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REVISED BEST PRACTICE GUIDANCE FOR THE USE OF REMOTE TECHNIQUES FOR ORNITHOLOGICAL MONITORING AT OFFSHORE WINDFARMS

Richard Walls, Chris Pendlebury, Richard Budgey, Kate Brookes & Prof Paul Thompson

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Copies available from:
www.offshorewind.co.uk
E-mail: cowrie@offshorewind.co.uk

Contact details:

Richard Walls:	wallsr@rpsgroup.com
Chris Pendlebury	chris.pendlebury@rpsgroup.com
Richard Budgey:	r.budgey@csl.gov.uk
Kate Brookes:	k.brookes@abdn.ac.uk
Professor Paul Thompson:	lighthouse@abdn.ac.uk

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Executive Summary

- This COWRIE report updates the Desholm *et al.* (2005) document on the use of remote techniques for offshore windfarm studies.
- This report is structured into:

  Section 1 – A Review of Remote Ornithological Monitoring Techniques

  (*An update on the previous report*)

  Section 2 – A Best Practice Guidance Framework for Remote Techniques for Ornithological Monitoring at Offshore Windfarms.
- 'Remote techniques' encompasses many technical methods for ornithological studies. These have been predominantly developed for scientific purposes many of which are documented in **Section 1** of this report and the previous COWRIE report. However, many are inappropriate or impractical to implement as monitoring solutions for the UK in terms of the Scottish Territorial Waters Round (STWR) and Round 3 (R3) developments.
- **Section 2** of this report provides a focus on a **'best practice' concept**, in particular on the potential role for integrated bird monitoring using selected 'remote techniques'. The remote techniques selected are proven to provide enhanced understanding of seabird and waterbird behaviour either during breeding, over-wintering or passage periods.
- **The most appropriate 'remote techniques' as defined in Section 2 of this report include radar, thermal cameras and tagging techniques**, as used successfully for previous onshore and offshore windfarm studies.
- This report aims to promote the wider concept of **ensuring that all bird monitoring techniques including 'remote techniques' (where necessary) are integrated as part of an Integrated Ornithological Monitoring Program (IOMP).**
- Within this IOMP concept the consortium indicate that a basic hierarchy of complementary survey methods can be implemented at any offshore windfarm site or zone. The bird monitoring techniques (including where appropriate 'remote techniques') best suited to the site or zone can be selected in consultation with the Statutory Nature Conservation Organisations (SNCOs) and other stakeholders (notably RSPB).
- The consortium also propose for recommended remote techniques **a traffic light system (Red / Amber / Green) indicating the appropriate use of individual techniques for potential monitoring of key species/species groups** at offshore windfarms (Section 2.3.3).
- This report aims to provide a **Guidance Framework** (Section 2.4) within the development process for offshore windfarms in the UK in order that 'remote techniques' successfully provide additional focus and value to standard baseline bird monitoring techniques (aerial and boat-based) during the EIA process.

Glossary

There are several terms used to describe radar in general and in particular.

Radar is used where the specific type is irrelevant in the current context. It is also used to describe the general principal of radar, or when describing the radar beam or other fundamental property.

Bird radar and **Bird detection radar** (**BDR**) is used for any type of radar when it is used for monitoring birds. This gives rise to the science of **radar ornithology**

Adapted marine radar is a radar system of the type commonly used on ships when it is used for bird detection. These are rotating surveillance radars operating in the X and S frequency bands. They may be operated vertically or horizontally. They are not equivalent to **ship based radars**

Vertical radar is an adapted marine radar operated with the axis of rotation turned through 90 degrees so the altitude of birds can be studied

Horizontal radar is an adapted marine radar operated in the standard configuration as used by the pilot of a ship.

Ship based radar is any type of bird detection radar used on a boat as opposed to a platform or on land.

Surveillance radar is a radar with a rotating antenna that records the spatial location of birds in the environment. Marine radar is of this type.

Avian Laboratory is a commercially available radar system that uses adapted marine radar. Additional functionality is included that tracks individual targets and records data to a database for later analysis.

Short range radar is any radar system with an operating range of between 1km and 15km. It includes adapted marine radar. Conversely Long range radar has a range of 50km – 200km and includes weather radar and air defence radar.

S-Band radar operates on a wavelength of 8-15cm and a frequency of 2-4GHz, allowing detection over distances of up to 11km for larger bird species. S-band radar is less sensitive to wave clutter than X-band radar. Typically used in the horizontal plane to track bird movements in plan view.

X-Band radar operates on a wavelength of 2.5-4cm and a frequency of 8-12 GHz. Given the smaller wavelength, X-band radar is more sensitive to bird targets but also has a shorter range, usually only 1-2km. Typically used in the vertical plane for measuring the altitude of migrating birds.

Acronyms

COWRIE – Committee on Offshore Wind Research into the Environment

EIA – Environmental Impact Assessment

IOMP – Integrated Ornithological Monitoring Program

NERI – National Environmental Research Institute

PPI – Plan Position Indicator

RADAR – Radio Detection and Ranging

R1 – Round 1 development round for UK offshore windfarms

R2 – Round 2 development round for UK offshore windfarms

R3 – Round 3 development round for UK offshore windfarms

REA – Regional Environmental Assessment

REZ – Renewable Energy Zones

RSPB – Royal Society for the Protection of Birds

SSI – Species Sensitivity Index

STWR – Scottish Territorial Waters Round for offshore windfarms

TADS – Thermal Animal Detection Systems

ZAP – Zonal Appraisal Process

Units

GHz – One *Gigahertz* represents 1 billion cycles per second. *Giga* is the standard multiplier for 1 billion, and *Hertz* is the standard unit for measuring frequencies, expressed as cycles or occurrences per second. One GHz is equivalent to one thousand *megahertz* (MHz).

NM – nautical mile.

ms^{-1} – metres per second.

1.1 A Review of Remote Monitoring Techniques for Birds

1.2 Introduction and Background

In 2004-2005 COWRIE commissioned the Natural Environmental Research Institute (NERI) and QinetiQ to provide 'Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore windfarms' (Desholm *et al.* 2005). This report provided a comprehensive and valuable technical review of remote techniques (existing and potential future advances), in particular covering radar and thermal cameras (TADS).

However, Desholm *et al.* (2005) did not provide offshore windfarm developers with clear and practical guidance on the 'best practice' application of remote techniques for effectively observing the behaviour of target bird species. In the UK, 'best practice' guidance to highlight appropriate remote techniques for assessing behaviour of individual target species, or groups of species, has been much needed. Consequently, the implementation of remote techniques in ornithological assessments within Environmental Impact Assessments (EIA) was variable during Round 1 (R1) and Round 2 (R2) in the UK.

On the 10th December 2007, John Hutton, Secretary of State for Business Enterprise and Regulatory Reform, announced the commencement of a Strategic Environmental Assessment (SEA) to examine 25GW of additional UK offshore wind energy generation capacity by 2020. This follows the 8GW planned for Rounds 1 and 2. This SEA was for areas considered as part of the R3 process, located beyond 12NM of the coastline. On Monday 26th January 2009 the UK Offshore Energy SEA Environmental Report was issued for public consultation. Public consultation on the Offshore Energy SEA Environmental Report closed in April 2009. In addition to the UK SEA the Scottish Government have also announced (on the 29th October 2008) an intention to conduct an SEA for offshore wind within inshore waters (inside 12NM around the Scottish coastline).

The Crown Estates (TCE) development process is already well underway for the Scottish Territorial Waters Round (STWR) and Round 3 (R3) leases. It is therefore important for all stakeholders to understand clearly the value of different remote techniques available (i.e. radar, radio-tracking, satellite-tracking and remote cameras), and how each of these may be effectively incorporated into EIA monitoring to enhance assessment. The importance of co-ordinating appropriate remote techniques within an Integrated Ornithological Monitoring Program (IOMP) is also stressed within this report.

In the previous COWRIE report, Desholm *et al.* (2005), highlighted the clear advantages which remote techniques (particularly radar) can provide in terms of collecting bird data:

- during darkness or low visibility,
- across extended time periods,
- over large spatial extent, and
- remotely in offshore regions.

The consortium for this report were commissioned by COWRIE to undertake a review and provide practical guidance. It is led by RPS, an international environmental consultancy, and includes two additional respected partner organisations: The Bird Management Unit, The Food and Environment Research Agency; and The University of Aberdeen. This consortium provides a range of perspectives, expertise, and direct experience in the development of ornithological assessments for the offshore wind industry including the use of remote techniques both in the UK and abroad.

1.3 Aim for Revised Guidance

The aim of this report was not to re-iterate technical information contained within the original COWRIE report but to provide clear 'best practice' guidance. Our aim is to ensure that this guidance is applicable for ornithological assessments made within the planning and EIA process for the STWR and R3 (Figure 1) in the UK. This report is therefore divided into two sections:

- **Section 1: A Review of Remote Ornithological Monitoring Techniques (update on previous report).**
- **Section 2: Best Practice Guidance Framework for Remote Techniques for Ornithological Monitoring at Offshore Windfarms.**

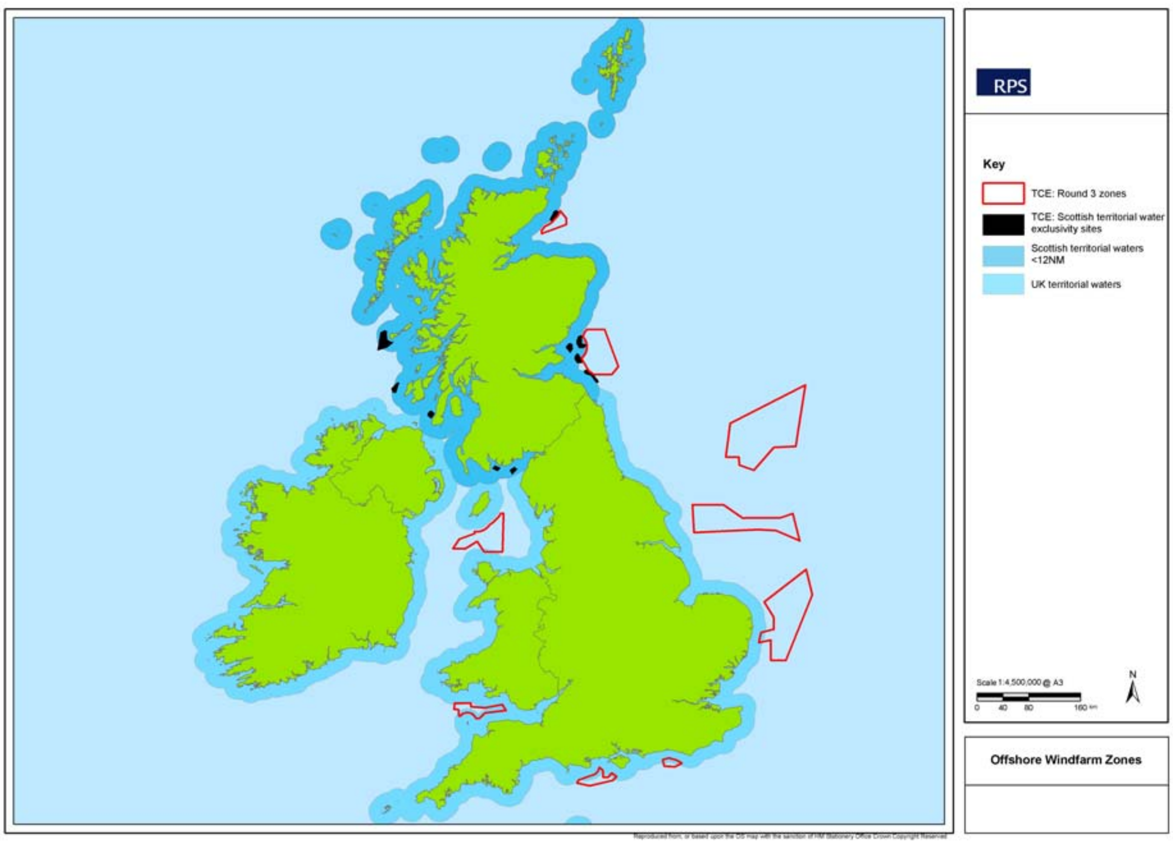


Figure 1. The Crown Estate R3 Zones (Red Polygons) and Scottish Territorial Waters Round Exclusivity Sites (Black shapes). Round 3 sites: clockwise from top: Zone 1 = Moray Firth, Zone 2 = Firth of Forth, Zone 3 = Dogger Bank, Zone 4 = Hornsea, Zone 5 = Norfolk, Zone 6 = Hastings, Zone 7 = West of Isle of Wight, Zone 8 = Bristol Channel, Zone 9 = Irish Sea.

1.4 Areas Outside the Project Scope

This COWRIE guidance concentrates on the use of specific remote techniques for ornithological assessment. Areas outside the scope of this work include:

- **HiDef Aerial Surveying**

  COWRIE has commissioned a number of studies into this potential monitoring technique www.offshorewindfarms.co.uk/Assets/HiDef%20Full%20scale%20trial%20-FINAL.pdf. The British Trust for Ornithology (BTO), along with COWRIE are reviewing the technical merits and application of this high definition aerial surveying remote technique during Q1-Q2 2009.

