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High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols

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Executive Summary

The aim of this report was to review trials of high definition imagery technology in the monitoring and assessment of bird numbers at offshore sites, and produce recommendations and protocols on its use alongside existing survey methodology, notably in light of its possible use in surveying round 3 wind farm development zones. The specific objectives are therefore as follows:

1. To summarise the existing high definition imagery studies that have taken place, assessing what parameters were used in each.
2. To undertake a workshop bringing together key users, developers and regulators of the industry, with a view to setting protocols and standards on the use of high definition imagery technology for seabird and mammal surveys.

Information on the trials of high definition imagery technology for survey were obtained from the following institutions and organisations: HiDef Aerial Surveying Ltd (hereafter also HiDef), the Danish National Environment Research Institute (NERI), APEM Ltd, the University of St. Andrews, and the RSK Group plc. Information was collated in the form of reports and summaries on particular surveys, and was split into technical categories of digital video and digital still photography for further summarising.

At the workshop, consensus was agreed that protocols depended on the aim of the particular survey. In particular, species may vary in their detectability and thus parameters required. Furthermore, the level at which the survey is conducted will influence subsequent parameters. Levels of survey that are likely to be required are

1. Characterisation to investigate what species assemblages are present, allowing population estimation and distribution, e.g. of a Round 3 development zone prior to collection of project-specific environmental baselines:
2. Baseline Environmental Impact Assessment (EIA) to assess, understand, and take account of a wind farm’s likely environmental impacts, before a development is given consent to proceed.
3. Before and After / Control and Impact Analysis (BACI) for a more detailed assessment and monitoring before and after a development requiring specific technical and survey design parameters.
4. Purposes of meeting Appropriate Assessment (AA) as part of the EIA process, to obtain detailed distribution data and accurate species identification to determine loss of habitat in marine Special Protection Areas (SPAs), or likely effect on onshore SPAs.
5. Common Standards Monitoring, a more detailed monitoring and a simple assessment for protected sites requiring accurate identification of species.

Parameters for which protocols could be developed include technical parameters, parameters on survey design and parameters on data analysis. The following is a summary of baseline protocols:

Technical

a. A current minimum flight height should be set as 450 m to avoid disturbance to birds, but this value could be lowered where increased resolution and species identification is required, and no disturbance is noted to species being surveyed.
b. The level of identification and observer error must be comparable between visual aerial surveys and high definition imagery to enable reliable comparisons, and standardised JNCC taxa groupings should be adhered to, including JNCC taxa groupings where species cannot be reliably determined.
c. A minimum resolution of 5 cm is suggested for all survey levels, with further increases encouraged so long as other minimum parameters are not jeopardised. However, if the level of species identification required by surveys (see above) can be shown to be made

accurately at a resolution coarser than 5 cm, then such resolutions should also be permitted. A lower limit of transect width is recommended as 200 m, and should allow the identification of the same species or species groupings used as standard by JNCC.

d. Colour images should be used in all surveys.
e. For video methods a minimum of 5 images (suggested range 5-10) of a bird spanning 0.5 s is necessary for reliable identification.
f. Exposure should be optimised for specific species if conducting species-specific surveys, such as darker birds or gulls, with an acceptable exposure chosen for general characterisation surveys that maximises the number of species groupings obtained.
g. Use of automation should be encouraged but with consideration of costs incurred. However, manual inspection can still give reliable identification at adequate costs and speed, and should remain the default protocol with full quality control, until there is appropriate evidence that a species can be detected more reliably and at increased speed and efficiency under automation.
h. A slower speed of travel of aircraft can result in clearer images and should be given consideration, for instance where species-specific surveys are concerned, but typical speeds of *ca*. 220 – 350 km.hr^{-1} (*ca.* 120-190 knots) are suitable for a baseline parameter range. Speed, however, will be a trade off between reducing travel time and image resolution appropriate for species identification.
i. Advances in technology should be trialled, explored and incorporated where they do not compromise the above criteria and provide improvements in species recognition, and increasing diurnal survey time.
j. Avoid surveying in low cloud or adverse weather conditions of Beaufort force 4 or above in order that birds are not missed and that they are correctly identified. However, undertaking surveys in higher wind speeds should be permissible but only if it can be demonstrated that birds are not missed and that species identification is not adversely affected in these conditions with the technology being used. Clearly with all survey techniques there will be a maximum limit on the wind speed where these technologies can be used, however this is yet to be determined.
k. Additional information on the sex and age of birds should be recorded where possible.

Survey Design and Analysis

Protocols on survey design depend on the objectives of the survey. In most cases, surveys are primarily undertaken in order to produce population estimates; a further aim may be to detect change, and this may be achieved either through a comparison of the population estimates (and their confidence limits) or by a statistical comparison of raw count data. Unless stated otherwise, the following recommendations assume that the surveys' main aim is to produce population estimates and that it is these estimates will be used for detecting change.

