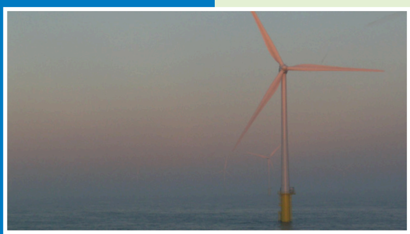
A review of methods to monitor collisions or micro-avoidance of birds with offshore wind turbines

Part 2:

Feasibility study of systems to monitor collisions

Strategic Ornithological Support Services Project SOSS-03A



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Preface

Frame of work

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'.

Following the review report that was produced for this task, several of the methods detailed were highlighted as having potential in monitoring collisions of birds with offshore wind turbines. The developers of these methods were approached in order to discuss the feasibility of developing and using their system for use in collision monitoring at offshore turbines.

These discussions allowed the current status, planned developments, practical aspects and the potential to tackle the question of monitoring collisions offshore to be explored, including potential developments needed, time-scales and costs.

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 already been erected. Notwithstanding the benefits of this development, collision victims among birds are considered one of the major ecological drawbacks of wind energy. Improving knowledge of the collision risks of birds with offshore wind turbines would have benefits for the assessment of the effects of wind farm developments at both the site-specific and cumulative levels, and thus help inform the consenting process for future offshore wind developments.

1.1 Aims of this report

The review report that was produced for SOSS 03A (Collier *et al.* 2011) provided an up-to-date insight into the methods that are being developed and/or tested to measure collision rates, or alternatively to measure micro-avoidance rates of birds, around wind turbines. From this review it has become evident as to what these potential methods are, the current status of each, and what is needed to permit deployment at offshore wind farm sites. It also became apparent that the potential methodologies to measure collisions offshore are limited to a small number of developers.

The review has shown that the challenge in having a method to measure collisions that is applicable offshore and that fulfils the requirements outlined in the review, lies in 1) quality of cameras, 2) filtering out noise of various types and 3) offshore testing.

In an attempt to resolve these issues, discussions with the developers of a selection of systems were arranged. These discussions aimed at examining the feasibility of each method for monitoring collision risk offshore, as well as highlighting the requirements still needed in order to realise these requirements.

The outcome of these discussions are documented in this report along with an overview of the steps necessary in order to arrive at a method that is applicable offshore; regarding both the steps that need to be taken in the development of the technology and steps to enable this development.

1.2 Requirements for monitoring collisions offshore

In their review report, Collier *et al.* (2011) outlined the following requirements for systems aimed at measuring bird collisions at offshore wind turbines:

1) can verify that a collision actually occurred;
2) will allow determination of the species (group) involved;

3) operate under circumstances both with and without daylight;
4) from multiple turbines throughout the wind farm array and throughout the year and;
5) across the entire rotor area;
6) suitably protected from weather conditions and salt water;
7) remote access of systems located offshore.

These requirements serve as a guidance. Although they might not be applicable in every situation (e.g. species-specific studies might not necessarily be required in all circumstances), they were used here as a benchmark against which each system could be compared. The actual requirements for a system to monitor collisions with offshore wind turbines largely depend on the specific aims of the project in question. It is, therefore, important to define the requirements for each specific situation.

2 Methods

2.1 Selection of systems

Based on the information in the review report (Collier *et al.* 2011), the three systems with the greatest potential of realising the monitoring of collisions of birds with offshore wind farms were: ID Stat; VARS; and WT-Bird. Each of these systems goes some way towards the requirements highlighted in the review, namely:

- include a trigger for direct detection of collisions (ID Stat, WT-Bird) and
- provide verification of collisions and species through camera(s) under a range of conditions (*e.g.* dark) (WT-Bird, VARS).

These systems have also undergone field-testing (although not all in the offshore environment) or have been deployed. This represents an important step beyond the concept and design phases.

In addition to the three systems mentioned above, the developers of the two other systems that were specifically designed for the detection of birds close to turbines (DT Bird and TADS) were contacted to ensure potential developments of these systems were not overlooked. Following this contact it became apparent that the development of DT Bird is ongoing and in the direction of low light and offshore use.