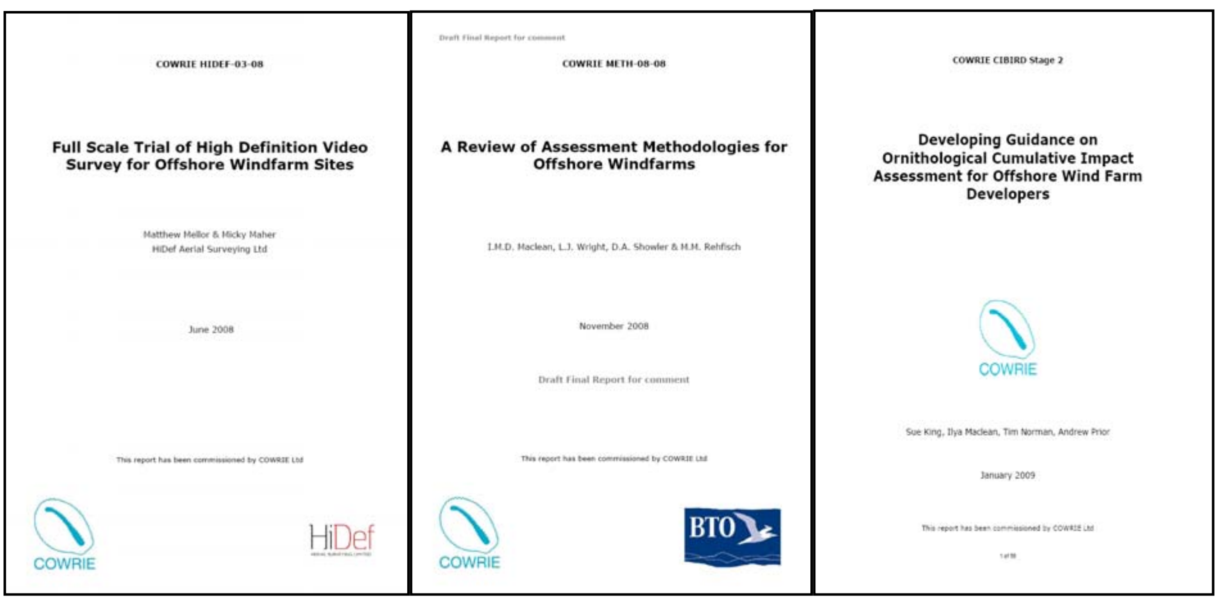
- **Standard Monitoring Techniques**: Aerial & Boat-based Surveying

  COWRIE have recently provided an update on the use of boat-based and aerial surveying techniques from R1 and R2 developments in the UK: Maclean *et al.* (2008) A review of assessment methodologies for offshore windfarms (draft).

- **Cumulative Impact Assessment**

  COWRIE have recently drafted: King .*et al.* (2009) Developing guidance on ornithological cumulative impact assessment for offshore windfarm developers.

Nevertheless, any selection or implementation of remote monitoring techniques must be considered within the context of this broader suite of techniques available for ornithological assessments during further offshore wind development in the UK.



1.5 Key Ornithological Species for Assessment in the UK

The key bird species which are likely to require specific consideration during future offshore windfarm developments in the UK will be determined by a number of 'risk factors'. The potential risk posed to a particular bird species is based on a combination of its ecology and the potential for coming into conflict with the physical offshore structures, the latter being determined by such as the location, layout, size and specification of the turbine arrays being developed within the STWR and R3 zones. Determining the potential risk for a species therefore involves consideration of the following elements, identified during R1 and R2 assessments:

- Geographic location in UK offshore waters
  (distance offshore, migratory pathways in Scotland, England, Wales & Ireland)
- Water depth
- Species distribution and abundance
- Seasonal variation
- Behavioural characteristics
- Turbine number, array/layout pattern, turbine size, air-gap characteristics

Example target species of seabirds and waterbirds of conservation concern identified during the assessment process for R1 and R2 included:

- **Common scoter**, *Melanitta nigra*
  (NW region: Shell Flats, North Hoyle, Gwynt y Môr and Aberdeen Bay)
- **Common eider**, *Somateria mollissima*
  (Aberdeen Bay)
- **Red-throated diver**, *Gavia stellata*
  (The Outer Thames estuary and the Greater Wash)
- **Pink-footed geese**, *Anser brachyrhynchus*
  (NW region and The Greater Wash on passage)
- **Whooper swan**, *Cygnus cygnus*
  (NW Region and The Greater Wash on passage)
- **Little gull**, *Larus minutus*
  (The Greater Wash on passage)
- **Lesser black-backed gull**, *Larus marinus*
  (The Outer Thames estuary)
- **Sandwich tern**, *Sterna sandvicensis*
  (Docking Shoal and Race Bank, The Greater Wash)
- **Little tern**, *Sternula albifrons*
  (Scroby Sands, Norfolk)

A key characteristic of offshore sites developed during R1 and R2 is that they are close to the coast (<12NM) in shallow water areas (<30m). Leases issued by The Crown Estate were also for specific individual offshore windfarm sites, rather than large geographic zones.

The greatest difference and challenge therefore for offshore wind developments during R3 is that The Crown Estate aims to accelerate the planning process by using exclusive development zones (Figure 1). The Crown Estate is currently offering nine development zones under the

Energy Act 2004 which allows the issue of leases for development beyond the territorial limit within Renewable Energy Zones (REZ) out to a distance of 200NM.

These development zones are located much further offshore, are of considerably greater area and are in deeper water (up to 50-60m to the seabed) than those of the previous R1 and R2 developments. As a result the bird species encountered are likely to include additional species/groups to key species identified during R1 and R2.

The RSPB report 'Round 3 offshore windfarm developments and birds at sea' (Langston 2008) is intended to provide a preliminary assessment of TCE potential development zones for R3 (Figure 1) and will be updated in light of plans for the STWR, notably in response to the SEAs for R3 and STWR. Nevertheless, the RSPB make recommendations on the appropriate level of survey effort for assessment and the appropriate use of remote techniques.

The RSPB and other non-statutory and statutory nature conservation stakeholders have highlighted the following aspects of bird ecology as important considerations during this new phase of the UK's development of offshore windfarms:

- **Seabird breeding colonies and Special Protected Areas (SPAs)**
- **Non-breeding distributions of birds at sea**
- **Bird movements, foraging ranges and feeding concentrations**

The Species Sensitivity Index (SSI) provides a robust scientific basis for identifying those bird species which may be at risk from offshore windfarm developments in European waters (Garthe & Hüppop 2004). The RSPB develop this further using SSI categories for birds in UK waters, and listing at risk species during breeding, non-breeding and migration (see Table 2 of Langston, 2008 and the appendix to this report). This list provides a comprehensive baseline from which to identify potential bird species which may be at risk from either collision, displacement, barrier effects or changes in habitat/prey availability as a result of the development of offshore windfarms in specific STWR sites and R3 zones.

In addition, the increase in scale and complexity associated with R3 will mean that additional species groups may be potentially affected during large scale, often international migration movements. Migrant bird species not specifically targeted for assessment during R1 and R2 are more likely to be of importance for assessment at the cumulative scale during the STWR and R3. However, remote techniques and radar in particular offer the only viable option for mass movement studies on a UK scale. These species could include migrating passerines (fieldfares, redwings, starlings, etc) and non-passerines (migrating ducks, waders and raptors such as short-eared owls and falcon species).

1.6 Key Aspects of Bird Behaviour for Assessment

The potential impacts of windfarms on individual birds and bird behaviour are typically defined as:

- collision risk,
- disturbance and displacement effects,
- barrier effects, and
- changes in foraging behaviour and (or) prey availability.

The change in the scale of development through the STWR and R3 zones requires an increase in the quality, consistency and spatio-temporal integration of ornithological data to detect potential impacts across UK waters. The size of the potential development zones will also require extensive datasets to assess the importance of different offshore areas, in different seasons, for a range of important UK and European seabirds and waterbirds.

It is therefore important to have clear guidelines on which bird behaviours should form part of site-specific assessments. These assessments will include generic behaviours applicable across all zones, and more site or zone specific behaviours dependent upon the geographic location of the potential development sites.

1.6.1 Generic Bird Behaviours

Seabird and waterbird behaviours which are important for assessment at all offshore wind developments, and can be used more widely to inform modelling and assessment work would include:

- **Flight characteristics:**

  Species flight type, flight altitudes, flight speed, flight manoeuvrability, wing-loading, avoidance behaviours and avoidance rates, flocking behaviour, and weather influences.

- **Feeding characteristics**:

  Feeding behaviour (surface-feeding, shallow-dive, deep-dive; maximum dive depths) prey species and behaviour, foraging range from breeding colonies, and the size of foraging aggregations.

- **Migration characteristics:**

  Key periods, key weather influences, migration pathways and migration stopover sites.

1.6.2 Site-specific Bird Behaviours

In contrast to these species-specific (or species group-specific) generic behaviours detailed above, site-specific bird behaviour relating to the precise location of the proposed windfarms is likely to be of key importance in determining potential impacts. This includes the following important elements identified during developments in the UK and abroad to date:

- **Determining site-specific habitat use:**

  Environmental determinants of food availability in foraging areas, feeding grounds, rafting or roosting areas – e.g. common scoter in Liverpool bay (Kaiser *et al.* 2006) and along the Aberdeenshire coastline, and in The Outer Thames Estuary the identification of over-wintering red-throated diver, O'Brien *et al*. 2008.

- **Geographic location and seascape / landscape setting:**

  Migration routes e.g. The Greater Wash and autumn passage for pink-footed goose migration, RPS 2008 & 2009; common eider in Danish waters at Horns Rev and Nysted, *Danish Offshore Wind – Key Environmental Issues*, Nov 2006 and at Kalmar Sound along the Swedish coast, Pettersson 2005.

- **Breeding colonies:**

  Little tern foraging behaviour, at Scroby Sands, North Denes SPA, Perrow *et al.* 2006.

1.7 Remote Techniques (Strengths & Weaknesses)

1.7.1 Bird Detection Radar

Bird Detection radar now comes in many forms, from small ship's radar (range <15km) to those used by weather services (range >100km). Desholm *et al*. (2005) suggest that adapted marine radar is the most suitable type for gathering bird data for offshore windfarm monitoring. These radar have certainly become more user friendly in recent years (e.g. the 'Avian Laboratory') and require less engineering knowledge from the user. Nevertheless, understanding of the principles of radar and the particular radar unit being used is still crucial for reliable interpretation of the data.

Marine radar, and other surveillance radar, return the position of a target in two dimensions of space. This can be horizontally, as with a normal ship's radar, or, in an adaptation commonly found in radar ornithology, vertically, where the axis of the radar antenna is turned through 90°. This latter adaptation returns the altitudes of birds. It is particularly useful in the offshore environment as it is less susceptible to sea clutter. Standard horizontal surveillance radar shows the movement of birds over the seascape and can be used for recording flight lines, patterns of movement, and long to medium range avoidance behaviour. So called Avian Laboratories, which generally have both a horizontal and a vertical antenna, record the locations of targets at every scan to a database along with other parameters such as reflectivity and target heading. This makes subsequent analysis of the data with GIS or statistical software straightforward.

So far, only X-band and S-band surveillance radar have been used in ornithological research in relation to wind power production facilities. Surveillance radar are produced for scanning 360˚ of azimuth (usually S-band radar) to monitor moving targets. However, in order to collect data on the flight altitude, supplementary radar with vertical scanning modes (usually X-band radar) have been applied, as well as modified systems where the scanning "T-bar" antenna have been substituted with a fixed parabolic dish.

Surveillance radar can be ship based or platform mounted. It is unlikely that many R3 sites will be close enough to the shore for land based short range radar to be used (STWR sites are within 12NM), but there may be scope for monitoring the departure direction and times of birds foraging from a colony as they head towards a potential windfarm site. When using radar out at sea, better quality data is likely to be obtained using a platform based setup rather than ship based. This is because a stable platform permits target tracking algorithms such as those used in 'Avian Laboratories' to function accurately. Additionally, the limit to the duration of operation of a platform mounted system will be less than that on a ship based system.

Ground Truthing (RADAR Calibration)

It is recommended 'best practice' to supplement bird radar with other observation methods, to provide 'ground truthing' or calibration. Information from trained field observers on bird species present is particularly important as species identification is rarely possible using radar. These direct observations will qualitatively inform a radar study, even if the observers cannot provide the same scale of observation (spatial and temporal) as the radar. At sea, ground truthing will be limited to boat based observation, platform based observation and remote video recording. Ground truthing at night is only possible using techniques such as night vision, thermal imaging or acoustic monitoring, which can operate over short ranges of approximately 0-500m.

Given the limited amount of supporting observations that are likely to be available, it is crucial that ground truthing is carefully considered during the study design phase, in order to maximise the integration of techniques.

Quantification

It is often assumed that the number of radar echoes seen on a radar PPI screen (Plan Position Indicator) matches the number of birds present within the area defined by the screen. In fact, estimates of the numbers of birds are only available by performing calibration exercises to estimate the 'probability of detection' for different bird types at different distances (see Schmaljohann *et al.* 2008). These methods are not generally suitable for marine type radar units which are difficult to calibrate and cannot distinguish flocks from individuals. Furthermore, the environmental conditions at sea are likely to be so variable that a calibration exercise will be of limited value.