It should also be noted that the recommendations are strongly interlinked and should not considered in isolation. Thus the 'Synthesis on Guidelines for Survey Design' provided in section 4.3.2 should be read in conjunction with these recommendations.

a. The same survey methodology should be maintained between consecutive surveys if the survey has the same purpose as the previous one, or a before-after assessment is required. Different survey methodologies should only be used if statistical comparison can be made and there is no bias in survey estimates from either survey.
b. Pseudoreplication can be avoided through using the transect strip as the level of analysis.
c. Where raw data are used for comparison of numbers before and after wind farm construction, covariates should be used in analysis to increase the power of detecting change.
d. For BACI analyses (and the EIA surveys that often form their baseline) which use population estimates and confidence limits to detect change, there should be a general recommendation for being able to detect a certain level of change with a certain degree of accuracy. The power to detect change is not necessarily based on the percentage of

the region covered and for larger survey regions, it is generally preferable to increase the number of samples (i.e. transect strips) rather than coverage *per se*. Detecting a halving or doubling of the population is suggested as a minimum benchmark for all surveys.

e. The number of transect strips used and their spacing are interconnected parameters that should reflect the level of precision required to meet the objectives of the study, whilst giving flexibility to contractors to design the survey around maximising efficiency and reducing costs. Following the recommendations for conventional surveys, a spacing of 2000 m and minimum of 20 transect lines is recommended as a starting point for designing digital surveys, provided this can be achieved in one survey flight.

However, the number of transect lines is of greater importance than spacing and, clearly, in certain circumstances it will not be possible to maintain a spacing of 2000 m and still survey the entire area in one flight or to maintain an acceptable number of transects. If the desired level of precision for the area surveyed can be achieved through strips separated by more than 2000 m, then such procedures should be taken. Likewise, for smaller regions, 20 transect lines may not be achievable unless spacing is reduced. However, provided that there is no risk of double counting or disturbing birds, this spacing could be lowered for high definition imagery surveys to meet the desired level of precision. We therefore suggest the spacing and number of transect strip parameters to be retained as flexible around the recommended minimum protocols, determined by survey practicalities, precision and survey objectives.

Decisions will ultimately also depend on costs. If image processing is costly relative to aircraft time then fly more flight lines and create a sub-sample within transect strips; if aircraft time is more costly, then sample wider spaced transect strips, whilst adhering to the desired level of precision.

Transect strips should be perpendicular to the coast or an environmental gradient to reduce heterogeneity of counts within strips.

f. Whenever possible, *the whole study area should to be covered in one single day*. Population estimates from different sub-areas surveyed on different occasions should not be summed together, even if the gaps between surveys are anything up to weeks apart, due to local bird movements and/or seasonal migration. If one day of effort does not give the recommended level of precision then conduct repeat surveys of the entire survey region over different days to allow the appropriate precision to be obtained, and better estimation of actual numbers, distributions, and peak and mean population estimates.

If covering the whole area in one day does not give adequate precision, and repeat surveys cannot be undertaken due to the availability of resources, then a less preferred option is to survey sections on *consecutive* days to meet the desired level of precision, assuming distributions are more likely to be similar. However, this option is primarily not recommended.

g. Two or more observers should assess images independently, but validation must also be carried out by an independent consultant or expert providing a minimum of 90% quality control. We also recommend producing a dissimilarity matrix of identification across species, to help assess the level of error surrounding identification of particular species and confusion between similar species pairs.

Further Provisos

a. Additional consideration should be given to the species being targeted and, where possible, an a priori knowledge of populations and distributions from previous surveys should be used. If the species has clumped distribution, then consider prioritising increasing the number of transect strips, or sub-sampling within each transect strip to meet the desired precision of the survey.

b. Adequate training should also be allowed for new observers processing images to achieve the required level of precision as specified in “Survey Design and Analysis d”.

c. Correction of time spent at the sea surface within video images is needed for surveying marine mammals, and caution should be placed in fully using high definition imagery for mammals and diving seabirds until more work is undertaken.

Glossary

High definition Imagery	Generic term for both photographic still or moving video image technology used for aerial surveys of birds and mammals.
Visual surveys	Conventional aerial surveys undertaken directly by observers in aircraft (or boats).
Flight line	The individual lines flown by aircraft during surveys.
Transect line	For visual surveys, counts are made in distance bands either side of a transect line (following flight lines flown by aircraft).
Transect strip	For high definition imagery approaches, a single transect strip is surveyed centred on the flight line.
Transect width	The total width of the transect strip imaged by high definition imagery approaches.
Image width	The width of the image covered by a camera. Equivalent to transect width if only one camera is used, but less if multiple camera systems are used.
Image resolution	The pixel resolution of the camera image at ground level, measured in cm.
Transect spacing	The distance between adjacent transect lines or, for high definition imagery approaches, the midpoints of two adjacent transect strips.
Transect separation	For high definition imagery approaches, the distance between the edges of adjacent transect strips.

