter half of 2011 (pers. comm. H. Kouwenhoven, Noordzeewind).

Advantages

- Collisions can be recorded both day and night.
- Species identification during daylight possible.
- Field tests onshore have been performed with satisfactory results.

Limitations

- Image quality currently insufficient to enable species identification during darkness.
- Suitability for offshore wind turbines unknown, although tests are currently in progress.

4.1.2 ID Stat

ID Stat is a system designed to detect bird and bat collisions with wind turbines that is currently under development in France (Delprat 2011). Directional microphones are placed within the hub of the turbines at the base of each rotor; these are positioned to detect sounds within the rotors. The microphones and accompanying software detect potential collisions and filter out background noise and noise from rain. Once a potential collision is registered, information such as date, time, turbine and sensor ID are stored using data loggers and a message can be sent to the user via the GSM (mobile phone) network.

At present, trials are being undertaken on Vestas turbines onshore in France. During field tests, collisions with the rotors of objects with a mass as little as 2.5 g were detected.

This system solely registers the collisions of flying birds and bats with the rotors of wind turbines through audible signals. There is no verification through visual means of the nature of the event, or of the type of subject colliding. The system is being designed as a prompt for ground searches. Without such verification this system is of limited use in offshore areas.

Advantages	*Limitations*
• Collision detection sensors, flags potential collision events. • Initial field tests for collision detection are promising.	• No visual verification of collision events with cameras, therefore of limited use offshore. • Signalling may have to be adapted if used in areas with poor GSM network coverage, such as offshore.

4.2 Systems for monitoring bird activity close to turbines

The following systems can be used to monitor the activity of flying birds close to wind turbines. Although these systems do not incorporate a trigger mechanism, collisions may be recorded and monitored indirectly. These systems may be more suited to the assessment of micro-avoidance rates and bird activity close to the turbines.

4.2.1 TADS

The Thermal Animal Detection System (TADS) was developed at the National Environmental Research Institute (NERI) in Denmark during the early 2000s (Desholm 2003). To identify bird collision events, this system uses a combination of infrared (thermal imaging) video cameras that are mounted on the base of the turbine tower and software. The software would initiate recording for a pre-defined length of time, such as 10 seconds, when at least one pixel exceeds a user-defined temperature threshold (Desholm 2003). During operation offshore, the majority of events recorded (1939 out of 1944) were due to non-bird events, such as clouds, atmospheric temperature changes and the rotors (Desholm 2005).

The infrared (thermal imaging) camera used had a resolution of 0.077 MP (320x240 pixels) and a field of view covering approximately 25 % (12^{o} lens) to 32 % (24^{o} lens) of the rotor area of a 2 MW turbine (figure 2.) (Desholm 2003). At this resolution, coverage of the entire rotor area could be obtained with three cameras fitted with the 24° lens, or six cameras to account for all wind directions (Desholm 2005). Birds the size of an Eider (*Somateria mollissima*) could be detected at a distance of up to 120-170 m using a 12° lens and up to 260-400 m using a 7° lens (Desholm 2003). Smaller passerines could be detected within 50 m of the camera.

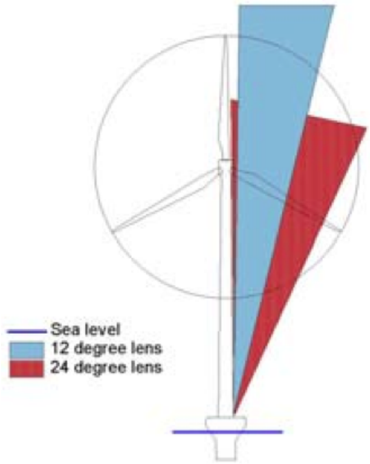

Figure 2. Schematic diagram of the field of view of infrared (thermal imaging) video cameras used in TADS for two lens types and a turbine with a hub height of 70m (from Desholm 2003).

Initial tests were undertaken on terrestrial 2 MW turbines and from 2003 the system was used offshore on 2.3 MW turbines at the Nysted offshore wind farm, Denmark (Desholm 2005; Desholm *et al.* 2006).

Advantages

- Infrared (thermal imaging) video camera enables detection during darkness and periods of poor visibility.
- Operational in offshore areas.

Limitations

- Limited field of view and resolution of infrared (thermal imaging) cameras.
- High false-positive detection rate (99.7% records were not triggered by birds).
- Detection events require human interpretation to conclude whether collision occurred and species involved. Depending on the number of detections, this may be time-costly.

4.2.2 DTBird

DTBird, a system for the detection of flying birds in the vicinity of wind turbines, was first developed by LIQUEN in Spain in 2005 (DTBird 2011). This system uses video cameras (visual light) together with image recognition software and has been developed to reduce bird collisions with wind turbines. DTBird detects flying birds in real-time and can respond by carrying out pre-programmed actions if birds are detected within a pre-defined risk-zone.