Radar at sea is therefore more suited to the collection of data on relative numbers and patterns of bird movement. A radar study has the potential to show how numbers of birds vary through time (e.g. during 24 hour periods, or seasonally), and how birds might have a preference for different geographic areas of seascape. More precise quantitative counts can be collected using other methods such as boat or aerial surveys to estimate densities.

Platform Mounted Radar

Some meteorological (met) masts designed for R3 may have the potential to incorporate bird radar. This will require a reliable power supply for the radar itself and space and power for communication systems, computers and cooling systems for those computers. There will also be a need to ensure all of these systems can withstand the extremely harsh conditions that might be experienced in the North Sea. It is important therefore that provision for radar is considered at the met mast design stage.

Communication with a land base-station would also be required, for both control and data archiving. If a cable to land is available, that would provide the most straightforward communication channel. Alternatively mobile telephone or satellite communications would be required. If unprocessed data are required, these would need to be archived at the platform and the computer storage media retrieved physically at intervals. This in turn must be planned carefully within likely Health & Safety and operational procedures.

Health and Safety

Working on offshore platforms requires a high level of health and safety awareness and training due to the nature of the working environment. All work must be reviewed by platform control staff prior to commencement, to ensure that it is safe to carry out and does not conflict with other activities. Depending on the work to be carried out, this can take several days, but for routine maintenance (e.g. transferring data to hard drives, changing computer settings), the process is less complicated. Non-standard modifications to radar equipment may need to be formally assessed for safety, including electrical safety, which can be a lengthy process (up to several weeks). Any work carried out on radar, or associated equipment, must be undertaken by a suitably qualified person (whose credentials will be checked by the platform management).

If helicopter transport is required to the platform, the HUET (helicopter underwater evacuation training) course must be completed. Transport by boat is likely to require a sea survival certificate. Depending on the platform, the BOSIET (basic offshore safety induction and emergency training) course may be required, which includes HUET and sea survival techniques.

Wave and Rain Clutter

At sea, any form of radar will be affected by rain and sea clutter which can significantly reduce the quantity of useable data returned. With the current generation of bird radars these problems are unavoidable, particularly during severe weather. Good quality data can be returned by a horizontally mounted marine surveillance radar up to sea states three to five. Vertically mounted radar is not affected by sea clutter at higher altitudes, but data from near the sea surface can be difficult to collect due to wave and spray clutter. Often, all targets lower than 100m are unusable.

Sea clutter can be reduced by mounting a radar as low as possible to the sea surface so that direct radar reflections from the sea are minimised (i.e. the minimum sea surface is illuminated by the scanning radar beam and side lobes). Alternatively, an antenna can be shielded from returns from the sea surface with a physical screen, ideally constructed from radar absorbent material.

Certain types of radar are better able to operate in high sea clutter environments than others. Doppler equipped marine radar can reportedly separate bird targets from waves using differences in target speed. Marine Doppler radar is more expensive than standard radar (four times at present), but the ability to collect data in higher sea states may make this a valuable technology for future consideration. Another technological development which may be of use in the future is frequency diversity processing. This technique separates targets from sea clutter on the basis of differences in returned reflectivity over very short time periods (reflectivity is much greater for waves than for solid objects). However, these systems are considerably more expensive than current standard radar systems. Rain clutter is more difficult to avoid, but the longer wavelength of S-Band radar is less susceptible to rain clutter than X-Band. If the collection of data during periods of precipitation is important, considerations should be given to the use of S-Band radar.

1.7.2 Ship Based Radar

Ship based radar is the only method that allows the straightforward collection of radar data prior to construction, i.e. before any permanent structures have been built, but the quality of the data obtained is generally inferior to that collected by platform or land based radar.

Where ship based radar has been used, the view has generally been a positive one – that the data obtained are of value and provide information that could not have been collected by standard methods alone. However, it has inherent limitations over and above those of radar in general.

Ship based radar is very susceptible to sea clutter because it is more difficult to install shielding around the radar or operate it close to sea level than with ground based radar. Up to 95% of data collected by horizontally scanning antennas may be worthless as a result (West of Duddon Sands EIA, Jan Blew pers comm.). A key limitation is that the rolling of the ship affects both horizontally and vertically operated radars. It prevents the successful operation of target tracking software, meaning that all bird targets must be counted manually after the event by acetate tracing or an equivalent software based method. This is a time consuming and potentially error-prone operation. Ship-roll also makes altitudinal data, especially at low altitudes (<100m), difficult to obtain because the horizon is constantly moving on the radar screen. A further problem is that as the orientation of the ship changes though the actions of tide and wind, so it becomes difficult to quantify passage rates, since the relationship between the ship and the direction of bird movement is not constant.

As well as all the standard benefits of radar (e.g. night time operation, objective data gathering, etc.), ship based radar offers flexibility in terms of when and where the radar is deployed. Costs are also lower compared to ground based radar because tracking software is not used, and lower than platform based radar because installation and operation is less complex.

Ship based radar tends to be similar to the standard marine radar used in ground based bird detection radar systems. However it is inadvisable to simply collect data from a ship's own navigation radar because it is likely that various clutter reduction algorithms will be in operation that would remove many bird targets. Also, a vertically mounted radar will usually perform better than a horizontally mounted one when ship based, and this can only be achieved with a dedicated bird detection radar antenna.

Ship based radar has been used in three windfarm environmental assessments in the UK (North Hoyle, West of Duddon/Walney and Gwynt y Môr). Very mixed success was reported, with some workers disregarding the radar data collected (Gwynt y Môr, West of Duddon Sands) while others claimed "The test proved the utility of MSR [Marine Surveillance Radar] on a boat for the mapping of movement of common Scoter" (North Hoyle). Throughout Northern Europe, ship based radar has often been used with success (Jan Blew pers comm.).

1.7.3 Long Range Radar

Radar systems in this category have an effective range of up to 150 km. They include weather radar, air defence and air traffic radar and are the only other systems, apart from ship based radar, that can collect data prior to windfarm construction.

These systems are in continuous operation, and often provide additional data such as altitude, Doppler and polarization parameters that allow more sophisticated analyses. Drawbacks include lower resolution and lack of low altitude data at larger distances due to the curvature of the earth. Long range radars are used for aircraft birdstrike reduction and migration research throughout Europe and North America but have not been used to date for strategic windfarm monitoring, probably due to the limited operational access, no definitive UK studies and a lack of awareness amongst stakeholders and environmental consultants.

In the UK, all three systems are in place, but weather radar is the most readily available for exploitation. There are 19 weather radar stations operational or planned in the UK, and many of these have effective ranges that include Round 3 sites. Weather radar has low spatial and temporal resolution; range bins (radar sampling area) are between 250m and 1km long and 1 degree wide, time steps are of the order of five to 10 minutes between consecutive sweeps of the same target. This makes them more suited to monitoring large scale passerine migration than movements of individual targets such as migrating geese. It is also probable that much of the bird activity at Round 3 sites will be of an intensity which is too low to be recorded. Nevertheless, UK weather radar can return a great deal of useful strategic bird data. A trial conducted jointly by the Met Office and CSL in 2006 recorded autumn influxes of passerines that were also detected by marine surveillance radar and ground observers, but a later attempt to monitor goose movements along the East coast of England was not successful. Air defence radar has a much higher resolution, as good as 30m by 0.4 degrees spatially and 10 seconds temporally. This allows individual birds to be monitored at up to 135km.

1.7.4 Military Tracking Radar

Military tracking radar has been used extensively within radar ornithology by the Swiss, Dutch, Israelis and Americans, predominantly for academic research and estimates of birdstrike avoidance. This has included a focus on migration of raptors, waders and passerines. Military tracking radar has the ability to track individual birds over very large distances in 3D but these exemplary abilities are largely unavailable to the commercial market in the UK and are unlikely to be widely available as a regularly deployable technique.

1.7.5 Thermal Cameras

Thermal cameras detect radiation in the infrared range of the electromagnetic spectrum (wavelengths between 2-15µm). Contrary to the technique used in active thermography, passive thermal imaging devices, widely used in censusing animal populations, do not rely on an external energy source to illuminate the target. It is purely the heat radiation of an object that creates a thermal image. As the radiation reaches the detector via the thermal camera, it is transformed into an electrical signal, amplified and transmitted to an array of light-emitting diodes that produce the final visible image. Thermal cameras can detect a target in complete visual darkness and can see through light fog, rain and smoke. Thermal imaging cameras make even small temperature differences visible; therefore they can be successfully used as tools to collect information on bird flights and behaviour in conditions of limited visibility.

One limitation to the use of infrared camera systems for the purposes of bird monitoring is the relatively low optical resolution of thermal imaging devices, which may prove critical in object definition. Consequently the operational distance is limited to 1-2km, depending on the focal length of the lens attached to the camera. Of course, the strength of the telephoto lens dictates the size of the area that will be effectively monitored (i.e. reduced monitoring area when using a telephoto lens), which should be accounted for when designing a species-specific monitoring programme.

With low thermal resolution, lack of colouration on the thermal image is another factor that may hinder bird identification. As birds appear white against a dark background, a considerable amount of skill and experience is needed to identify birds based on body shape, wing beat frequency and flock formation.

Furthermore the practicalities of designing an infrared camera system capable of reliably meeting the harsh demands of an outdoor environment are very complex, especially where remote and automated operation is concerned. Nonetheless, successful operation has been achieved in Denmark and Sweden in studies of collision rates (Desholm *et al.* 2006). However, it remains unclear to what extent these techniques might be used to routinely collect data in the extreme conditions experienced at R3 sites.

Different methods of data recording and processing must be considered, given the period of a study and staff available to process recordings. The latter can be achieved either by fast-forward viewing of the recordings or by superimposing several hours of data onto a single frame. Each method has its limitations (for a detailed account see Desholm *et al*. 2006). A highly specified, good resolution infrared camera is expensive, costing approximately £20,000-30,000. This would also require specific lenses for the precise application resulting in an overall approximate camera and lens cost of £35,000 – 40,000.

1.7.6 Image Intensification – Night vision

Whereas thermal animal detection systems (TADS) use infrared imagery to detect heat emitted from objects in the far-infrared spectrum, image intensifying devices such as night scopes and night vision goggles detect radiation reflected off objects in the near-infrared part of the spectrum (wavelengths about 1µm). As a consequence the image intensifying devices can only work where a small amount of ambient light is present (e.g. from moon or stars). The integral part of an image intensifier unit is an image intensifier tube that uses the photoelectric effect to amplify very weak light. An image is displayed on a phosphor screen, which gives the scene a green hue. Some models of intensifiers can be incorporated into camcorders, digital SLR and CCTV cameras. This permits adaption of a low-light imaging system in terms of resolution, sensitivity, spectral response, gain, output brightness and budget.

The image intensifying devices enable estimation of the overall proportions of birds flying at low altitudes and the relative number of birds observed per hour. Cloud cover, fog, and wet weather can interfere with detections of birds using these visual methods.

1.7.7 Methods for Tagging and Tracking Individual Birds

All tagging methods must take into account the mass of the tag as a proportion of the body mass of the bird. In all cases, tag mass should be minimised. Guidelines used by the UK Home Office suggest that tags should not exceed 5% of body mass (Gaunt & Oring 1999), but other authors have suggested that for albatrosses and petrels, tags should be no more than 3% of body mass (Phillips *et al.* 2003). For guillemots and razorbills, no adverse effects were found when tag mass was 1.2% or less of body mass (Wanless *et al.* 1988). For some species, this will reduce the number of available methods for tracking (Table 1). The attachment method must also be considered carefully. Most workers use strips of Tesa tape, skin-bond or dental floss to fix the tag to the feathers on the back but some species are capable of preening these out after relatively short periods. Harnesses have been used, although Phillips *et al.* (2003) advised that they should be avoided to reduce the detrimental effects of tagging on albatrosses and petrels.

For all tags there is a trade-off between battery life and detection range, which are both constrained by limits on tag size. As well as a bird's body mass, consideration is also required on its foraging behaviour. For example, it is possible that some birds, such as common scoter, may not be suitable for tagging due to effects on diving energetics (A. Fox per comm.). Additionally, for all tagging procedures consideration of how the bird will be caught is also required.

Table 1. Range of masses (grams) of seabirds (Robinson, 2005). Percentages are calculated on the middle value in the range.