Consequently, meetings with the developers of the following systems were held:

- DT Bird;
- ID Stat;
- VARS;
- WT-Bird.

Following discussions with DeTect Inc. over their Merlin Scada bird radar system in spring 2011, it became evident that this system is limited in registering the collisions of birds with wind turbines because of limitations in detecting collision events (possible detection loss around turbines) and the difficulties of species identification. Based on the information available at the time, ATOM (Pandion Systems / Normandeau Associates Inc.) is currently in the early development stage and the possibility to record collision events seem someway off.

Based on information available during this study, TADS (Mark Desholm, University of Aarhus) was deemed to be limited in its use for the detection of collisions. The main reasons being, the lack of a trigger system, low camera resolution (meaning poor identification of smaller species) and the high false-positive rate (searching footage for collision events is time consuming). In response to an email outlining these limitations, the developer of TADS provided information as to recent developments of the system. This includes a software-based trigger system, which reduces the time taken to find potential collision events. It also includes the possibility of using multiple cameras to give effectively a larger field of view, while retaining the possibility of identification of smaller species. This can however be said for all types of cameras. The information received, however, was not sufficient to provide a full description of the system in chapter 3.

2.2 Discussions

Meetings were held between October and December 2011. Each discussion was held in person between one or more of the developers of the system in question and two staff from Bureau Waardenburg. The names and dates of the meetings are provided in chapter 3.

During the meetings the system in question was discussed with the aim of determining:

- the realistic potential of the system to measure collisions of birds with turbines offshore and under the range of conditions outlined in the review (*i.e.* darkness);
- the potential of the system to fulfil the requirements outlined in § 1.2;
- developments needed to address these requirements;
- the estimated financial investment needed to develop a working system;
- the estimated time frame needed before a system can be tested and then be operational.

Following each meeting, a summary of the information discussed was sent to the relevant developer for comment before it was incorporated in this report. This process formed an important part of the information gathering process. In particular, by enabling open discussions with developers through the proviso that commercially sensitive information could be retained and by providing confirmation of the information discussed.

3 Summaries of discussions

Below follows the information gathered during the discussions with developers. This includes information on the current status, planned developments, limitations in the recording of collisions of birds with turbines offshore, practical considerations and availability and costs.

3.1 ID Stat

The meeting over ID Stat took place in Nantes, France, on the 28th of October 2011 between Bertrand Delprat (Calidris) and Sjoerd Dirksen and Mark Collier (both Bureau Waardenburg).

Developer contact details:
Bertrand Delprat, Calidris, 14 rue Picard, 44 620 La Montagne, France.
bertrand.delprat@calidris.fr

3.1.1 Current status

Field-testing of ID Stat in an onshore turbine is continuing during the winter and spring of 2011/2012.

Although species or group recognition (or even size of species) is not possible, the idea behind ID Stat is to develop a simple and reliable system that can be installed in a large number of turbines to provide broad-scale patterns of the frequency and timing of collisions of birds and bats with wind turbines. The reliability of the detection system is currently under testing, although the developer is confident that the software filters out potential triggers from background noise such as the creaking of turbines and rain.

At present, ID Stat records event data, such as date, time, turbine ID, rotor ID, etc. and sends this information to the user via the GSM network. This can be modified, through means of the dedicated computer card, depending on the user's requirements. For example, to send the message via email and to write the data to a local storage media (hard drive), including sound recordings of events.

Remote access to adjust settings is possible. The ID Stat trigger system could also be developed to activate cameras, although to date this area of development has not been followed.

3.1.2 Planned developments

Further tests are planned at other turbines, including at a demonstration offshore turbine that is planned to be built at an onshore location in March 2012. This will provide the opportunity for testing with an offshore-specification turbine while validating with ground searches. This will give further insight into the occurrence of false triggers, which is currently unknown. It is planned that the results of the testing are made available in scientific publications. This may involve further field tests, and collaborations, in the U.S.

3.1.3 Limitations

Although information as to the number and timing of collisions could be obtained, information as to the species concerned could only be obtained offshore if used in combination with cameras.