Since first being installed in a wind farm in 2009, additional modules have been developed; such as those aimed at scaring birds in close proximity to the turbines (DTBird - Dissuasion) and stopping turbines when birds fly within a pre-defined risk area (DTBird - Stop Control). These modules have been installed in turbines in 2010 and 2011 respectively. To date, DTBird has been installed in three wind farms in Spain and one in Italy.

A module for the detection of collisions (DTBird - Collision Control) has been developed to record collisions of medium to large birds, such as larger raptors and vultures. This software records data from events when a flying bird is detected close to a pre-defined area, such as the area around the rotors of a wind turbine. Depending on the position of the camera, more than one wind turbine may be monitored simultaneously.

The cameras used in DTBird detect visible light and detection is not possible during darkness and can be restricted at times of poor visibility, such as twilight, fog or heavy rain (pers. comm. M. de la Puente Nilsson). In general, birds with a wingspan of 30 cm and more can be detected (pers. comm. M. de la Puente Nilsson). Depending on environmental conditions and the size and characteristics of the species, birds may be detected from several metres up to 1 km from the camera.

The system has been developed for detecting larger, and possibly slower flying, birds such as larger raptors and vultures. The level of detection of smaller and faster flying birds, particularly over dynamic backgrounds such as water, remains to be tested.

Advantages

- Operational in wind farms, although currently only onshore.
- May provide information on both micro-avoidance and collisions.
- Resolution of visual light cameras likely to provide good images for use in species recognition.

Limitations

- Detection of low-flying, small and fast-flying birds and with a range of backgrounds uncertain.
- Detection events require human interpretation to conclude whether collision occurred. Depending on the number of detections, this may be time-costly.
- Only suitable for daytime use and limited use during periods of poor visibility.

4.2.3 VARS

The Visual Automated Recording System (VARS) uses motion detection infrared (active infrared) video cameras together with infrared lamps for detecting and recording flying birds and bats. VARS was developed in the mid-2000s by Jan Kube and colleagues at the Institute of Applied Ecology (IfAÖ) in Germany (Schulz *et al.* 2009, IfAÖ 2011).

In 2007, two systems started operating at an offshore platform in the Baltic Sea (IfAÖ 2011). VARS was later (2009 or later) installed at the Alpha Ventus offshore wind farm in Germany (Coppack *et al.* 2011a). The infrared (active infrared) video cameras are mounted on the nacelle of the turbines and have a relatively narrow field of view (figure 3.) (Coppack *et al.* 2011a).

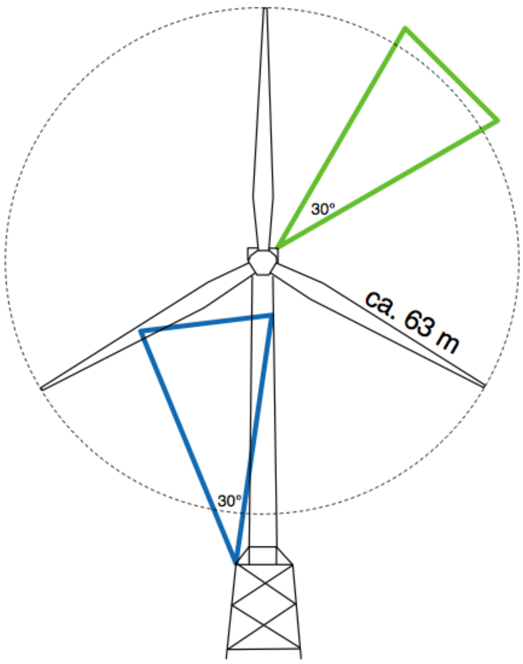

Figure 3. Schematic diagram of the field of view of the motion detection infrared (active infrared) video cameras used in VARS for small passerines shown on a turbine with a rotor length of approximately 63 m (from Coppack 2010).

The VARS system has been used to assess the numbers of flying birds close to the turbines (Coppack *et al.* 2011a; Coppack *et al.* 2011b), although its suitability for monitoring collisions (through limited field of view and motion detector sensitivity) or avoidance rates (through limited field of view range) is at present unknown.

Advantages

- Operational in offshore areas.
- Infrared (active infrared) video camera enables detection during darkness.

Limitations

- Narrow field of view and detection range.
- Rotors have to be excluded from the field of view to exclude false positives. This limits the use for detection of collisions.
- Detection events require human

interpretation to conclude if a collision possibly occurred. Depending on the number of detections, this may be time-costly.

4.2.4 Merlin Avian Radar

The Merlin Avian Radar System combines radar with specialist computer software and has been developed by DeTect in the United States (DeTect 2011). This system can be customized to monitor the movements of flying birds at various spatial scales, including close to the turbines. Specifically, the Merlin Avian Radar System can be used with the Merlin SCADA software, which detects flying birds close to the turbines in real-time and can carry out pre-programmed actions, such as stopping turbines. To date, over 70 systems are operational in relation to wind farms throughout the world (DeTect 2011).