Species	Scientific name	Lower	Upper	5% body	3% body	1.2% body
Razorbill	*Alca torde*	525	705	30.7	18.4	7.4
Black guillemot	*Cepphus grylle*	360	480	21.0	12.6	5.0
Puffin	*Fratercula arctica*	325	450	19.4	11.6	4.6
Guillemot	*Uria aalge*	770	1010	44.5	26.7	10.7
Gannet	*Morus bassanus*	3000	3000	150.0	90.0	36.0
Shag	*Phalacrocorax aristotelis*	1540	2100	91.0	54.6	21.8
Cormorant	*Phalacrocorax carbo*	2100	2500	115.0	69.0	27.6
Fulmar	*Fulmarus glacialis*	595	970	39.1	23.5	9.4
Manx shearwater	*Puffinus puffinus*	330	455	19.6	11.8	4.7
Storm petrel	*Hydrobates pelagicus*	22.5	29.1	1.3	0.8	0.3
Leach's storm petrel	*Oceanodroma pelagicus*	39.8	53.3	2.3	1.4	0.6
Great skua	*Catharacta skua*	1300	1500	70.0	42.0	16.8
Arctic skua	*Stercorarius parasiticus*	360	476	20.9	12.5	5.0
Herring gull	*Larus argentatus*	757	1264	50.5	30.3	12.1
Common gull	*Larus canus*	328	497	20.6	12.5	4.9
Lesser black backed	*Larus fuscus*	686	999	42.1	25.3	10.1
Great black backed gull	*Larus marinus*	1290	1920	80.2	48.2	19.3
Black headed gull	*Larus ridibundus*	240	348	14.7	8.8	3.5
Kittiwake	*Rissa tridactyla*	310	434	18.6	11.2	4.5
Little tern	*Sterna albifrons*	56	56	2.8	1.7	0.7
Roseate tern	*Sterna dougallii*	110	110	5.5	3.3	1.3
Common tern	*Sterna hirundo*	113	144	6.4	3.9	1.5
Arctic tern	*Sterna paradisaea*	90.5	119	5.2	3.1	1.3
Sandwich tern	*Sterna sandvicensis*	214	261	11.9	7.1	2.8
Greylag goose	*Anser anser*	2800	3900	167.5	100.5	40.2
Pink footed goose	*Anser brachyrhynchus*	2220	3400	140.5	84.3	33.7
Common scoter	*Melanitta nigra*	1000	1000	50.0	30.0	12.0
Eider	*Somateria mollissima*	1830	2350	104.5	62.7	25.1

The inclusion of species in Table 1 does not necessarily make the species a suitable candidate for the attachment of tags. This will depend primarily on the study aims,

1.7.8 Radio-Tracking

Radio tracking can provide a useful means of identifying key foraging areas for birds from a particular colony (Perrow *et al.* 2006), or, if birds can be caught on the water at a proposed windfarm site, to find which colony they belong to. Data collection can be an intensive process, but with multiple observers tracking the same target to allow triangulation, fairly accurate positions can be recorded. Tags are available in sizes appropriate to all of the birds likely to be of interest, but the range and battery life can be limited on the smallest tags. Prices for individual tags are less than £150, while the receiver and antenna required cost around £2000. Boat/vessel and personnel costs per day also increase the cost and intensive and extended periods at sea may be required. However, this has been employed very successfully in the UK to address particular questions about short-range (<25km) movements of seabirds.

1.7.9 Satellite Tracking

Satellite tracking has many of the same strengths and weaknesses as radio-tracking. It is likely to be used to achieve similar objectives, but is more suited for tracking larger-scale movements. The tags are more expensive, but positions of birds are estimated on each pass of the satellite and relayed to users via the ARGOS system. The number of locations obtained each day depends upon the latitude and the birds behaviour, but is typically a maximum of 12-18 passes per day in UK waters. This helps to reduce costs because observers are not required to follow birds and also improves data quality by incorporating known errors in location precision, which are not easily recorded with manual tracking. These methods have been used very successfully for large pelagic seabirds.

The tag transmits to a satellite, which calculates its position and transmits this to a receiving station. Be as only one satellite is involved, the positional accuracy is, at best, 4 km at best and can be as low as 493 km (Soutullo *et al.* 2007). The tags have become smaller, and it is now possible to have a battery powered tag of 20 g and a solar powered tag of 9.5 g. Whilst solar powered tags may allow tag life to be extended for some species, these will not be suitable for seabirds wintering in northern latitudes. The lifespan of battery powered tags is dependent upon the required frequency of bird locations. Individual tags cost around US$2900, and users must also pay for ARGOS satellite time, which would be around US$180 for a month of continuous transmission. Rates are reduced, and battery life extended, if transmission is duty cycled (i.e. the equipment is active for a set proportion of the day) but this may compromise some study designs. Since the manufacturers are based in the USA, there is also import duty and VAT to pay in UK.

1.7.10 GPS Tracking

GPS tags enable higher quality data on location to be collected than is typically possible with either radio tracking or (ARGOS) satellite tracking. This is because the tag receives signals from several satellites and from this, calculates its own position through triangulation. The more satellites the tag can make contact with, the more accurate the location. Manufacturers claim accuracy to within ±10-15 m, but studies have shown that positions can be accurate to within 5 m without correction (Hulbert & French 2001). Such high levels of accuracy may not be necessary for some of the questions likely to be asked.

One key disadvantage of GPS loggers is that they archive data rather than transmit data, and so the bird must be re-caught in order to retrieve them. This is not necessarily difficult at breeding colonies where birds return to incubate or feed chicks, although repeated disturbance may cause desertion of the nest. Advances in GPS technology and miniaturisation mean that device sizes are constantly being reduced. Another potential advance is the use of Bluetooth technology which can negate the need to re-capture birds by enabling remote downloading of data over workable distances (10-20m). However, these devices are not available yet. Currently, commercially available tags costs around £850. A second disadvantage, is that the power requirements of GPS loggers are high, and the smallest (<20g) loggers that are likely to be deployed on most UK seabirds can only record data for 2-3 days. Nevertheless, these loggers can provide important fine scale data on the distribution of birds as small as 400g (Guilford *et al.* 2009).

1.7.11 Satellite Linked GPS

Satellite linked GPS tags offer the accuracy of GPS and the convenience of transmitted data as with ARGOS satellite tags. The position of the bird is calculated in the tag, as in GPS tags, and this information is uploaded to the ARGOS satellite. However, the weight of such tags is greater than the satellite tags, with the very smallest solar powered tags weighing 22 g and battery powered tags weighing at least 40 g. The price per tag also increases to around US$3600, plus the associated cost of ARGOS satellite time.

1.7.12 Global Location Sensing

GLS tags are very small and can be attached to a ring on the bird's leg. They sense ambient light levels and from this, determine sunset and sunrise times. Latitude is determined by day length and longitude by the difference in the time of midday in relation to Greenwich Mean Time. Deriving positions in this way leads to lower accuracy than some of the techniques previously discussed, with mean error being 186 km (Phillips *et al.* 2004). However, the tags can continue logging for longer periods than GPS or satellite tags (at least a year) and are cheaper, at around £150 each. The tag must be retrieved from the bird to collect the data. Their key strength is in providing data on large scale migratory movements (e.g. Guilford *et al.* 2009). However, their wet dry sensors also provide data on activity patterns that could be used to assess species-specific variation in levels of night time flight. Some heavier and more expensive devices also provide data on temperature that can be used to improve the precision of locations.

1.7.13 Laser Rangefinders

Laser rangefinders, available as handheld devices (Pettersson 2005) commonly used in the surveying industry, can be used to estimate the altitude of birds. Results can be displayed on a screen or recorded to a database. Accuracy is very high, with estimates given to the nearest cm. The angle to the bird from the observer may be required to calculate altitudes but some rangefinders return altitude directly. The effective range for birds may be much lower than the maximum range quoted for the device because of the small target size, and it is often difficult to ‘fix’ on a bird target as it is flying, so the amount of data collected can be low. Nevertheless, it can be a relatively inexpensive method of collecting accurate height data at very close range (<200m). In addition rangefinder binoculars are available but do not provide any significant advance for routinely gathering accurate data on bird movements.

1.7.14 Stereo Flock-filming

Stereo photography is used to study detailed aspects of bird flock structure and the responses of birds and bird flocks to nearby obstacles, in this case wind turbines. Using the parallax shift between the images of the same bird in left and right camera images, the three dimensional position of the bird in space can be calculated and followed through time if video images are collected.

It is more suited to the collection of generic data on flock density and close range avoidance behaviour for use in the development of collision risk models than for collecting field data specific to a particular windfarm development, though it could also be used for the calculation of bird flight altitude.

1.7.15 Acoustic Monitoring

Acoustic monitoring methods for migrating passerines and waders have been used successfully in a small number of studies for onshore windfarms in the United States (Evans 2003). However their application at a large scale offshore windfarms across STWR sites and R3 zones at sea would be largely unproven. Potential problems with wind noise, wave noise and precipitation noise would be expected to cause significant reductions in detection capability. Acoustic monitoring only provides species discrimination for those species that call, so this has limited application (usually only for some passerine migrants).

1.7.16 Data Analysis Techniques

The appropriate analysis, interpretation and presentation of radar data is as important a part of a radar study as the collection of the data.

Many radar studies have attempted to gather accurate estimates of the number of birds passing through an area. This may be possible with sophisticated radar equipment, but with marine radar, where a single target may be several birds, it is much more complicated. Studies that have attempted this have used correction factors to adjust the number of birds, which work on the assumption that flocks are of a similar or the same size. Samples of flocks are observed visually, to count the number of birds within them and the average value is multiplied by the number of flocks. The assumption that flocks are of the same size is probably not valid, since bird behaviours change throughout the day and the seasons. For example, wintering wildfowl are likely to enter and exit roost sites in large flocks, but may move around and between foraging sites in smaller groups. Equally, numbers of birds on migration are often variable and can appear early and late in the passage season, with peak flocks being very much larger than early or late ones without a sufficient period of sampling & intensity.

Other methods that have been suggested include using distance sampling techniques to adjust densities of birds to account for reduced detection at greater distances. This is feasible, but relies upon the assumption that the real density of birds within the area of interest was actually homogeneous, to avoid falsely over-inflating the numbers of birds. Therefore, the areas over which such adjustment is carried out should be relatively small.

This does not mean that radar is not capable of producing data that are useful and informative for windfarm EIAs, but that the data should be used in an informed manner based on its limitations. Radar data are very useful for determining flight directions through windfarms and also from colonies, if there are concerns about birds from a particular colony (notably an SPA) using the site. Radar can also determine, with much greater accuracy than many of the other techniques mentioned, the proximity of a target to windfarms and turbines. The potential installation of a radar early in the monitoring process would provide an initial overview of the level of activity at the site, through the number of tracks recorded. The number of tracks can also be used as a relative measure with which to scale visual counts of birds at the site, during periods when no surveys were conducted.

The protocol for this would be to carry out visual vantage point surveys, at the same time as running the radar. The relationship between the two at that particular site should be determined through at least 12hrs recorded on 3 consecutive days of observation and the equation of the line determined using linear regression. Visual surveys are likely to be necessary at intervals throughout the process, and the results of these can be used to refine the relationship with the number of tracks recorded by the radar. For the periods between visual surveys, an estimate of the number of birds at the site can be obtained through rearrangement of the equation of the line calculated during periods with a visual observer. However, whilst these techniques can be routinely incorporated into terrestrial or coastal radar studies, it remains to be seen whether it is practical to conduct such validations across R3 zones.

Data from 'Avian Laboratory' Type Radars

A key feature of 'Avian laboratories' is 'front-end' processing software that distinguishes birds from other targets, such as aircraft and clutter, and uses a 'track-while-scan' algorithm to identify and mark the same target on successive scans allowing them to be grouped together into a track (or flightline). All individual bird positions are recorded to a database at each scan along with their track identification code so it is possible to display an individual bird or flock's flight path using GIS software and to build up a picture of the patterns of movement.

Even after processing by the 'avian laboratory' software, extensive quality control and post processing of the recorded data is required when working offshore. Some flightlines will be lost by the tracking algorithm of the radar and found again later, resulting in multiple tracks for the same target. To avoid over counting, these should be considered as one movement. The separate track sections should be reconnected, or all but one of the tracks should be deleted. Similarly, the track-while-scan algorithms used are sometimes prone to connect the movement of two bird targets into a single track, especially if a second bird is found immediately after another is lost, even if they are some distance apart, and these should be split into separate parts. Some tracks will simply be the result of clutter or other radar noise and should be discarded. These tracks will tend to be very short - in terms of the number of separate registrations that comprise them - and have a high degree of sinuosity, allowing them to be readily identified and deleted from the database.

For short term studies, these methods of quality assuring (QA) data are possible using a combination of GIS and other software such as Excel or Matlab. However, for longer deployments, the resulting data sets can be extremely large, and will require specialist programming and data handling skills. Automated routines are almost certainly required given the quantities of data to be processed, for which rule sets will have to be developed that categorise tracks into target or noise and split or group tracks appropriately. Different rule sets may be needed for different species or environmental conditions. All of these inputs require skilled staff inputs and have associated data processing costs.

Supporting observations

In addition to the standard ship based and aerial observations, which may be used to support radar observations, further ground truthing observations should be made to help validate the dataset. These can be in the form of visual observations using an adaption of land based vantage point surveys or they can be 'view bearing' observations, where the observer looks only in one direction and notes the time and details of all birds that cross that line. Results using this method are much easier to compare directly to the results obtained by radar because the position of birds seen is more accurate. It is a particularly useful method for observing migratory birds if the view bearing is perpendicular to the direction of migration.

In addition to standard observations with binoculars, other secondary methods, including acoustic monitoring, night vision and thermal imaging or standard daylight video monitoring may be used to provide cross-referenced datasets. These methods can be used manually, from a ship for example where they are particularly valuable during periods of low visibility. or at night. They have the potential to be used remotely, for example for collecting data from a met mast.