3.1.4 Practical considerations

Based on current installations, no modification of the turbine itself is needed; the microphones are attached to the inside of the blades and the system connected to the power supply in the hub.

3.1.5 Availability and costs

It is expected that ID Stat will be available in summer/autumn 2012. What the exact cost of the system will be is currently unknown, however, it is expected that a post-testing system for a single turbine (three microphones in three rotors) will cost in the order of 20,000-25,000 Euro.

3.2 WT-Bird

The meeting to discuss WT-Bird took place on the 2nd of November 2011 in Petten, the Netherlands, between Henk Oostrum and Hans Verhoef (both Energy Research Centre of the Netherlands, ECN) and Karen Krijgsveld and Mark Collier (both Bureau Waardenburg).

Developer contact details:
Henk Oostrum, Energy Research Centre of the Netherlands, Westerduinweg 3, 1755 LE Petten, the Netherlands.
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www.ecn.nl

3.2.1 Current status

WT-Bird has been operational on a single turbine at an offshore wind farm in the Netherlands since July 2010, which has allowed the validation of the trigger system. Optimisation of the filtering algorithm would ideally be continued for another year. Here, the trigger component that counts rate of impact has been installed and is operational. The camera component that is needed to identify the species involved with collision events has not yet been installed. Data from this installation are not yet publicly available. Remote access to data and settings is possible.

According to the developers, collisions are detected with a fairly high accuracy. Any false alarms can largely be filtered out manually by listening to the recordings.

3.2.2 Planned developments

Due to the nature of the funding behind the development of WT-Bird, the system and its component parts have not undergone specific development during the past few years. However, updating the various components of WT-Bird, specifically the cameras, would be fairly straightforward and allows some flexibility as to the type and specifications of cameras used. The same is true for the camera housing; this would be based on the latest availability. Further development would be aimed as well at further decreasing the false alarm rate from impacts, but this trigger system is applicable in the offshore situation as it is. The number of false triggers has been crudely estimated as currently between 25-50 per actual collision. False triggers originate from a variety of sources, mostly mechanical. Some development will go into fine-tuning the filter to each specific type of turbine into which the system is placed.

3.2.3 Limitations

The active infrared cameras that were last used with WT-Bird in an onshore situation provided limited information as to the species concerned, especially when smaller species were involved. This was largely due to the resolution of the active infrared cameras, making it difficult to detect smaller species visually. Current cameras are likely to show improvement in this respect, although probably not a vast improvement as infrared technology available is not developing as fast as visual light cameras in terms of resolution.

The number of false triggers could require some daily time investment, needed to filter out false trigger from actual collisions by ear.

3.2.4 Practical considerations

Based on experience the installation on new turbines requires validation and tuning of the trigger system to the specific turbines that are used. For a new model of turbine this is expected to take around three months after installation on a running wind turbine. The validation period aims to reduce the number of false triggers by adjusting the algorithm used in identifying a collision. Not all false triggers can be removed with this filter but reviewing the visual data recorded with cameras can validate events. The longer the validation period the potentially better the filter can be tuned, with the aim of registering fewer false triggers. This estimate is based on traditional turbines, direct-drive turbines may differ in the levels and types of sounds produced and may, therefore, require further validation. Additional installations in tested turbine models will require a shorter validation period.

The trigger system is built into the inside of the rotor blades. This requires the attachment of components to the turbine. To date this has met with no objection from turbine manufacturers.

3.2.5 Availability and costs

WT-Bird, when including only the impact trigger, could be ready for installation within a few months of being ordered. A complete system operating with cameras would take a year. Prior to installation the most appropriate cameras and housings would be sought. Following installation on a new type of turbine a validation period of around six months is needed, for turbine types at which WT-Bird has been previously tested or used this is likely to be shorter.

The costs of WT-Bird will depend on the exact specifications of the various components used, but based on current information is expected to be in the order of 80,000 to 100,000 Euros per turbine (detection sensors for three rotors). This would include installation costs but travel costs are not taken into account. Also the costs for cameras are not included.