Acronyms

HiDef	HiDef Aerial Surveying Ltd
NERI	Danish National Environmental Research Institute

1. Background

It is now widely acknowledged that mitigation of human-induced climate-change must be addressed through reduction of carbon emissions of developed economies. Following the Kyoto Protocol in 1997, in which industrial nations agreed to reduce greenhouse gas emissions by an average of 5% (compared to 1990) by 2012, the UK Government has committed to obtaining 10% of the UK's energy from renewable sources by 2010 and 20% by 2020.

In June 2008, the Crown Estate launched its "Round 3" leasing programme for the delivery of up to 25 GW of new offshore wind farm sites by 2020. Although wind farms serve to reduce carbon emissions, they can also be detrimental to wildlife, for instance through displacement of animals from their natural habitat, or collision risks with wind turbines, for which birds are most likely to be affected (Exo *et al*. 2003; Garthe and Hüppop 2004; Desholm and Kahlert 2005). Wild birds in the UK are protected under the 1981 Wildlife and Countryside Act. European coastal and inshore waters also support globally significant numbers of seabirds (Carter *et al*. 1993; Skov *et al*. 1995) and EU states are required to protect species under the EU Directive on the Conservation of Wild Birds (79/409/EEC, the Birds Directive). Together with the United Nations Law of the Seas (United Nations 1982) and the EU Directive on the Assessment of the Effects of Certain Plans and Programmes on the Environment (2001/42/EC, the SEA Directive), these agreements require states to accept responsibility for assessing the effects of major offshore development on the environment, and this requires the development of suitable survey methodologies.

Previously, visual techniques have been used for surveying seabirds and marine mammals, including ship-based, aerial survey, and to a lesser extent shore-based counts of birds. Conventional aerial surveys involve direct recording by observers, with a recommended flying altitude of 80 m; data are later transcribed and geo-referenced using GPS. In a recent COWRIE report (Camphuysen *et al*. 2004), a comparison was made between ship and aerial sampling methods for marine birds, with guidance protocols produced for survey protocols. Although this approach has been used effectively, reliably and safely, and has an advantage in that a relatively wide band of water is surveyed per transect line, there are also several disadvantages. These include:

- Safety concerns associated with the use of low-flying aircraft within an operational wind farm, potentially limiting the use of this method for post-construction monitoring of birds and marine mammals
- Observer bias, particularly when observers are "swamped" by large numbers of birds and unable to accurately record numbers
- The possible disturbing effect of low-flying aircraft on the distribution and double-counting of birds which, in effect, limits the number of flight lines that can be flown.
- The lack of a permanent observation record

Recent technological advances have enabled use of high definition imagery for survey. Typical advantages of such techniques will include:

- The ability to survey at heights greater than those of operational wind farms and which do not disturb birds
- The ability to record all birds within the transect strip and obtain a permanent observation record, that can subsequently be revisited

A recent report (Maclean *et al*. 2009) that reviewed high definition imagery methodology concluded that certain concerns needed to be addressed before its use for surveys (for wind farm assessments); in particular the narrowness of transect strips imaged, the time taken to process images after surveys, and the lack of comparisons to conventional aerial surveys. Although some of these concerns may have been addressed through more recent developments, there has been no review of the most recent surveys and trials of equipment, nor any re-assessment of their applicability for seabird and mammal surveys. The development of high definition imagery to date has also focused more on the improvements to technology rather than use of the data and assessment and informing the planning process. Hence, it is important that regulators agree methods that are employed to collect those data.

Often a lack of common approaches are used in different studies, as well as a lack of common outputs, which makes the assessment of cumulative impacts of wind farm developments much more difficult (Maclean & Rehfisch 2008). This is likely to be increasingly important in the context of this report, as guidelines on the use of high definition studies should not just be compatible across other high definition surveys, but also to those of conventional aerial surveys.

1.1 Objectives

The aim of this report was to review trials of high definition imagery technology in the monitoring and assessment of bird numbers at offshore sites, and produce recommendations and protocols on its use alongside existing survey methodology, notably in light of its possible use in surveying round 3 wind farm development zones.

The specific objectives are therefore as follows:

- To summarise the existing high definition imagery studies that have taken place, assessing what parameters have been used in each.
- To undertake a workshop bringing together key users, developers and regulators of the industry, with a view to setting protocols and standards on the use of high definition imagery technology for seabird and mammal surveys.

The aim of this report is thus not to critically compare different high definition imagery methods, but rather to produce a set of protocols for their future use.

2. Methods

Information on the trials of high definition imagery technology for survey were obtained from the following institutions and organisations: HiDef Aerial Surveying Ltd (hereafter also HiDef), the Danish National Environment Research Institute (NERI), APEM Ltd, the University of St. Andrews, and the RSK Group plc. Information was collated in the form of reports and summaries on particular surveys, and was split into technical categories of digital video and digital still photography for further summarising.