Methods for quantifying the data collected by electronic imaging or acoustic monitoring may also need to be developed. Where standard methods do not exist, results from these methods should be calibrated to standard observer methods (see above, Section 15), and then they can be used to correct radar counts, or used as counts in their own right.

Table 2. A list of strengths and weaknesses of remote techniques for monitoring birds.

Technique	**Strengths**	**Weaknesses**
Strengths and weaknesses common to all radar systems (unless otherwise stated in specific section)	1. Data can be collected during night time and during periods of poor visibility 2. Objective data collection possible with reduced observer time required from ornithologists 3. Data collection over large area 4. Data collection over long period	1. Susceptibility to adverse wind conditions (wave clutter) 2. Susceptibility to rain (more so X–Band than S-Band) 3. Species discrimination very limited 4. Flock size discrimination very limited 5. Expensive to deploy during pre-construction with limited offshore infrastructure
Ship Based Radar	1. Can be deployed for pre-construction monitoring 2. Cheaper and more flexible than permanent systems 3. Multiple and flexible radar positioning possible	1. Requires high level of manual input (acetates) to find and record birds 2. Very susceptible to wave clutter and adverse weather conditions 3. Only records a small percentage of birds present 4. Poor data quality in contrast to platform and land-based radar monitoring 5. Only vertical radar providing good quality data
Long Range Radar	1. Can be used for pre-construction monitoring 2. Systems already in place 3. Large detection range 4. Strategic approach to monitoring mass movements	1. Unproven technology in UK 2. Curvature of earth effects mean low altitude detection unavailable, especially. at distance 3. Limited use on a site-specific basis at low altitude particularly for STWR and R3

Military Tracking Radar	1. 'Species' identification possible 2. Quantitative passage rates can be measured 3. Movements of single birds	1. Very expensive 2. Little scope for remote deployment at sea 3. Not suitable for observing movements over a large area 4. No UK suppliers currently and limited European suppliers 5. Security issues from MOD / DE
Thermal Cameras	1. Night time and low-visibility monitoring 2. Species-specific I.D. possible 3. Observations of avoidance behaviour possible 4. Proven application in Danish Studies	1. Expensive to deploy 2. Limited detection range dependent on species size
Image Intensification – Night Vision	1. Night time and low-visibility monitoring 2. Species-specific I.D. possible 3. Cheaper per unit than thermal cameras	1. Limited detection range dependent on species size 2. Ambient light requirements 3. Poor quality images in contrast to Thermal Cameras
Radio-Tracking	1. Ability to monitor movements over long distance (with multiple detectors), and confirm movements from colony or roost to sea 2. Pre-construction use possible if boat-based detector used 3. Individual based modeling information	1. Requires two observers (or boats) to track an individual bird – mass movement data not possible 2. May not produce definitive or representative information because of small sample size. 3. Access to colony or roost may be difficult 4. Licensing requirements to fit tags from BTO
Satellite Tracking	1. Ability to monitor movements over long distance without observers 2. Data on long-distance movements available 3. Data downloaded via ARGOS, so no need to re-catch bird 4. Solar-powered units extend the time-period over which movements can be tracked, e.g. return migrations	1. More expensive than radio/tracking 2. Tags are heavier than radio/tags, limiting the number of species they can be used on 3. Positional accuracy can be low (4 km at best) 4. May reveal limited info if tag fails 5. Poor weather conditions can affect data recording for tags with solar-powered elements 6. BTO license require specialist researchers

GPS Tracking	1. Positional accuracy high (±15 m)	1. Must re-catch bird to retrieve logger and data 2. Bird must weigh minimum 1500g to carry tag 3. BTO license requirements require specialist researchers
Satellite Linked GPS	1. Combines high resolution of GPS tracking with convenience of data download from satellite	1. Increased tag mass 2. Expensive per unit
Global Location Sensing	1. Ability to monitor movements over large areas and long time periods (up to 2 years) 2. Very small and inexpensive	1. Resolution of fixes is low (186 km) 2. No data without sunset/sunrise (e.g. in arctic winter or summer) 3. Must re-catch bird to retrieve logger and data
ALTERNATIVE REMOTE TECHNIQUES LARGELY UNPROVEN FOR ORNITHOLOGICAL MONITORING FOR OFFSHORE ENVIRONMENTS AND IN PARTICUALR AT WINDFARMS		
Laser Rangefinders	1. Accurate altitude data possible (for development of collision risk models)	1. Effective range quite limited for birds (up to approximately 50 m) 2. Difficult to measure large quantities of birds
Stereo Flock/Filming	1. Detailed information on flock structure and interactions with turbines possible (for development of collision risk models)	1. Equipment cumbersome 2. Requires large degree of manual input for data analysis 3. Unproven offshore
Acoustic Monitoring	1. May be the only way to confirm collisions (vibration monitoring) 2. Species discrimination possible	1. Not suitable for boat deployment (presence of boat may effect birds within range of detector) 2. Requires very large amount of specialist analysis 3. Noise contamination offshore

1.8 Remote Techniques (Case Studies)

1.8.1 DOWNVInD Project

The aim of the DOWNVInD radar project was to test the use of an automated bird detection radar system located on an oil platform for tracking birds offshore and to find whether it could be run without an observer for extended periods. This had a great potential advantage at offshore locations, where the logistics of having an observer present are complicated by transport availability and weather conditions.

Detection and tracking of birds with radar was trialled at the Beatrice oil field, in the Moray Firth, Scotland where two 5 MW turbines were installed in the summers of 2006 and 2007. The site is 22 km from land and the seabed is at a depth of 40 m, making the turbines the furthest offshore and in the deepest water of any installed to date worldwide. The oil field has three fixed platforms, the largest of which, and the only manned platform, is the Beatrice Alpha.

To the north of the site is the East Caithness Cliffs Special Protection Area (SPA), which is designated for its breeding seabird assemblage. In particular, this area holds up to 10% of the UK's breeding common guillemots *Uria aalge*, accounting for 3.2% of the East Atlantic population (JNCC 2001). Historical surveys suggest that the Smith Bank, on which the Beatrice site is located, is an important feeding area for these birds during the breeding season (Mudge *et al.* 1984, Stone *et al.* 1995).

Radar Installation

An S-band marine surveillance radar (FAR-2137S, Furuno, Nishinomiya, Japan) was installed on the Beatrice Alpha platform in June 2005 for the purpose of recording fine-scale bird movements through the proposed wind turbine area. S-band radar was chosen over the more common X-band because the longer wavelength is less affected by rain clutter. The radar has a peak output of 30 kW and is located approximately 35 m above sea level (Figure 2). The site would ideally not have been so high, but this was the only available site on the oil platform that allowed a view over the wind turbine site, space for the display unit and access to a power supply. The radar scans an arc of 240° (the remaining 120° is obscured by the Beatrice Alpha platform), with a 1.5 NM radius, chosen to allow the greatest discrimination between targets in order to investigate fine-scale movement patterns. A position for a target can be obtained every 2.3 seconds, since the radar antenna rotates at 26 rpm.

Figure 2. The S-band radar (larger antenna) in position on Beatrice Alpha platform, overlooking the wind turbine site (© University of Aberdeen).

Initial Set-up

The radar was initially furnished with off-the-shelf boat tracking software (MaxSea Professional version 10.3.5) which was intended to be able to track birds automatically. It used the radar's own automatic anti-clutter and tracking settings. However, trials with concurrent visual observations showed large differences in the number of birds tracked and many of the radar tracks could not be linked to a visual target. Data from the system could also not be downloaded in any useful format as no time or date information was included. For these reasons it was decided that the software was not fit for purpose.

Following this, tenders were requested from two companies to supply specialist bird detection and tracking software or 'avian laboratory'. Merlin software from DeTect (Inc), Florida was installed on the Beatrice Alpha platform in March 2006 and was functional by June 2006. The system records tracks into a Microsoft Access database, including a unique track ID, time, date and position information.

Sea Clutter

In common with other radar studies of seabirds (Krijgsveld *et al.* 2005), sea clutter was identified as a serious problem in the data. As highlighted above sea clutter tracks tend to be short and move in random directions and are more likely to be produced under rough sea conditions. To ameliorate the effects of sea clutter, a clutter shield was installed on the radar in April 2007. This is an aluminium tray fitted to the underside of the antenna, to reduce the size of the sector that the radar beam covers on its lower side. In effect this means that the beam will reach the water at a greater distance than without the shield and so detect wave movements less readily. This seemed to reduce the extent of the clutter somewhat, but the effect is not quantified and a great deal of clutter still remained in the data.

More sea clutter tracks were recorded in high sea states and this generally resulted in many short tracks, with more scattered patterns of movement. In order to remove these tracks from the dataset, filters were developed based on data collected in June 2006, when visual line transect surveys showed a high density of birds at the site. These filters removed tracks created in all but calm conditions, as well as short tracks and tracks with a large amount of variation in heading. The remaining dataset was around 1.25% of the original, leaving 475,932 tracks from 2059 hours of observations, over 109 days, between June 2006 and August 2007. This gives high power to detect patterns with statistical analyses.

Remote Management

There are disadvantages to running the radar without a visual observer making concurrent observations. The most obvious of these is that there is no species identity or flock size data. Additional to this however, was the problem of power loss or system malfunction. Without a dedicated operator, such problems could go undetected for significant periods of time and this accounted for loss of potential data on 211 out of 422 days.

In response to this, a remote link was established between the radar PC and the network server on the Beatrice Alpha platform in November 2006, which allowed remote access to the PC, through the Talisman network, using VNC viewer. Procedures were put into place which ensured that the functioning of the system was checked regularly. All management of the system was subsequently carried out this way, greatly reducing the number of trips made offshore. However, remote management was not helpful in cases where there was a loss of power and the radar itself needed to be switched back on.

Data were almost always brought ashore on external hard drives, at intervals of around two months. Some data were transferred through the network, but this was very slow and not practical for more than occasional uses. This has severe implications for the feasibility of offshore installations including remote monitoring radars.

Data Uses

The data have been used primarily for research purposes, to understand more about how birds move around this offshore windfarm sites as well as in investigations of the suitability of the monitoring technique. Flight speeds have been used to investigate the effect of wind on collision probability and the distribution of tracks has been used to investigate detection probability questions.

The data can also be used to answer questions about use of the site prior to construction. For example, although accurate counts of birds are not possible, because a single target may account for many birds (Schmaljohann *et al.* 2008), relative measures of birds using the site can be achieved. This was demonstrated at the Beatrice site using data collected by an independent visual observer, taking hourly scans of all birds present. The counts of birds sampled by the ornithologist have a significant linear relationship with the number of tracks recorded by the radar in the same hour.

Although species identity cannot be acquired through this radar system, calculation of the airspeed (the physiological component of flight speed) of tracks, by removing the effect of wind, made it possible to distinguish groups of species. Two main groups were evident, gulls and auks, with airspeeds in modal classes of 13-14 ms^{-1} and 20-21 ms^{-1} respectively. Visual data support this, with approximately 80% of birds at the site belonging to one of these two groups.

Radar Case Study Summaries

In addition to the DOWNVInD Project a number of offshore and onshore windfarm environmental assessments have also used radar. The methods and results tabulated in Tables 3-11.

Table 3.	
Site	**Beatrice oil field, Moray Firth**
Nature of site	Offshore windfarm and oil field, 22 km from land.
Species of concern	Auks, gulls, fulmars, gannets, skuas.
Radar location	Oil platform.
Radar type	Marine surveillance radar (“Avian Laboratory”).
Antenna types	S band (horizontal).
Method of data collection and storage	Automatic recording of targets to database. System run without operator or visual observer for extended periods. Data stored on external hard drives, manually shipped to land every 3 months.
Duration of radar study	Two years. Radar operational for 211 days in total.
Spatial extent of radar coverage	2.8 km maximum range – Intended to focus on fine scale movements.
Specific radar ground truthing observations made?	Good relationship found between number of tracks recorded by radar and number of birds seen by independent visual observer. No attempt made to gather data on species identity. Unsuccessful attempts made to truth radar by boat, largely due to the slow speed of the boat.
Data analysis methods	Large scale filtering of data using purpose written software required to remove clutter. Flight lines mapped in GIS software and average flight directions over time and in relation to wind calculated. Activity levels over time (annual, seasonal and diurnal) monitored. Flight speeds calculated and used to parameterise Band collision model. Before and after installation comparison of flight proximity to turbine.
Extent to which radar data used in final report	Not used in EIA. Used extensively in academic research.
Reason for exclusion of radar data from final report	Radar not functional before EIA completed.

Problems reported	Sea clutter accounted for a very large proportion of data, so strict criteria had to be used in filters. Difficulty in managing system offshore, because operator could only be present for short periods. System shutdown occurred approximately once a month, because of power cuts or technical problems, leading to data loss, until operator could be present. Remote management through oil platform server network, and VNC viewer helped, but not with power cuts, as it is necessary to manually push the power switch on the radar. Data could not be transferred regularly through the network due to the size of the databases.