The operating range and sensitivity of the surveillance radars and software can be modified. Generally, multiple wind turbines can be monitored and detection of small passerines is possible. Detection with radar is possible during periods of darkness, although this can be limited during poor environmental conditions, such as rain, fog or high sea state; the latter through false detections of waves. Detection shadow, behind turbines, may be an issue but from observations, this is likely to be minimal when the range that is used is small enough (Krijgsveld *et al.* 2011).

Species cannot be determined other than by interpreting size of the object, and no discrimination can be made between echoes consisting of 1 large bird or multiple small birds. Data are stored electronically and can include date, time, track length, track speed and reflectivity (to provide an approximate indication of relative size of the object). Bird tracks are spatially referenced, enabling the distance to the turbines to be calculated.

Advantages

- Available and already being used in wind farms, including offshore.
- Can provide information on micro-avoidance both during day and night.
- Coverage of multiple turbines.

Limitations

- No verification of potential collision events.
- Detection during precipitation or fog can be unreliable.
- No information on species or absolute numbers.

5 Systems under design

The following systems are known to be in the design or conception phase. As far as is known no field trials of these systems have been undertaken. Similar to the previous chapter, the systems have been divided into two groups: those that aim to directly detect collision events (section 5.1) and those that aim to monitor bird activity close to the turbine (section 5.2). The former are suitable for the detection of collisions only, whereas the latter may be suitable for the assessment of micro-avoidance and may also be suitable or adapted for the monitoring of collisions.

5.1 Systems for direct detection of collisions

No further systems were identified that are aimed at directly detecting bird collisions with wind turbines and are in the initial design phases.

5.2 Systems for monitoring bird activity close to turbines

One systems that aims to monitor bird activity close to the turbines is currently in the design or conception phase and has yet to be tested under field conditions.

ATOM

The Acoustic/Thermographic Offshore Monitoring System (ATOM) is currently under development in the United States (Pandion Systems 2011). This system comprises infrared (thermal imaging) video cameras in combination with microphones that record both audible and ultrasonic sound (for bats). It is aimed at parallel recording of images and sounds to monitor the presence and species of birds (and bats) in the vicinity of the wind turbine.

The infrared (thermal infrared) cameras and microphones are mounted on the base of the turbine or similar structure. Each camera records images of approximately half of the rotor diameter. The distance at which bird sounds can be detected has not been defined, although it is likely to depend on environmental conditions as well as the species concerned. Ultrasound (from bats) can be detected at a distance of up to 20 m from the microphone. The system aims to calibrate the flight altitude of birds by using triangulation between two cameras.

A preliminary version of an ATOM system was developed in 2009-2010 although it is planned that the first offshore version is to be trialled under field conditions in summer 2011 (Gordon 2011). Currently, the system continually records images and sound. Software to identify bird events in these recordings is currently under development and is not expected to be available for a year (pers. comm. C. Gordon). The ATOM system is not specifically aimed at recording collisions and is being developed for recording and identifying birds (and bats) that are present in the vicinity of wind turbines offshore.

Advantages	*Limitations*
• Infrared (thermal imaging) cameras detect birds during periods of poor visibility.	• No results from field tests available; range of detection and identification unknown. • Currently no software for the flagging of data; human interpretation of images and sound recordings is needed to identify bird events, this may be time-costly.

6 Conclusions and recommendations

A total of seven systems aimed at recording bird collisions with, or the bird activity close to, wind turbines have been identified (table 1). Of these, six are currently in operation or are undergoing testing and one is in the design stage. The direct detection of collisions with the wind turbines or rotors was possible with two of the systems. The remaining systems monitor bird activity close to the turbine and may be suitable or adapted for the monitoring of collisions. The exact specifications of each system are to some extent variable depending on the specifications of the components used and software settings. The features of each system in relation to the requirements for a collision detection system for use with wind turbines offshore as outlined in section 1.3 are given in table 1.

Table 1. Overview of collision and bird activity detection systems for wind turbines in relation to the requirements outlined in section 1.3.

	WT-Bird	ID Stat	TADS	DTBird	VARS	Merlin Avian Radar	ATOM
Detection sensor	Acoustic	Acoustic	Image-based	Image analysis	Image-based	Image analysis	-
Collision detection	+	+	-	-	-	-	-
Camera type	Active infrared	-	Thermal imaging	Visual light	Active infrared	-	Thermal imaging
Collision verification (through images)	+	-	+	+	+	-	+
Species (or group) determination	+	-	+	+	+	-	+
Operation at night	+	Detection only	+	-	+	+	+
Coverage of rotor-swept area	Single turbine	Single turbine	Partial	Multiple turbines	Partial	Multiple turbines	?
Suitable for use under offshore conditions	Under test offshore	Under test onshore	+	In operation onshore	+	+	Under design
Remote access	+	+	+	+	?	+	?
Coverage of multiple turbines	-	-	-	+	-	+	-
Coverage of entire rotor-swept area	+	+	-	+	-	+	?