Following the acquisition of reports, the information was summarised in the form of an interim report. A workshop was then scheduled for attendance by key users, developers, and regulators of the industry based on the report and to work towards agreement of protocols. This meeting was held at the Eco Innovation Centre in Peterborough on the 30th July 2009, hosted by the British Trust for Ornithology (BTO), and attended by: Niall Burton (BTO), Phil Atkinson (BTO), Chris Thaxter (BTO), Rowena Langston (RSPB), Jack Farnham (DECC), Andy Webb (JNCC), Craig Bloomer (JNCC), Allan Drewitt (Natural England), Jessica Orr (CCW), Andy Douse (SNH), Matt Mellor (HiDef), Mark Robinson (HiDef), Tony Fox (NERI), Will Hunter (RSK Orbital), Mark Gash (RSK Carter Ecological), Rebecca Woodward (WWT), Keith Henson (DONG London Array), Matt Britton (E.ON London Array), Gero Vella (RES), Alastair Mackay (npower), Steve Buckland (University of St Andrews), Eric Rexstad (University of St Andrews), Adrian Williams (APEM), David Bradley (APEM), Tim Norman (Crown Estate), Chris Lloyd (Crown Estate), David Still (COWRIE); Apologies: Juliet Shrimpton (PMSS), Stuart Clough (APEM).

RSPB, Royal Society for the Protection of Birds; DECC, Department of Energy and Climate Change; JNCC, Joint Nature Conservation Commission; NE, Natural England; CCW, Countryside Council for Wales; SNH, Scottish Natural Heritage; HiDef, HiDef Aerial Surveying Ltd; React Engineering; NERI, Danish National Environment Research Institute; RSK Group plc; WWT, Wildfowl and Wetlands Trust; DONG, Dansk Olie og Naturgas A/S; NIRAS; E.ON Climate and Renewables, RES, Renewable Energy Systems; npower, University of St Andrews; APEM Ltd;

Crown Estate; COWRIE, Collaborative Offshore Wind Research Into The Environment; PMSS Consultancy.

The structure of this workshop was in the form of short presentations, initially from the BTO summarising the advantages of conventional aerial and boat surveys alongside high definition imagery techniques, followed by a summary of the different trials and surveys that had taken place to date. After a brief question and answer session, developers were then invited to give short presentations enhancing understanding of the surveys, ahead of further plenary with the developers. Following a short break, the focus was then turned towards identification of potential protocols and standards that could be set to allow effective monitoring of seabirds and marine mammals using this technology, with a view to comparability with conventional survey outputs. Following lunch, the afternoon session was reserved for regulators of the industry for further discussion and agreement of specific protocols, notably in light of the possible use of high definition imagery approaches in surveying round 3 wind farm development zones.

3. High Definition Surveys

3.1 HiDef Aerial Surveying Ltd

Trials of imagery technology have been undertaken in the UK by Hi Def at the Shell Flats area near Blackpool, Rhyl Flats in North Wales, Carmarthen Bay (inner bay) – four near simultaneous surveys in conjunction with WWT – the Norfolk coast (wind farm round 3 development zone 5), and further surveys at Moray, Hastings, Isle of Wight, and Bristol Channel (Round 3 Zones 1,6,7,8) (Mellor *et al*. 2007; Mellor & Maher 2008; Hexter 2009a, b).

3.1.1 Methods

HiDef use a multiple fixed digital video camera system, which is forward looking and at a steep angle (30-45º from vertical). Pixel resolution is 2 cm, sufficient to resolve small features such as feet or beaks.

Earlier trials funded by COWRIE (Mellor *et al*. 2007; Mellor & Maher 2008) highlighted potential for the use of video systems from airplanes, rather than helicopters, planes being quieter, more cost effective and more environmentally friendly in fuel consumption. HiDef currently image four 50 m strips, using four individual cameras, equally spaced at 55 m (giving a total image width of 200 m across an overall transect strip of 365 m), from 609 m (2000 ft), flying at *ca*. 270 $km.hr^{-1}$ (150 knots). Thus far coverage of 10% to 20% has been obtained in surveys, although it is anticipated that anything up to 100% or even over (multiple passes) may be feasible at some sites. Each bird or object is visible in the video for >0.5 seconds, meaning that observers can see at least one wingbeat. The video is manually reviewed offline and only birds that cross the horizontal image centreline are counted.

As all birds are detected in the frame, there is no need to apply a detection rate function, and the population of the area can potentially be obtained by scaling the observations to the proportion of the total area. A variety of statistical processing techniques can be used. Kernel density estimators have been used to produce images of bird density distributions (Mellor *et al*. 2007). Population estimation may be estimated more precisely using transect strips for estimation of abundance with bootstrapped confidence intervals (Rexstad & Buckland 2009; see section 3.5).