Table 4.	
Site	**Largie Windfarm, Mull of Kintyre**
Nature of site	Onshore windfarm.
Species of concern	Greenland white-fronted geese.
Radar type	Marine surveillance radar ('Avian Laboratory').
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	12 days in total over two years.
Spatial extent of radar coverage	11km maximum range, 7km effective range – windfarm site and roost/feeding sites covered.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Goose flight lines mapped using GIS software. Quantitative estimates of movement rates made on extrapolation from mean flock sizes.
Extent to which radar data used in final report	Provided major part of EIA report.
Reason for exclusion of radar data from final report	Not excluded.
Problems reported	Terrain caused radar shadows. Limited period of deployment.

Table 5.	
Site	**Drums and Easter Hatton**
Nature of site	Offshore windfarm.
Species of concern	All seabirds.
Radar location	On land.
Radar type	Marine surveillance radar ('Avian Laboratory').
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	11 days, one visit (October / November).
Spatial extent of radar coverage	11km maximum range, 7km effective range – Reached to edge of windfarm boundary.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Relative movement rates at different times compared.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not known.
Problems reported	Wave clutter seriously affected horizontal radar capability for significant part of study.
Suggestions for improvement / overcoming problems	Increase duration of study to ensure periods of better weather included in study, utilise radar screen to shield clutter.

Table 6.	
Site	**Aberdeen (Blackdog)**
Nature of site	Offshore windfarm
Species of concern	All seabirds.
Radar location	On land.
Radar type	Marine surveillance radar ('Avian Laboratory').
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	17 days, one visit in April.
Spatial extent of radar coverage	11km maximum range, 7km effective range.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Relative movement rates at different times compared.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not known.
Problems reported	Effective radar range not sufficient to cover windfarm area. Low flying birds missed by radar, comparison with boat based survey unsuccessful because of lack of liaison between contractors.
Suggestions for improvement / overcoming problems	

Table 7.	
Site	**Lynn and Inner Dowsing (L-ID)**
Nature of site	Offshore windfarm
Species of concern	Migratory geese (pink-footed geese).
Radar location	On land.
Radar type	Marine surveillance radar (‘Avian Laboratory’).
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Raw data screen recorded as video and goose movements manually extracted from playback at later time.
Duration of radar study	Two periods of 6 weeks over two successive autumn migration periods.
Spatial extent of radar coverage	11km effective range for horizontal radar – full coverage of windfarm site.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Flight lines analysed for movement rages and avoidance behaviours.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not Known.
Problems reported	Lack of altitude data over turbine arrays. Occasional sea clutter exacerbated by elevation of radar antennas (to see over earth bank).
Suggestions for improvement / overcoming problems	

Table 8.	
Site	**Dunbeath**
Nature of site	Onshore windfarm
Species of concern	Golden plover.
Radar type	Marine surveillance radar (‘Avian Laboratory’).
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	Four visits of 5 days each.
Spatial extent of radar coverage	11km maximum range, 7km effective range.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Relative movement rates at different times compared.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not known.
Problems reported	Radar shadow caused by topography.

Table 9.

Site	**Gwynt y Môr**
Nature of site	Offshore windfarm
Species of concern for radar study	Common scoter.
Radar type	Marine surveillance radar - ship based (ship's own radar).
Radar location	Ship was anchored at four locations around windfarm where birds of concern were expected to be present.
Antenna types	Not stated.
Method of data collection and storage	Not stated.
Duration of radar study	One period of five days – three hours per day.
Spatial extent of radar coverage	Initially 3-4km, revised to 8km.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Not stated.
Extent to which radar data used in final report	Not used.
Reason for exclusion of radar data from final report	Document states "The detailed data derived from the radar study are not available".
Problems reported	None.

Table 10.	
Site	**Sherringham Shoals**
Nature of site	Inshore windfarm
Species of concern for radar study	All seabirds.
Radar type	Marine surveillance radar (‘Avian Laboratory’).
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	Continuous operation for one period of six days and one of four days during October of two successive years.
Spatial extent of radar coverage	11km maximum range, 7km effective range. Windfarm site beyond radar range.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Relative movement rates at different times compared.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not known.
Problems reported	

Table 11.	
Site	**Walney**
Nature of site	Offshore windfarm
Species of concern for radar study	All seabirds.
Radar type	Marine surveillance radar – Ship based (Dedicated bird detection antennas).
Antenna types	S-Band (horizontal) and X-Band (vertical).
Method of data collection and storage	Automatic recording of targets to database and collection of screen dumps for visualisation of movements.
Duration of radar study	Continuous operation for one period of six days and one of four days during October of two successive years.
Spatial extent of radar coverage	11km maximum range, 7km effective range. Windfarm site beyond radar range.
Specific radar ground truthing observations made?	Yes.
Data analysis methods	Flight lines mapped using GIS software. Relative movement rates at different times compared.
Extent to which radar data used in final report	Unknown.
Reason for exclusion of radar data from final report	Not known.
Problems reported	Not known.

1.9 Summary of Appropriate 'Best Practice' Remote Techniques

After a review of the previous COWRIE report and a review of the current available literature for remote techniques the following accepted technologies are most likely to offer the greatest benefits for enhancing data for EIA purposes:

- Land-based radar
- Platform based radar
- Boat-based radar (with caveats about set-up)
- Shore-based radar
- Thermal cameras & night vision
- Tagging techniques (Radio, Satellite, GPS and Satellite GPS)

In Section 2 of this report 'remote techniques' are defined as these techniques bulleted above. They are referred to throughout the 'best practice guidance framework' as 'remote techniques'.

However, none of these remote techniques provide a single solution to collecting bird data and all have strengths and weaknesses outlined in the previous review in Section 1. The importance of using these techniques as part of an Integrated Ornithological Monitoring Program (IOMP) cannot be stressed enough by the consortium.

1.10 Practical Application of 'Best Practice' Remote Techniques

The timeline for assessment work at offshore windfarms is driven by the consenting process of which EIA is one part. The application of remote techniques at the appropriate stage of this pathway is therefore of key importance. Remote techniques for the STWR and R3 are not a default requirement at all sites/zones and should only be used where their application enhances the quality of the assessment process.

For example, the application of remote techniques as a part of baseline monitoring should not be seen as a default requirement for sites/zones (this will be detailed in section 2).

Recommendations listed here represent the minimum reasonable standards for a study. While these specifications should be met and techniques included for standardisation across the board, we welcome efforts to exceed these standards. For example:

Radar Study

1. Prior to the installation of a met mast, ship-based radar provides an alternative acceptable technique in conjunction with baseline techniques if appropriate for the species present.
2. If one or more met masts are to be installed, the potential for a platform based radar to be used should be considered. It would therefore be advisable to consider provision for a bird detection radar at the met mast design stage.
3. There should be a general requirement to collect generic data where possible e.g. on flight heights and avoidance behaviour, which should be made available to all workers (radar, thermal camera or video footage).

4. It is important to ensure remote techniques are appropriately integrated into the ornithological monitoring program or IOMP.

Recommended Technical Specifications for Radar

1. For ship based radar, vertically operated radar will provide the most value. For platform based applications, vertical and horizontal radar should both be used.
2. A ship based radar study should use dedicated radar antennas on which the user can control parameter settings. The ship's own radars should not be used for reasons detailed in the review section (Section 1.7.2).

Vertical radar technical specifications:

1. Transmitted power output: minimum 25kW, in the X-band frequency.
2. Range: 1.5km.
3. Beam: 20° to 25° by 0.9° to 1.2°.

Horizontal radar technical specifications:

1. Transmitted power output: minimum 25kW.
2. Range: 3km. A greater range is desirable. Up to 11km or more is achievable with the S-band frequency.
3. Beam: 0.9° to 1.2° by 20° to 25°.

Recommended Data Collection and Presentation Methods

1. If an 'Avian Laboratory' type radar station is used, quantitative data should be expressed in terms of targets per scan, or unique tracks within a given time period. If other types of radar are used, for example where tracks must be traced from the radar screen onto acetates, at least 12 to 15 radar images per hour should be collected.
2. Supporting ground truthing observations should be made, to permit calibration of radar observations and to identify the species under observation.

Vertical radar data

1. Collect data on the altitudinal distribution of birds in 100m height bands or finer resolution.
2. Migratory passage rates may be presented if appropriate and the user has confidence in the quantitative accuracy of the data. Radar must be oriented perpendicular to main migration movement to record passage rates.
3. Present data showing the temporal variation at different time scales (day, season, etc) in the data collected.

Horizontal radar data

1. Collect data on the spatial distribution of birds over the seascape.
2. Data may be presented qualitatively or quantitatively if there is sufficient confidence in the extrapolation of bird counts from supporting ground truthing observations.
3. If data is expressed quantitatively, densities of birds over the seascape should be given (tracks per km^2 or echoes per scan per km^2) for comparison with other monitoring techniques, e.g. aerial surveying.
4. Radar noise reduction routines should be used and correction factors applied if possible.
5. The radar antennas should be located so as to maximise the value of data collected. If necessary more than one antenna should be used to ensure adequate coverage of the proposed windfarm site.

Recommended Study Duration

Ship-based radar

1. Data should be collected throughout the period that the species of concern is likely to be present in the area of the windfarm development.
2. At least 125 hours of data should be collected within each month of the study, including four periods of continuous 24 hour monitoring.

Platform-based radar

1. Ideally data will be collected continuously from a platform-based radar, otherwise the duration of data collection should be at least as extensive as quoted for ship-based radar.

Supporting observations (ground truthing)

1. This refers to observations in addition to standard boat-based and aerial survey observations, though these could also be used for ground truthing a radar with a precise methodology.
2. Supporting ground truthing observations (to correlate numbers and confirm species present) should be made as often as possible ideally daily during dawn to dusk but as a minimum weekly to ensure a representative sample through the key months of the year.

1.10.1 Estimated Deployment Cost

Ship-based radar

Costs include the purchase or hiring of radar hardware, the installation of the antennas on the ship and the costs of hiring the ship itself, though this could potentially be the same ship that is used for boat-based bird surveying.

A basic X-Band antenna radar costs approximately £15,000-20,000 but the costs of installing a system on a ship, in the vertical configuration will have to be investigated by the environmental consultant. A specialist radar engineer or experienced radar ornithologist should also be consulted.

Platform-based radar

Costs for installing a radar system on a met mast are significantly greater. Factors to consider include:

1. Cost of modifications to met mast design to allow radar installation.
2. Cost of radar equipment (including avian laboratory specification and ancillary equipment).
3. Cost of offshore specific factors (harsh offshore environment protection, power generation and communications links).
4. Cost of installing radar.
5. Cost of operations and maintenance programme.
6. Cost of communications.

For costs associated with the design of the met masts and work on the mast itself, it is necessary to seek advice from specialist engineering companies experienced in met mast design for offshore environments. It is likely that the costs associated with installing a radar will not be significant compared to the costs of siting the met mast itself. A typical avian laboratory, in a platform mounted configuration, costs approximately £50,000-60,000 per antenna. This includes the antennas and ancillary computer equipment. Other essential start up costs include power supply and communications, while ongoing costs include maintenance visits. It is therefore highly likely that the cost for a single radar antenna per met mast would be a minimum of £100,000-150,000 excluding all subsequent analysis costs, operation & maintenance, and interpretation and reporting for the dataset.

Thermal Camera

FLIR camera costs current in July 2008 and Outersight (UK) Ltd in August 2008.

1. FLIR ThermaCAM SC640 and 7 degree lens package: £37,599 plus VAT
2. FLIR ThermaCAM SC640 and 12 degree lens package: £35,999 plus VAT
3. Camera housing c/w germanium aperture and integration equipment: £4,108 plus VAT

These costs do not include any offshore installation or site work including communications links and subsequent analysis. Costs for the camera are approximately £30,000-40,000 and installation costs on a met mast might cost approximately £10,000-25,000.

2. Best Practice Guidance Framework: Remote Techniques

2.1 Introduction: Best Practice use of 'Remote Techniques'

Section 2 of this report is intended to provide a clear 'best practice guidance framework' for the offshore wind industry in the appropriate use of remote techniques as part of an Integrated Ornithological Monitoring Program (IOMP).

The objective of this is the flexible use of ornithological monitoring techniques should be coordinated effectively within a monitoring program in order that the complementary benefits and strengths of 'remote techniques' (radar, thermal cameras and tracking studies) contribute to an improved ornithological understanding of site(s) and zone(s) within both a regional and national/international context.

This will be particularly important as cumulative effects of proposed developments in the offshore environment are considered in greater detail (COWRIE: King *et al.* 2009). Therefore it is important that remote techniques are used as part of an IOMP acknowledging the following key points to their use:

- Remote techniques are **NOT applicable in all cases** i.e. are not a 'panacea' .
- **Clear goals must be scoped, stated and agreed at the start** of the assessment process by all stakeholders (statutory, non-statutory and environmental consultancies) for all bird monitoring requirements.
- The importance of a stated clear goal for the integration of monitoring techniques with the aim of **standardised outputs and conclusions.**
- Remote techniques should be used to provide **complementary information to standard ornithological monitoring techniques not instead of these valuable data.**
- The limited availability of equipment and suppliers must be borne in mind.
- The specialist involvement of experienced specialist practitioners must be ensured.