3.3 VARS (Visual Automated Recording System)

The meeting over VARS took place in Hamburg, Germany, on the 11th of November 2011 between Timothy Coppack (Institut für Angewandte Ökosystemforschung - Institute for Applied Ecology, IfAÖ GmbH) and Karen Krijgsveld and Mark Collier (both Bureau Waardenburg).

Developer contact details:
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3.3.1 Current status

VARS has been operational at the first German offshore wind farm since September 2010, where two VARS (active infrared) cameras are installed on one of the turbines. Currently, one camera is attached to the nacelle and covers an area just behind the rotors approximately between one and two o'clock (a 30^{o} field of view parallel to the rotor-swept area). The second camera is positioned at the base of the turbine and faces upwards towards the rotors. The camera output and saved images can be accessed remotely using an internet connection.

The motion-controlled cameras are always on and sequences of images are recorded once the trigger threshold is reached. This trigger threshold consists of a specified change in pixels, thus when something enters the frame. This triggering system can result in false triggers from the rotors, waves, rain at night, fast-moving aircraft, shooting stars and occasionally clouds. Currently, images are checked manually as no automated filtering of these false triggers has yet been developed.

VARS has been designed to measure the numbers of flying birds through the rotor-swept area. This in itself could be used in collision risk models and would remove the large uncertainty associated with avoidance estimates. As a collision detection system, VARS could potentially be used by reviewing the recorded images to determine whether a collision has occurred. Depending on the species involved and the conditions, species identification is possible on the basis of the general impression of size, shape and movement (or jizz).

Under good conditions the detection of small birds is almost complete up until 60m and detection is possible, although not for every bird, up to 80m.

3.3.2 Planned developments

This is dependent on future funding and is currently focused on the long-term measurement of activity rates close to the turbines in conjunction with the flux of birds recorded with dedicated bird radar over a wider area.

3.3.3 Limitations

Due to false triggers by moving rotors, it is not possible to monitor the rotor-swept area directly, but only the area directly adjacent to it. This is also true for false triggers due to waves, which means that cameras have to face upward, which in turn implies that if located on the nacelle, cameras can only monitor the parts of the rotor-swept area from the nacelle and upward. During testing, problems were noted with a camera positioned low on the tower facing upwards, with which high numbers of false triggers from the rotors were registered. A filter algorithm could solve this problem. This means that currently only higher-flying birds can be detected with the system. Birds colliding with the rotor below the nacelle cannot be monitored. These will mostly be low-flying seabirds.

Another limitation of the system is that the trigger mechanism involved prevents the coverage of the actual rotor-swept area. Although coverage of the area adjacent to the rotors will provide information on the birds passing through the rotor-swept area, data on actual collisions are not collected and these will have to be calculated based on collision risks.

3.3.4 Practical considerations

The developer foresees no problems with installation in offshore turbines. Currently, there are no issues of fouling of camera lens and housings when positioned high on the nacelle and using Lotutec-type coatings.

3.3.5 Availability and costs

VARS is potentially available within a period of a few months providing availability of cameras and other components. The cost of VARS is dependent on the exact specifications of the cameras used, but based on current information is expected to be in the order of 25,000 Euro per camera system (covering a 30^{o} area close to a single turbine).

3.4 DT Bird

An initial telephone conversation over DT Bird took place on the 10th of November 2011 between Marcos De la Puente Nilsson (Liquen/DT Bird) and Mark Collier (Bureau Waardenburg). Following this conversation, a meeting was held in Amsterdam, the Netherlands, on the 30th of November 2011 between Agustín Riopérez Postigo (Liquen/DT Bird) and Karen Krijgsveld and Mark Collier (both Bureau Waardenburg).

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3.4.1 Current status

DT Bird, with its various modules, is operational at onshore turbines. Of the DT Bird modules currently available, DT Bird Collision Control is the most appropriate for monitoring collisions with offshore turbines. The standard setup of this module uses two visual light cameras at the bottom of the turbines, each covering 180° around the turbines. This system uses real-time image recognition software to detect flying birds in a specified area of the image, such as close to the rotor-swept area. Images are recorded for a pre-determined time (for example, 10 seconds) prior to and after a bird enters this specified area. The balance of frame speed and resolution can be specified by the user. The exact settings depend on the specific aim of the installation.