3.1.2 Advantages

The moving images from HiDef enable birds to be distinguished from white caps on the sea and reflections, and approximate measurements of wingspan and body size can help refine classifications. A total of 25 avian species/families have been recorded to date (see Table 4.2); the system is also good for cetaceans which can be seen at considerable depth when the water is clear. Observers can also distinguish the gender of scoter by colour difference and there is the potential to note further information such as direction of flight, and the approximate height of flying birds.

Other technical advantages include the high airspeed which enables rapid coverage (e.g. 3 days required to cover R3 Zone 5, around 5000 km^2). The video also gives high tolerance against white caps and glare, plus interference with birds greatly reduced due to high flying height. Survey has also taken place over built wind farms.

3.1.3 Challenges and Improvements

Initial difficulties have all now been addressed. Earlier issues with image quality in low light conditions have been corrected by the use of very sensitive cameras. The steep view angle and camera response means that even observers with previous experience of aerial survey require additional training to identify some species. Furthermore, identifying all species in mixed flocks may present challenges, although exposure can be optimised for species of interest. Earlier trials (Mellor & Maher 2008) found that common scoter monitored at Shell Flats, Blackpool (14-15 March 2008: 19 tracks 300 m apart) sometimes flushed if flight heights were lower than 270 m ASL, but greater than this height there was little signs of awareness. Some, disturbance to scoter was still noted in more recent surveys undertaken at 600 m, but the majority of birds imaged were sitting or swimming and those in flight were detected close to their point of take off. It appears as though birds disturbed from this altitude rarely fly any distance, sometimes only flying a few meters before landing.

Other species issues arise with gull species, which may be hard to distinguish if exposure is optimised for dark birds; this issue is addressed by exposing to distinguish gulls, and then post processing to increase contrast of dark birds. Fulmars and gulls can be confused if gliding or shearing, although use of video rather than stills provides the ability to distinguish between them in many cases. Under some lighting conditions, the probability of detection of smaller species such as auks may be less than 1; this issue has been addressed by enabling the orientation of the cameras to be varied between a few preset values to avoid glare.

Although all surveys to date have been conducted with a resolution of 2cm, the HiDef system is also capable of imaging at 4 cm (in which case coverage per hours flying is doubled relative to a 2cm survey) or 1cm (in which case coverage rate is halved).

References

Mellor, M., Craig, T., Baillie, D. & Woolaghan, P. (2007) Trial of High Definition Video Survey and its Applicability to Survey of Offshore Wind farm Sites. HiDef Aerial Surveying Limited Report commissioned by COWRIE.

Mellor, M. & Maher, M. (2008) Full Scale Trial of High Definition Video Survey for Offshore Wind farm Sites. HiDef Aerial Surveying Limited Report commissioned by COWRIE.

Hexter, R. (2009a) High Resolution Video Survey of Seabirds and Mammals in the Norfolk Area. Cowrie Ltd.

Hexter, R. (2009b) High Resolution Video Survey of Seabirds and Mammals in the Rhyl Flats Area. Cowrie Ltd.

Additional information was supplied for the more recent trial at Carmarthen Bay in the form of a PowerPoint presentation.

3.2 APEM Ltd

APEM Ltd have recently trialled high resolution aerial still photography in a survey of Carmarthen Bay, South Wales (March 2009), in collaboration with WWT and St. Andrews to compare survey methodologies (see section 3.5). Pre trials and development were also undertaken during 2008 and 2009 at Barrow-in-Furness, Morecambe Bay, Liverpool Bay, Jumbles Reservoir and the River Kent.

3.2.1 Methods

Surveys at Carmarthen Bay were conducted using a modified twin engine aircraft containing a MIDAS imaging system (high resolution 16.7 megapixel camera with 50 mm lens), and flight navigation software. Flight planning software was used to pre-programme 15 survey transect strips in conjunction with GPS, and the system automatically fires an exposure (together with GPS location and information such as heading, altitude and speed) each time the aircraft crosses one of the predetermined image locations, removing human error in image acquisition.

Flight altitude was 457 m (1,500 ft), and images were captured at a resolution of *ca.* 7 cm Ground Sampling Distance (GSD), providing a survey width of *ca*. 330 m per transect strip. Survey height and resolution were chosen from pre-survey trials to allow bird identification but prevent flushing. Images were examined on screen by trained observers, and were geo-referenced and uploaded to a GIS for identification to the required taxonomic level and further statistical analysis. Large gulls (e.g. herring gull), small gulls (e.g. black headed gull), scoter, cormorant, migratory birds (flying in flock formation), oystercatcher, other waders (unidentified species) and crow spp. were all identified (see Table 4.2), although the survey targeted scoters.