6.1 Detecting collisions

Currently, no system for the direct measurement of bird collisions with offshore wind turbines is available. Of the two systems designed to measure collisions of birds with wind turbines, WT-Bird has a number of advantages over ID Stat, particularly in relation to offshore environments. The main advantage of WT-Bird is that as well as a collision detection trigger (microphones and accelerometers) the infrared (active infrared) cameras provide validation as to the source of the trigger as well as possible identification of the species concerned. Although WT-Bird has been calibrated for use with terrestrial turbines, further development would be required before this system could be operational on offshore turbines; at present tests to make WT-Bird operational offshore are underway. Based on current information, the resolution of the infrared cameras would also need improvement to improve species identification during periods of darkness.

6.2 Measuring avoidance rates

A number of systems aimed to monitor the movements of birds close to wind turbines are available. These systems use a variety of cameras (TADS, DTBird and VARS) or radar (Merlin Avian Radar). Both DTBird and Merlin Avian Radar have the capability of monitoring the airspace around multiple wind turbines, whereas TADS and VARS have a limited field of view, limited to part of a single rotor-swept area. This limited field of view may restrict the usefulness of measured avoidance rates for use in collision risk models as avoidance further from the turbines will not be measured. Even for systems that monitor the airspace around multiple turbines, macro-avoidance (avoidance of the entire wind farm) may not always be recorded if beyond the range of detection. Furthermore, a measure of flux (the number of birds flying through the airspace) will need to be measured to provide context for the numbers of birds showing avoidance.

Of the two systems using cameras, both TADS and VARS use infrared cameras (thermal imaging and active infrared respectively), and would therefore provide information during periods when the functionality of DTBird, with visual light cameras, is limited. Both TADS and VARS have been developed and tested for offshore use, although both have limited fields of view and require human interpretation of images to detect potential collision events. Based on knowledge of infrared cameras, the infrared (active infrared) cameras used by VARS are less expensive and provide higher resolution, although they have a lower detection range than the infrared (thermal imaging) cameras used by TADS. In both cases the range of detection is less than the entire rotor-swept area, meaning that birds showing avoidance at greater spatial scales will not be recorded. This may limit the use for determining avoidance rates.

Similar to TADS and VARS, Merlin Avian Radar has also been used in offshore situations and also provides information on flying birds irrespective of the available light. This system has the potential to monitor bird activity at a larger spatial scale than the two infrared camera-based systems, although detail in the immediate vicinity of the rotors is less. Furthermore, the radar-based system provides no opportunity for determining the species involved.

6.3 Recommendations

In order to assess the level of collision related mortality of birds with wind turbines, direct measurement of collisions is preferable over indirect estimation of collision related mortality through collision risk models. Variation in the (estimates of) numbers of flying birds (fluxes), of the proportion of birds at risk, and in particular, of macro- and micro-avoidance rates, limit the certainty with which estimates from collision risk models reflect the actual situation. The direct measurement of collisions can therefore serve as validation for these models.

Of the systems known to be currently available or in development, WT-Bird is the only system that is specifically designed to directly monitor the actual collisions of birds with wind turbines, although the applicability of WT-Bird in offshore situations (on Vestas turbines) is not yet known. Several systems are capable of monitoring bird movements close to the turbines, of which some are currently in use. Each system has merits and limitations and the most suitable systems will no doubt depend on the specific situation and availability. With each of these systems the interpretation of data gathered will play an important role in its effectiveness. Furthermore, there may be restrictions as to the type of system that can be used resulting from the practicalities of fitting a system to wind turbines. Considerations include restrictions from manufacturers, such as in relation to warranties or physical load limits and modifications needed to turbines. In order to fully assess the feasibility of applying any of the described technologies to wind turbines, it is advisable to consult developers to discuss the steps needed to ensure their actualisation.

Because of the current limitations of each of the systems developed to detect collisions, and because of the difficulties encountered during development of these systems, more time and funding for development and tests would be required to develop a system that meets the requirements needed in the offshore environment. Any system should be backed up by an underlying research program and appropriate analyses, which carefully evaluates any results and assesses these in the context of improving knowledge on collision risks offshore. Consideration should also be given to the factors potentially influencing any results, such as wind farm, environmental, geographical and ecological factors.

Finally, it is recommended that the results of collision monitoring be made widely available to ensure better assessment of the effects of existing and future offshore wind turbines on bird populations and to improve mitigation.

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