Although DT Bird does not feature a collision detection mechanism, the detection module records images whenever birds come into a specified area. If focused on the area immediately surrounding the rotor-swept area the images of birds flying in close proximity or through the rotor-swept area would be recorded (although this 'trigger' area cannot cover the rotor-swept area the images recorded can cover this area and thus collisions would be recorded). Reviewing these images could potentially allow collisions to be detected.

Of relevance for offshore use is the fact that one system, running the detection module, has been operational in the offshore environment (lighthouse) since summer 2011.

3.4.2 Planned developments

DT Bird is currently developing a system that will work during periods of darkness. The exact specifications and types of cameras (for example, active or passive infrared) being used would depend on the specific need. The image recognition software would be adapted for specific use in low light. Various types of camera systems are being developed. The specific details are currently commercially sensitive however, and have, therefore, not been disclosed.

The system will be based on current DT Bird system and is said to provide bird or bat detection in situations with zero, or almost zero external light (c. <1 lux). For systems deployed offshore, appropriate housings and mounting would be sought.

3.4.3 Limitations

During daylight, based on the ability of DT Bird systems' software to recognise flying birds and the quality of the images, collisions can be identified from passerines to large birds, but species identifications for small birds can be limited in some low light conditions.

At night, the ability to identify species concerned would largely depend on the quality of the image, which is largely limited by the cameras available and the specific conditions. Assuming the use of active infrared cameras, the image quality is not likely to be too dissimilar to other infrared systems. The sensitivity of the system to detect birds at night would require validation.

Currently, a false trigger rate of one every one to four days has been noted on the DT Bird Collision Control module onshore (using visual light cameras). In practice this means that a (10 second) video is recorded where no collisions can be seen (in systems using stop control or dissuasion modules, activation occurs at a different stage and is thus not affected).

3.4.4 Practical considerations

The manufacturers foresee no problems with installation in offshore turbines.

3.4.5 Availability and costs

It is expected that DT Bird with the zero/low light capabilities is available in autumn 2012. Although in development for a specific project it may be able to be realised sooner. The estimated costs for development of a collisions detection module that would function at night and for the system itself are not currently available.

The estimated cost of a DT Bird Collision Control module for daytime only use is between 15,000-35,000 Euros depending on the number ordered. Depending on species and location one system is most likely to be able to cover one turbine; for large species during daytime only possibly several. The cost estimate includes installation (although depending on costs of accessing the actual site may actually be higher), as well as the standard service period and access to data. DT Bird offers the possibility of data analysis at an extra cost.

4 Conclusions and recommendations

4.1 Summary of current status

With the current high rate of development of offshore wind energy internationally, the development of systems to measure the collisions of birds with offshore turbines is also beginning to increase. This report has highlighted the rate of recent developments as well as the range of developments planned for the near future. All of the systems highlighted here are all aiming towards offshore applicability. Based on the information obtained over the planned developments of the systems here, many advancements can be expected over the coming years.

Currently, no system offers all the requirements specified in § 1.2 and only two are known to be undergoing testing at offshore turbines. Specific development of most systems is dictated by funding. Nevertheless, development of all systems is ongoing, although this might not necessarily be in line with all of the objectives for monitoring collisions outlined in § 1.2 (*i.e.* species determination). An overview of the four systems discussed in chapter 3 is given in table 4.1. During the production of this report, developments of the camera-based TADS system came to light; however, information as to its current status was insufficient to enable inclusion in this discussion (see §2.1 and Collier *et al.* 2011).

Table 4.1 Summary of the current status, costs and availability of the four systems studies along with the steps needed for collision monitoring offshore.