Bray-Curtis distance measures compared similarity between observers' post-processed estimates (n = 5) and demonstrated low variability and high precision akin to laboratory based assessments. A bootstrap approach was used to measure the precision of population estimates (Efron, 1982) and to determine how many samples/images were required to estimate population size. Random bootstrap samples were taken from: (1) 591 autocorrelated images, (2) 296 independently sampled images, and (3) 15 transect strips, with 1000 iterations to generate 95% confidence intervals.

Scoter population estimates varied according to the method of analysis adopted, highlighting the need for targeted experimental design (Fig. 3.1), but were within the range of previous estimates of the scoter population in Carmarthen Bay derived using various survey methods (Fig. 3.1).

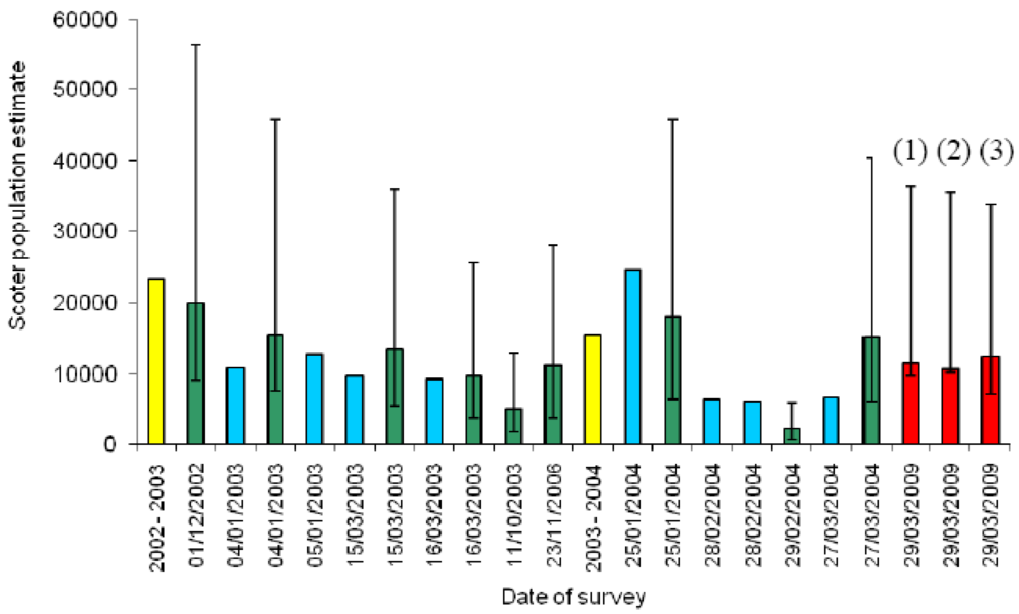

Figure 3.1. Scoter population estimates from Carmarthen Bay using various survey methods presented with 95% confidence intervals where available (data from UK common scoter Biodiversity Action Plan 4th & 5th Steering Group Meetings and APEM aerial surveys). Yellow – ground based monitoring peak count for year; Green – distance-method aerial surveys; Blue – census-method aerial surveys; Red – APEM aerial photographic survey (1 – 3; (1) 296 independent images, (2) 15 transect strips, (3) 591 autocorrelated images). [Reproduced with permission from Bradley *et al*. (2009b, c)]

3.2.2 Advantages

The data produced by APEM Ltd indicate that high resolution aerial still photography provides a reliable method to estimate bird populations. Indeed flying at altitude means that birds are not flushed and with the camera mounted through the hull no areas (and thus birds) beneath the plane are missed. A minimum sample size (survey effort) can be calculated that allows the detection of a pre-determined change in the population to be assessed at a known level of statistical precision. Whilst the current estimate was derived from a survey that covered approximately 15% of the Bay, a survey that covered approximately 75% of Carmarthen Bay would provide data that would allow a doubling or halving of the scoter population to be determined; consistent with the Environment Agency's requirements for fish populations. For less clustered bird groups *ca*. 50% of the survey area would need to be covered (Bradley *et al*. 2009b, c). The still image collected is a permanent record and can be revisited as required and single birds can be given spatial co-ordinates within a GIS that allows further analysis to be undertaken e.g. bird position with respect to water depth and sediment type.

3.2.3 Challenges/Improvements

The purchase of a new Vulcanair P68 Observer Twin engine survey aircraft by APEM Ltd will allow flight at *ca*. one third slower speeds, further reducing motion blur and increasing image clarity. Upgrading to a 60 megapixel system would increase transect width imaged (*ca*. 600m) or, with an 80 mm lens upgrade, improve resolution (*ca*. 3.5 cm GSD); all at *ca*. 457 m (1500 ft). However, resolution up to 20 mm is potentially obtainable at *ca*. 305 m (1000 ft). An Inertial Navigation System will also provide improved geo-referencing; reducing processing time. Statistical improvements are also expected when surveys are designed specifically for a predetermined species, habitat or region coupled with data analysis methods such as cluster or adaptive sampling.