2.2 Integrated Ornithological Monitoring Programs (IOMP)

The need for an IOMP has become more pressing as the scale of the STWR and R3 development process accelerates in UK offshore waters. The pace of development is driven by important national sustainability and renewable energy targets for 2020, giving rise to The Crown Estate development programme for the marine environment.

In order to fulfil these challenging targets in balance with marine wildlife conservation, a clear focus on assessment requirements appropriate for the scale of growth is required. It is envisaged that the growth of the offshore wind, wave and tidal marine industry over the next decades will be significant. The importance for guidance on 'best practice' ornithological monitoring methods including remote techniques is therefore very clear.

It is proposed that, against this accelerated development background, the appropriate and effective use of 'remote techniques' for ornithological monitoring needs to be fully appreciated. This includes an understanding of each method's strengths and weaknesses, and how they are best integrated with complementary techniques. Section 1 of this report and the previous COWRIE report provided a technical review of the relative merits of the individual remote techniques. However, the consortium propose the following concept in order to understand the 'best practice' application of remote techniques within an IOMP:

- **The Integrated Ornithological Monitoring Program (IOMP) concept**

  See simple hierarchy triangle diagram (Figure 3), it is envisaged that remote techniques are to be applied (tier 2, the middle) in addition to baseline standard monitoring techniques (tier 1 at the base) such as aerial surveying and boat-based surveying and on top of these methods the importance of modelling [tier 3, the top] for STWR and R3 should not be underestimated. The IOMP will select the most appropriate elements from this diagram to address specific questions at the proposed site.

- **Defining** the time and place for remote techniques within the assessment process (pre-consent EIA, post-consent baseline, post-construction monitoring).
- **Stakeholder scoping, iteration of ongoing requirements** (not always fixed requirements) – importance of a feedback mechanism as survey results are gathered.
- **IOMP Coordinator Role**

  (Potential offshore equivalent for each zone of Ecological Clerk of Works for onshore wind development).

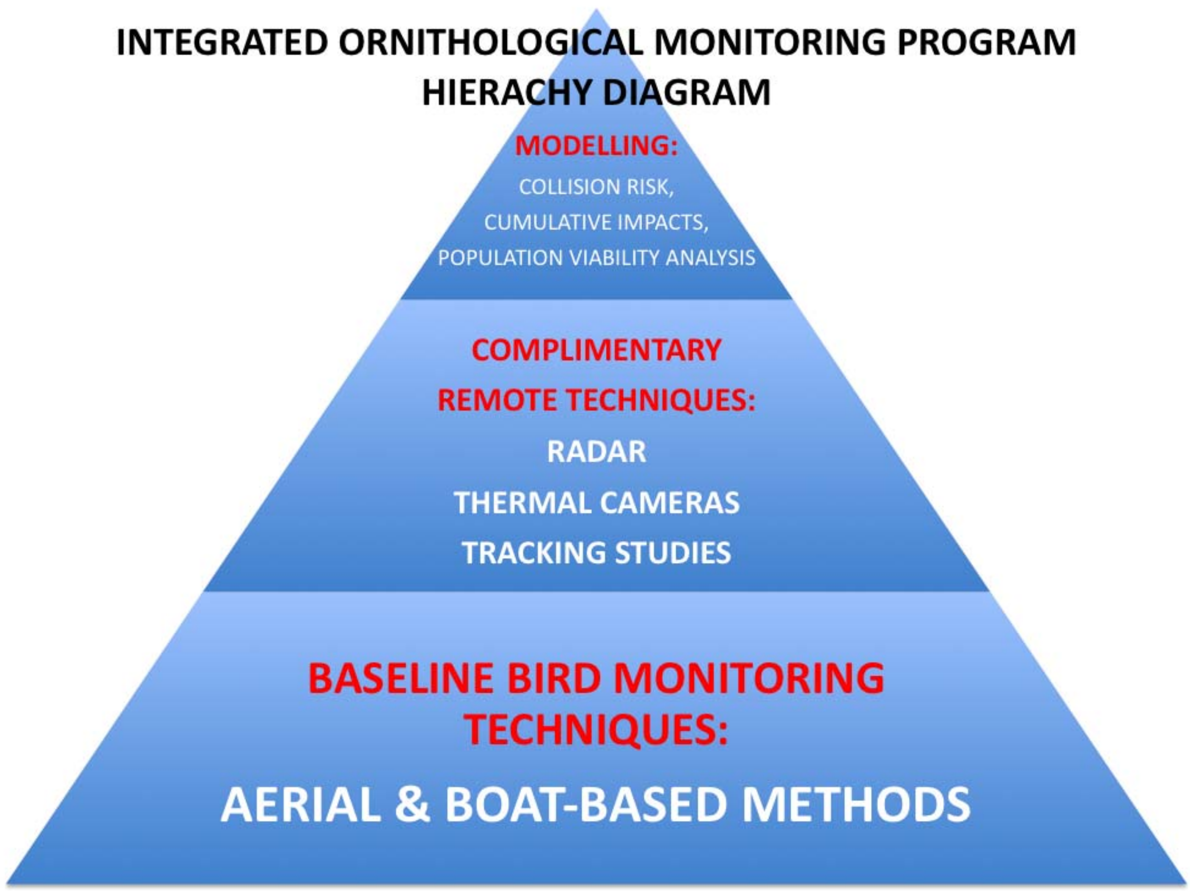


Figure 3.- IOMP: Integrated Ornithological Monitoring Program survey techniques hierarchy diagram

2.3 The Recommended Approach for Identyfing Appropriate 'Remote Techniques'

2.3.1 STEP 1: Site Selection: Offshore Windfarm Area Physical Characteristics

As highlighted the Crown Estate intends to lease large areas of the seabed for the development of offshore wind and marine technologies in UK waters. Within there, offshore windfarm developers in conjunction with experienced environmental advisors will determine proposed offshore windfarm sites. These identified areas will be based on constraints (physical, biological and human) within STWR and R3 zones.

The **physical site characteristics which will most directly affect the bird species present** and the scope of ornithological assessment required as part of an IOMP are likely to be:

- geographic location,
- water depth,
- seabed bathymetry,
- seabed characteristics,
- distance from shore,
- coastal processes (mixing currents, tidal range, wave heights etc), and
- size of site or zone.

2.3.2 STEP 2: Identifying Target Bird Species with Potential to Occur in the Site / Zone

The next step is to identify, through a desk study the potential use of the proposed site/zone by birds to assess whether 'remote techniques' may be of value.

This needs to identify which potential species are of key importance ('target species' i.e. those species with a high potential SSI value as determined by Garthe & Hüppop, 2004) and may require additional assessment methods such as remote techniques over and above baseline data collection methods (from aerial and boat-based surveying).

This review should include all available existing datasets (e.g. JNCC ESAS data, SEA information, information from the nearest offshore and onshore sites including R1 and R2 developments) applicable for the zone/sites proposed. In addition this should include consultation with key stakeholders, in particular statutory bodies (JNCC, SNH, NE and CCW) as well as non-statutory bodies (notably RSPB), so that these stakeholders are involved as early as possible in the assessment and development process. The aim should be to determine at an early stage:

- **Which bird species utilise the site / zone?**

  (including: breeding, overwintering, migration: spring & autumn and during darkness)

- **Which 'target species' in particular are at potential risk from large scale offshore windfarm developments?**

  (including: breeding, overwintering, migration: spring & autumn and during darkness)

- **The connectivity of designated sites for 'target species' with the proposed offshore windfarm site or zone.**

  (including: breeding, overwintering, migration: spring & autumn and during darkness)

It is highly likely that an ornithological review will identify significant knowledge gaps for the areas identified as part of the STWR and R3 zones.

The review may identify a requirement for the implementation of a preliminary baseline survey program at key times of the year aimed at identifying likely use by seabirds and waterbirds. This could also be undertaken at either a site-specific scale for an EIA or across a development zone as indicated within R3 (in order to inform a REA/ZAP).

2.3.3 STEP 3: Identify Target Bird Species Behaviour at Potential Risk

Following identification of the 'target species' and species assemblages for a site or zone during Step 1 and Step 2 (through desk-based review and possibly preliminary baseline surveys), the **key behaviours of these 'target species' should be identified and scoped for assessment.** This should include provision for assessment throughout the construction, operation and decommissioning stages as well as potential cumulative effects**. Potential points for consideration include:**

- **scoping agreement on target species behaviours** with stakeholders
- **site-specific** bird behaviours (as defined in Section 1),
- **generic** bird behaviours (as defined in Section 1),
- **cumulative risks** (see King *et al.* 2009),
- **collision risks**,
- **displacement effects**,
- **barrier effects**,
- **changes in prey availability**, and

  appropriate recommended Remote Techniques Matrix (Figure 4; A traffic light system to aid the selection of appropriate 'remote techniques' and in order to rule out inappropriate options)

	Radar: Land-based	Radar: Platform-based	Radar: Boat-based	Thermal Cameras	Radio-tracking	Satellite-tracking
Swan sp.	M	M	M	M		M
Goose sp.	M	M	M	M		M
Duck sp.	M	M	M	M		M
Seaduck sp.	W & B	W & B		W & B	?	?
Diver sp.	W & B			W & B	?	?
Auk sp.	W & B	W & B		W & B	B	
Gannet	W & B	W & B	W & B	W & B	B	B
Tern sp.	B	B		B	B	
Skua sp.	W & B	W & B	W & B	W & B	B	B
Shearwaters	B & M			B	B	?
Petrel sp.				B		
Wader sp.	M	M	M	M		?
Passerine sp.	M	M	M	M		
Raptor sp.	M	M	M	M		M

CLEAR ADVANTAGES OF INTEGRATING REMOTE TECHNIQUES	POSSIBLE APPLICATION OF REMOTE TECHNIQUE	INAPPROPRIATE REMOTE TECHNIQUE FOR SPECIES GROUP	M = MIGRATION/ PASSAGE	W = OVERWINTER	B = BREEDING	? = UNCLEAR IN THE UK

Figure 4. Traffic light system for Appropriate Remote Techniques for Ornithological Monitoring.

2.3.4 STEP 4: Construct an IOMP for EIA

If 'remote techniques' are applicable to enhance the assessment process, implement them into an IOMP with stakeholder agreement. Decide upon the scope, techniques and duration to ensure an IOMP is constructed which is capable of providing appropriate data for conducting robust assessments as part of the EIA process, as well as potential further requirements for pre and post construction monitoring.

The IOMP should consist of the following potential elements in a **COMPLEMENTARY** manner but should only include remote techniques if they are required for the species or species groups present:

- **Baseline Techniques** (aerial and boat-based techniques)
- **Remote Techniques** (radar, thermal cameras and tagging techniques)
- **Modelling** (cumulative effects, collision risk modelling population viability analysis and spatial distribution modelling)

2.3.5 STEP 5 & STEP 6: Collect Integrated Survey Data in line with IOMP

The next step is to include 'remote techniques' when and where applicable for the site/zone and revise the assessment process as required in line with survey findings. This role should potentially be undertaken by an IOMP coordinator responsible for over-seeing monitoring within sites or zones in order that a coordinated approach is maintained with a high degree of continuity throughout the STWR and R3 process, due to the scale of developments planned.

2.4 Best Practice Framework Diagram

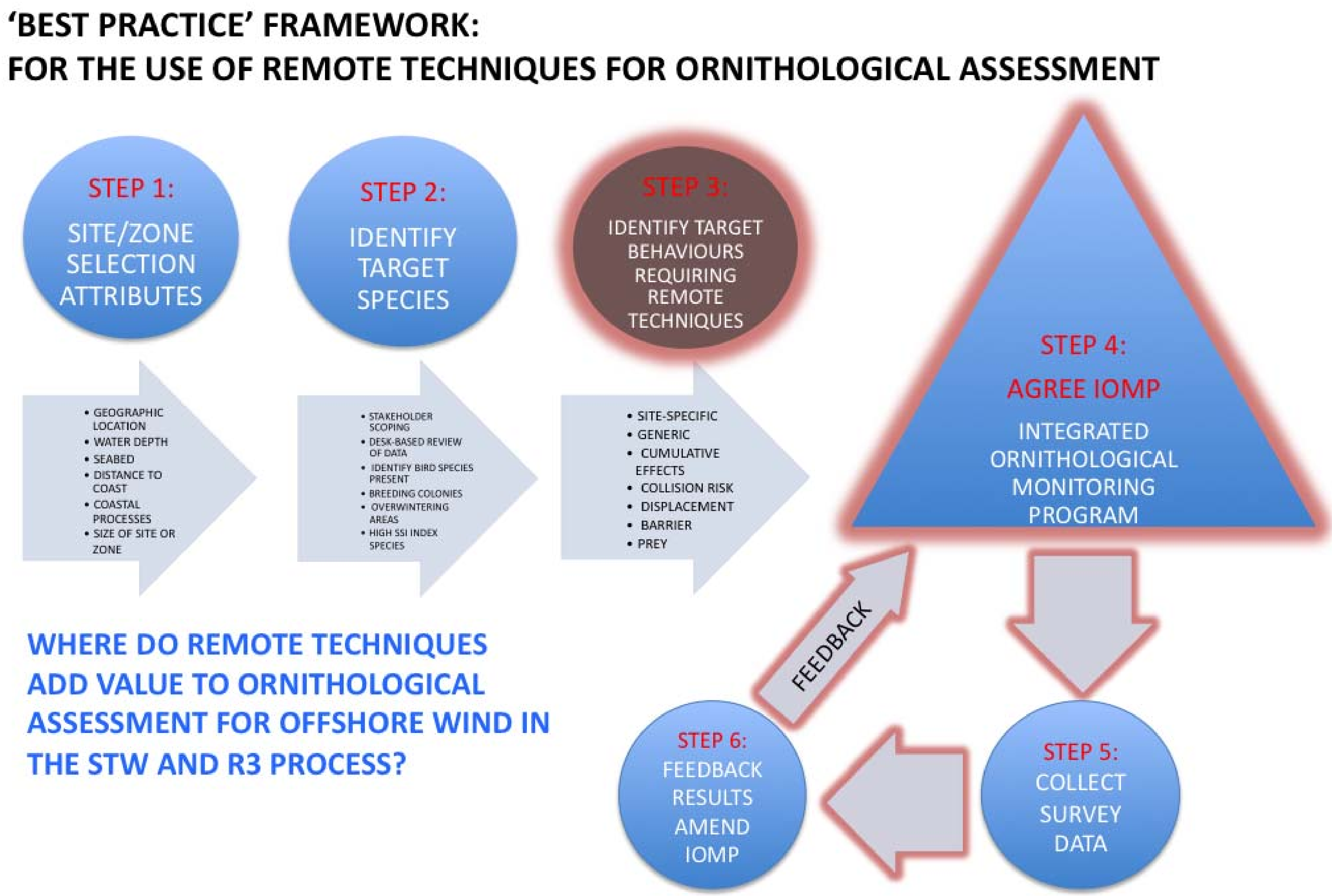


Figure 5. Best Practice Framework for the use of remote techniques for ornithological assessment at offshore windfarms.