	ID Stat	WT-Bird	VARS	DT Bird
Detection trigger	acoustic, contact (collision)	acoustic, contact (collision)	image-based (not collision)	image-based (not collision)
Camera type	none	active IR	active IR	visual light
Current status	testing onshore	operational offshore (trigger only)	operational offshore	operational onshore/testing offshore
System available	summer/autumn 2012	a few months (trigger only)	a few months	now (daytime use)
Estimated costs in Euros per turbine (unless stated)	20,000-25,000	80,000-100,000	25,000 (per camera system)	15,000-35,000
Potential limitations in collision monitoring	no camera validation	camera validation onshore only, not offshore	no coverage of rotor-swept area	night time coverage not yet available
Planned camera type	none	active IR	active IR	active IR (?)
Steps needed for collision monitoring offshore	offshore testing + develop and add cameras	add cameras offshore	trigger system + coverage of lower rotors	IR cameras + offshore testing

Detection triggering

Two systems currently include collision detection sensors (ID Stat, WT-Bird). The other two include an image-based trigger as to when a bird is present (VARS, DT Bird). These two approaches both seem to be suitable in answering the question as to whether a collision has occurred (either by a direct trigger or by reviewing images; albeit that in the case of VARS the specific trigger used restricts coverage of the moving rotors, which limits the suitability in monitoring collisions), and the most appropriate system would be that which detects all collisions while recording the lowest number of false triggers. Here, the value of field-testing and validation becomes apparent (as has been carried out for WT-Bird).

Camera limitations in species identification

Cameras provide an important component to several systems. The recorded images not only allow trigger events to be validated, but under some circumstances for species to be identified. The level of species identification is dependent on many factors, most of which are related to external conditions surrounding the event such as weather, light conditions, distance to camera, species involved, the angle of the bird relative to the camera and trajectory through the frame. These external factors seem to be more limiting than the cameras used, which would have potentially similar specifications in each of the systems.

Based on information obtained, visual light cameras provide higher resolution than active infrared cameras. This ultimately translates as a wider field of view or improved image resolution. This can be overcome by using multiple active infrared cameras in order to cover the same field of view but inevitably this would have financial implications. Other limitations of active infrared cameras are the limited colour and range. These limitations urge the use of such cameras only when the task cannot be fulfilled by visual light cameras; i.e. at night. Ultimately, however, the choice of camera type depends on the specific aims of the study. If the species concerned are only active during the day then visual light cameras would suffice. If, however, the focal species are active both day and night and are easily distinguished on shape and size alone then infrared cameras may be more suitable.

Offshore proofing

None of the developers had encountered, or foresee, any difficulties with deploying their systems at turbines offshore. Similarly, protected against weather and salt water, and remote access to data or settings were not noted as difficulties in realising their systems in offshore areas. Many options for ‘weatherproofing’ seem available from protective housings to water repellent lens coatings. Experience and testing do play a vital role here however, because the harsh conditions in combination with the remoteness of sites means that maintenance visits may be restricted and costly.

4.2 Feasibility to measure collisions offshore

This study aimed to provide clear guidance as to the steps needed in order to arrive at a method that is applicable offshore; regarding both the steps that need to be taken in the development of the technology and steps to enable this development. Following the meetings with developers it became clear that an off-the-shelf solution for all situations does not exist. Furthermore, the steps needed to arrive at a system to monitor collisions offshore depends largely on funding as well as on the specific questions at hand, such as:

1) count only collisions or also verify species?
2) under all weather conditions?
3) count seabirds, migrating birds or both?
4) monitor in daylight as well as during night time?

Defining these questions does not only help to determine the appropriate system and/or components that are required, but also to define the physical set-up and settings used, such as the type, number and positions of cameras and the sensitivity of trigger thresholds.

Costs involved

Defining the specific requirements of the system will ultimately determine the amount of development required. This is perhaps one of the most important factors with regards to costs and time. With this in mind it becomes clear that time and costs of development cannot be specified until the requirements of the system have been defined.

One important step that can be defined however, is testing under field conditions. This should aim to ensure the consistency of results under a wide range of conditions and for the range of species in question. This is particularly important if considering the irregularity and relative infrequency of events and to reduce the level of human interpretation of event data, particularly if such systems are to be employed at large-scale. This has already been an important aspect of the (offshore) testing by VARS and WT-Bird. Both have been running tests offshore extensively, and are operational offshore. ID-stat and DT bird are less advanced in this respect.