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3.3 Danish National Environment Research Institute (NERI, University of Aarhus)

The Danish National Environment Research Institute (NERI, University of Aarhus) have used high spatial resolution image data for remote sensing of individual seabirds in coastal Danish waters (Horns Reef, Samsø, and Aalborg Bay) (Groom *et al*. 2007), and have more recently applied the technique to making a total count and mapping the distribution of lesser flamingos *Phoeniconaias minor* at Kamfers Dam lake (*ca*. 525 ha) close to Kimberly, South Africa (Groom *et al*. in press; Groom *et al*. in prep.). Further trials using image data have also taken place for gull and tern colonies in Denmark, for cliff-nesting seabirds in NW Greenland, as well as for lesser kestrel in South Africa.

3.3.1 Methods

This NERI technique involves object-based image analysis to map the instantaneous distributions of individual birds based on geo-referenced still photography, thereby removing human decisions from assessing the image representation of each individual bird.

Recent historical development

Initial Danish trials took place using digital still photography imagery generated from a vertically mounted Hasselblad camera with a PhaseOne Light Phase H20 digital camera back with an air reconnaissance lens. The system was flown at *ca*. 600 m and gave a ground resolution of 10 cm. Visual assessment of these images revealed strong image patterns of common eider *Somateria mollissima* and common scoter *Melanitta nigra* (e.g. male eider, a bright *ca*. 7x3 pixel cluster), although in the un-manipulated visual spectrum image data scoter (a dark *ca*. 3x3 pixel cluster) were impossible to consistently detect relative to surrounding dark sea surface image data. Object-based image analysis (Benz *et al*. 2004) of single-band image data was applied through image simple segmentation and standard nearest-neighbour supervised classification of objects as target classes. This technique correctly identified all 171 male eiders, 62 out of 64 female eiders and 207 out of 222 scoters that had been identified by visual assessment with high confidence.

Worked example of technique application to flamingos

More sophisticated object-based image analysis was used to estimate the total number of lesser flamingos at Kamfers Dam lake (South Africa), based on 31 aerial photos that provided complete coverage of the lake (Groom *et al*. in press; Groom *et al*. in prep). In this study colour air survey transparencies were scanned-in, geo-registered (with 10 x 10 cm pixels) and mosaiced. The individual birds were mapped using an algorithm based around quadtree segmentation of the image data and sequential image object thresholding. A total of 81,664 lesser flamingos were estimated through the automated method and a comparison with visual manual counts of sampled areas showed an overall < 2% underestimation.

Proposals for offshore applications

The above experiences have been vital to establish the viability of the methods. Future offshore surveys will benefit from most recent advances in camera technology which gives 5-6 cm resolution in ca. 700 x 450 m scenes. This imagery can be gathered at 680 m or similar altitudes at speeds of up to 350 km/h. Improvements to the software algorithms described for scoter and eiders will improve the level of object detection, identification and mapping of these and other species in offshore surveys.

3.3.2 Advantages

Object based methods allowed the detailed mapping of individuals, species, and the gender of scoter and eider in still images. Object based analysis was subsequently highly successful in providing accurate estimates of the numbers of lesser flamingo at Kamfers Dam. Thus object based methods provide a more efficient and effective alternative approach to traditional methods of local population size estimation, e.g.:

- manual interpretation and counting across an image of tens of thousands of birds and of largely empty scenes is very laborious and likely subject to high count error hence image based automation is useful.
- although pixel-based methods, such as single band level slicing or supervised classification, can also in many cases correctly label the pixels corresponding to birds (Groom *et al*. 2007), post-hoc pixel clustering is necessary to translate the number of pixels to the number of birds; there are methodological image data analysis advantages to making the pixel segmentation first, i.e. by object based methods.

Highly accurate geo-referenced sampled scenes provide spatially explicit species-specific mapping that will support spatial modelling of avian abundance over far greater spatial scales.

Aerial surveys with human observers undertaken by NERI are flown at 160 to 180 $km.h^{-1}$, so the still image plus object based analysis approach represents also a quicker survey method.

Further increases in ground resolutions are also possible through improvements in technology (<3 cm), increasing possibilities for accurate bird species and gender mapping associated with size, shape and plumage characteristics.

3.3.3 Challenges/Improvements

For most reliable results, images must be obtained from altitudes that avoid disturbance to the birds being surveyed. At the same time, the ground resolution of the images must be fine enough to identify birds to species or species group. The images should be sufficiently well geo-rectified and cover as large a sea area as is possible. These demands are optimally achieved by the use of large-format airborne camera systems, such as the Vexcel systems.