2.5 Conclusion

Remote techniques as defined in Section 2 of this report have the potential to provide a robust and valuable role for bird monitoring at offshore windfarms. However, they are only part of the solution in terms of effective monitoring in a scientifically rigorous and integrated manner. It is important that they are neither regarded as default techniques nor, alternatively, as methods to be ignored by developers because of their apparent novelty or cost. Remote techniques should be integrated effectively with existing methods to enable timely and comprehensive EIA as well as pre and post construction monitoring.

In particular, they offer much utility for collecting data that other techniques simply cannot accomplish. Issues surrounding mass movements in low visibility, darkness and over large spatial scales or temporal periods can all be overcome by remote techniques. Tagging studies can provide direct individual based data from birds from which to refine understanding of potential impacts, enabling better-informed assessments.

The consortium has been keen to stress the importance of an integrated approach to all bird monitoring at offshore windfarms (through an IOMP concept) as part of the STWR and R3 process. Therefore, dependent on the location of the proposed site/zone and the bird species present (and the behaviours which may place them at risk from the presence of an offshore windfarm), remote techniques have a particular role to play.

The integrated monitoring requirements for a site or zone can be usefully mapped out within the simple framework (Section 2.4) proposed by the consortium, in order to determine the contribution which remote techniques can make to the overall ornithological assessment.

Remote techniques should always be viewed as complementary to, rather than a replacement of standard survey techniques (notably aerial and boat-based surveying) and modelling (e.g. population viability analysis, collision risks analysis etc.).

2.6 Recommendations

- Use an IOMP concept including a designated coordinator during STWR and R3.
- Integrate remote techniques with baseline bird monitoring techniques and modelling.
- Agree and record specific scoping details with stakeholders for an IOMP.
- Employ traffic light system for determining appropriate use of remote techniques.
- Define questions for ‘target species’ assessments.
- Standardise approaches and outputs across methods.
- Undertake Cumulative Impact Assessments in line with King *et al.* 2009.

References

Danish Offshore Wind (Nov 2006) – Key Environmental Issues. Published by DONG Energy, Vattenfall, The Danish Energy Authority and the Danish Forrest and Nature Agency.

Desholm, M., Fox, T. & Beasley, P. (2005) *Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore windfarms*. REMTECH-05-2004 Report Commissioned by COWRIE Ltd.

Desholm M., Fox A. D., Beasley P. D. L., Kahlert J. (2006) Remote techniques for counting and estimating the number of bird–wind turbine collisions at sea: a review. *Ibis* 148: 76-89.

Evans, W.R. (2003) *Applications of Acoustic Bird Monitoring for the Wind Power Industry*. Cornell Laboratory of Ornithology, Ithaca, NY. National Avian - Wind Power Planning Meeting III.

Gaunt, A.S. & Oring, L.W. (1997) *Guidelines to the use of wild birds in research*. The Ornithological Council, Washington D.C.

Garthe, S. & Hüppop, O. (2004) Scaling possible adverse effects of marine windfarms on seabirds: developing and applying a vulnerability index. *Journal of Applied Ecology* 41(4), 724-734.

Guilford, T., Meade, J., Willis, J., Phillips, R.A., Boyle, D., Roberts, S., Collett, M., Freeman, R. & Perrins, C.M. (2009) Migration and stopover in a small pelagic seabird, the Manx shearwater Puffinus puffinus: insights from machine learning. *Proceedings of the Royal Society* 276 (1660), 1215-1223

Hulbert, I.A.R. & French, J. (2001) The accuracy of GPS for wildlife telemetry and habitat mapping. *Journal of Applied Ecology*, 38, 869-878.

Kaiser, M.J., Galanidi, M., Showler, D.A., Elliott, A.J., Caldow, R.W.G., Rees, E.I.S. Stillman, R.A. & Sutherland, W.J. (2006) Distribution and behaviour of common scoter Melanitta nigra relative to prey resources and environmental parameters. *Ibis* 148, (s1), 110-128.

King, S. Maclean, I, Norman, T. & Prior, A. (2009) *Developing Guidance on Ornithological Cumulative Impact Assessment for Offshore Windfarm Developers*. Report Commissioned by COWRIE Ltd.

Krijgsveld, K.L., Lensink, R., Schekkerman, H., Wiersma, P., Poot, M.J.M., Meesters, E.H.W.G., & Dirksen, S. (2005) *Baseline studies North Sea windfarms: fluxes, flight paths and altitude of flying birds 2003-2004*. National Institute for Coastal and Marine Management, The Hague, Netherlands.

Langston, R.H.W. (2008) *Round 3 Offshore Windfarm Developments and birds at sea*. RSPB Conservation Science Department.

Maclean, I.M.D, Wright, L.J., Showler, D.A. & Rehfisch, M.M. (2008) A Review of Assessment Methodologies for Offshore Windfarms. British Trust for Ornithology Report Commissioned by COWRIE Ltd.

Mudge, G.P., Crooke, C.H. & Barrett, T. (1984) *The offshore distribution and abundance of seabirds in the Moray Firth*. RSPB, Munlochy.

O'Brien, S.H., Wilson, L., Webb, A. & Cranswick, P.A. (2008) Revised estimate of numbers of wintering Red-throated Divers Gavia stellata in Great Britain. *Bird Study*, 55 (2) 152-160.

Perrow, M.R., Skeate, E.R., Lines, P., Brown, D. & Tomlinson, M.L. (2006) Radio telemetry as a tool for impact assessment of windfarms: the case of little terns, Sterna albifrons at Scroby Sands, Norfolk, UK. *Ibis*, 148 (1), 57-75.

Pettersson, J. (2005) A pilot study of radar surveillance and flight altitude measurement to investigate passerine and waterfowl behaviour during migration over sea, in low visibility, and at night at Kalmar Sound. *Vindhall Report Series*.

Phillips, R.A., Silk, J.R.D., Croxall, J.P., Afanasyev, V., & Briggs, D.R. (2004) Accuracy of geolocation estimates for flying seabirds. *Marine Ecology Progress Series*, 266, 265-272.

Phillips, R.A., Xavier, J.C., & Croxall, J.P. (2003) Effects of satellite transmitters on albatrosses and petrels. *Auk*, 120, 1082-1090.

Robinson, R.A. (2005). BirdFacts: profiles of birds occurring in Britain and Ireland, BTO Research Report 407 (http://www.bto.org/birdfacts). BTO, Thetford.

Schmaljohann, H., Liechti, F., Bachler, E., Steuri, T., & Bruderer, B. (2008) Quantification of bird migration by radar - a detection probability problem. *Ibis*, 150, 342-355.

Stone, C.J., Webb, A., Barton, C., Ratcliffe, N., Reed, T.C., Tasker, M.L., Camphuysen, C.J. & Pienkowski, M.W. (1995) *An atlas of seabird distribution in north-west European waters*. JNCC Peterborough, UK.

Soutullo, A., Cadahía, L., Urios, V., Ferrer, M., & Negro, J.J. (2007) Accuracy of lightweight satellite telemetry: a case study in the Iberian Peninsula. *Journal of Wildlife Management*, 71, 1010-1015.

RPS (2008) *Lynn & Inner Dowsing Offshore Windfarm: Remote sensing of pink-footed geese autumn passage by bird detection radar*. RPS Monitoring Report. Commissioned by Centrica Renewable Energy Ltd. March 2008.

RPS (2009) *Lynn & Inner Dowsing Offshore Windfarm: Remote sensing of pink-footed geese autumn passage by bird detection radar*. RPS Monitoring Report. Commissioned by Centrica Renewable Energy Ltd. March 2009.

Wanless, S., Harris, M.P., & Morris, J.A. (1988) The effect of radio transmitters on the behaviour of common murres and razorbills during chick rearing. *Condor*, **90**, 816-823.

Appendix

Table 1: from RSPB : Langston, R. (November, 2008) Round 3 Offshore Windfarm Developments and Birds at Sea.

Table 1: RSPB Guidance **Foraging Radius from Breeding Colonies**	**Species**
5km	Little tern Arctic tern Black guillemot
15km	Manx shearwater (rafting birds only) Cormorant Shag Black-headed gull Common gull
20-30km	Common, arctic, roseate and sandwich tern
40km	Great skua Herring, lesser and great black-backed gulls Kittiwake Guillemot Razorbill Puffin
>100km	Northern fulmar Manx shearwater European storm petrel Leach's petrel Northern gannet

Table 2: RSPB: Langston, R. (November, 2008) Round 3 Offshore Windfarm Developments and Birds at Sea.

Table 2: Species for which studies at wind farms, or other known aspects of behaviour, indicate higher risks (e.g. Garthe & Hüppop 2004) or for which priority conservation status and uncertainty about likely impacts contribute to them being identified as focal species in relation to proposed wind farms.

Species	Collision[1]	Displacement[1]	Barrier[1]	Habitat/ Prey[1]	SSI[2]	GB/UK Min %[3]	Cumulative Impact[4]
Black-throated Diver	*	***		*	44.0	*	***
Red-throated Diver	*	***		*	43.3	**	***
Velvet Scoter		**		**	27.0	*	**
Sandwich Tern	**			*	25.0	**	**
Great Cormorant	**	*			23.3	**	**
Common Eider	*	*		**	20.4	*	**
Great black-backed Gull	**				18.3	**	**
Common scoter		*		**	16.9	*	**
Northern Gannet	**				16.5	***	***
Razorbill		*		?	15.8	*	**
Atlantic Puffin		*		?	15.0	*	**
Common Tern	**				15.0	*	**
Lesser black-backed Gull	**				13.8	***	***
Arctic Tern	**				13.3	*	**
Little Gull	*				12.8	?	?
Great Skua	**				12.4	***	***
Common Guillemot		*		?	12.0	**	**
Mew (Common) Gull	*				12.0	*	**
Herring Gull	*				11.0	*	**
Arctic Skua	**				10.0	*	**
Black-legged Kittiwake	**				7.5	*	*
Black-headed Gull	*				7.5	*	*
Northern Fulmar	*				5.8	*	*
Great Northern Diver		***		*	ns	**	***
Manx Shearwater	?	?		?	ns	***	***
Balearic Shearwater	?	?		?	ns	?	?
European Storm-petrel		?		?	ns	*	*
Leach's Storm petrel		?		?	ns	*	*
European Shag		*		*	ns	**	**
Roseate Tern	**				ns	*	**
Little Tern	*				ns	*	*
Mediterranean Gull	*				ns	*	*
Long-tailed Duck		**		**	ns	*	**
Goldeneye		?		?	ns	*	?
Red-breasted Merganser		?		?	ns	*	?
Whooper Swan	**				ns	*	**
Bewick's Swan	**				ns	**	**
Pink-footed Goose	*				ns	***	***
Dark-bellied Brent Goose	*				ns	?	?
Light-bellied Brent Goose	*				ns	?	?

[1]assessment based on combination of experience from operational wind farms and Garthe & Hüppop 2004.
[2]ns = no Species-specific Sensitivity Index (SSI) score presented in Garthe & Hüppop 2004; NB this score takes account of SPEC status.
[3] The minimum % of the relevant biogeographical population breeding in Britain, is taken from Mitchell *et al.* 2004; UK non-breeding population estimates are from Baker *et al.* 2006 as a % of European populations from BirdLife International 2004, converted accordingly: * < 25%; ** 25 – 50 %; *** > 50%.
[4]cumulative impact taken as the highest score across the table for each species