Comparison of functionality

In order to provide a comparison between the four systems we make the following assessment on the basis of their current status and capabilities only[1] (summarised in table 4.2). Here we have chosen criteria based on those outlined in § 1.2, and with those criteria deemed most important in realising the monitoring of collisions at offshore wind turbines considered first. It is important to remember that this comparison is based on the systems that are currently available and that developments are ongoing.

[1] We consider WT-Bird as having the camera component installed. Although not trialled offshore, the full system has been tested and validated at terrestrial turbines and the addition of cameras is here considered a relatively minor step.

1) **Collision detection**. Collision detection is possible with three of the systems: ID Stat, WT-Bird and DT Bird (VARS has no coverage of the rotor-swept area).
2) **Collision detection under poor visibility.** When visibility is very poor, as for instance during rain, fog or heavy clouds, cameras (DT bird, VARS) will not be able to detect collisions. In this case only ID-stat and WT-Bird will allow collision detection.
   Collision risks are expected to be high under these conditions. Therefore this aspect will be relevant, especially when flight activity and species composition are not monitored.
3) **Species identification**. Species (or group) determination is possible with WT-Bird, VARS and DT Bird (ID Stat has no cameras).
   Only WT-Bird and DT Bird can combine collision detection with species identification.
   Detection of seabirds or of migrating birds at higher altitudes is dependent on resolution of cameras and position on the turbine, which can be arranged for all three systems.
4) **Species identification at night**. WT-Bird and VARS offer night time coverage by means of infrared cameras. DT Bird is developing night time coverage but currently uses visual light cameras only.
   This means that only WT-bird can combine collision detection with species identification both during day and at night.
5) **Tested offshore**. Three systems have been deployed offshore: WT-Bird, VARS and DT Bird. Only WT-Bird and VARS have undergone critical testing at offshore wind turbines. For WT-Bird this applies to the detection trigger only, the complete system including cameras has been tested on terrestrial turbines. DT Bird is operational at terrestrial wind farms, while one camera with the bird detection software is being tested at an offshore lighthouse.

Table 4.2 Comparison of functionalities of the four systems studied, based on their current status.

	ID Stat	WT-Bird	VARS	DT Bird
1) collision detection	Yes	Yes	No	Yes
2) collision detection under poor visibility	Yes	Yes	No	No
2) species (group) identification	No	Yes (if cameras installed)	Yes	Yes
3) species (group) identification at night	No	Yes (if cameras installed)	Yes	No (nocturnal system in development)
4) tested under offshore conditions	No	Yes	Yes	Yes

By combining systems, the limitations in collision detection and species identification summarised above can be overcome. The developers have expressed a keen interest in joining forces with other developers.

In conclusion

Based on the comparison above, WT-Bird and DT Bird offer the most complete systems by not only detecting actual collisions but also providing visual data for potential collision events. In this context, ID stat can be considered as a collision detection component and VARS as a camera component, which in combination would provide a comparable system. Offshore testing and validation has already been highlighted as an important stage in the realisation of a collision monitoring system. For all systems this is likely to make a significant contribution to development costs. Therefore, it has not been possible to estimate the costs and time required to see each of the systems through to a final product. Offshore testing and validation is likely to play an important role in the realisation of a suitable system. With this in mind offshore testing of one or more, or a combination of systems, is recommended.

Perhaps most importantly, any system should be used as part of a focused research program, aimed at tackling the question of bird collisions at offshore turbines. Research should aim at identifying the factors related to collision events and their relative frequency, through comparisons with flight intensity and species composition. The above will not only determine what system is most applicable for the purpose, but also the structure of this program and analysis of data.

5 Literature

Collier, M.P., S. Dirksen & K.L. Krijgsveld, 2011. A review of methods to monitor collisions or micro-avoidance of birds with offshore wind turbines. Part 1: Review. Report 11-078. Bureau Waardenburg, Culemborg, Netherlands.

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