As is the case with aerial survey methods based on transect line data collection, the still-photo plus object based analysis method is a snap shot of bird distributions, designed primarily to acquire data on birds present on the water surface, and is less suitable for mapping distributions of highly mobile species such as tern species and flying gulls. Movement of flamingo flocks during photography within the South Africa example could have also resulted in double counting, though that was not evidenced in the photos, and survey height was sufficient to eliminate disturbance effects. The use of large format camera systems (11500 x 7500 pixels) provides simultaneous coverage of larger areas along widely separated transects, reducing the risk of missed birds or double counting through movement. Civil satellite image systems do not yet have fine enough spatial resolution to detect most types of sea bird, and do not have the flexibility of image place and date, or operability under cloud cover, that still imaging from aircraft can provide.

A previous challenge was image scene vignetting, but successive scene overlap, improved internal programme training, and masking would eliminate this issue. There are also high costs associated with front-end development of algorithms within existing commercially available software applications, especially for new species. Auk species cannot currently be split to species by this method under the current resolution, but this is also often the case with visual counts at far lower altitudes.

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3.4 The RSK Group plc

The RSK Group plc have also recently begun to look into surveying using high definition imagery. Insufficient work / surveys had been undertaken to date to present any information to the workshop, though it is important that the group's work is included in any future review.

3.5 Comparison Among Methods: Carmarthen Bay

The recent survey at Carmarthen Bay SPA during March 2009 used a combination of traditional visual approaches and high definition techniques in order to allow a comparison of methodologies. Aerial surveys using human observers (WWT) following protocols of Camphuysen *et al*. (2004) with distance sampling methods were carried out in addition to visual shore based counts (the latter suffering problems in precision calculation). Digital still data were collected and processed by APEM Ltd and digital video imagery were captured and processed by HiDef. Analysis was conducted by the University of St. Andrews. SPA-wide estimates of common scoter abundance and estimates of precision were obtained.

The methodology used for visual surveys included regular spacing of transect lines at 2000 m (following Camphuysen *et al*. 2004), resulting in 15 transect lines across the bay in total. Still imaging methods also used the same protocol (2000 m spacing between centre-lines, thus a 1700 m separation between transect strips), whereas video survey resulted in 29-30 transect strips (with a separation of 300 m). In each transect strip, the multiple 4-camera system surveyed image width strips of 50m with 55m gaps giving a transect width of 365m.

Shore-based estimates were obtained by simply summing counts from vantage points (no precision); visual survey data were analysed using detection functions; both digital surveys were treated as transect strips to estimate abundance with bootstrapped confidence intervals. A finite population correction factor was applied to the visual survey coefficient of variation (encounter rate variance component) after Buckland *et al*. (2001). The variance in the estimated abundance was also positively correlated with the magnitude of the abundance estimate.

The coefficient of variation (CV) for visual surveys is shown in Table 3.1. The exact number of common scoter are not known, hence discussion of the precision of the methods is necessary. As expected, increasing the proportion of the study region covered provided increased precision, but the patchy distribution of seaducks contributed to large CVs for this species. Digital still surveys had the same number of transect strips as the visual surveys transect lines (15), but there was variation per day on the number of transect strips containing scoter, thus increasing variance. Digital video had twice the number of transect strips as still images and visual. There was a positive relationship between patchiness (as measured by proportion of transects without scoter detections) and uncertainty in abundance estimates.

The confidence limits around the estimates from the visual aerial surveys encompassed the shore-based estimates (Fig. 3.1; Table 3.1). However, both visual aerial survey and shore-based estimates of scoter at Carmarthen Bay were typically lower than those obtained by digital methods, suggesting either that the latter could have overestimated numbers or that the former were underestimates.

Shore-based counts were originally intended as a baseline to compare to other surveys. However, some birds occur too far offshore to see and hence may be missed by shore observers (Banks et al. 2008), and some birds within range may not have been counted due to decreasing detection with increasing distance. Observers also shifted between shore count locations, producing an unknown error. Thus shore-based counts could have produced an underestimate of population size. Visual aerial surveys may also produce underestimates because of the disturbance that can occur during surveys, which appears to be negated by the flying heights used for digital methods.

In a separate survey for the Round 3 Norfolk Region, visual and high definition methods produced more comparable population estimates for gulls; however, digital methods underestimated population size of seabirds compared to visual methods (Burt et al. 2009). Further comparative studies are therefore necessary, and will depend on survey design. Whilst visual methods achieved greater precision at Carmarthen Bay than digital (still) methods, by using high definition cameras more effectively and by increasing numbers of transects, much higher levels of precision could be obtained by digital methods. Such comparisons across methods nevertheless provide a step towards the development of survey protocols.

Table 3.1. Initial estimates, coverage, and coefficients of variation for visual (aerial), video and still images; Cov = coverage obtained through each method, Est = estimate of population size, CV = coefficient of variation of the estimate [reproduced with permission from Rexstad & Buckland (2009)]

Date	Shore	Visual			Digital Still			Digital Video		
	Est	Cov	Est	CV	Cov	Est	CV	Cov	Est	CV
15-Mar	8272	0.257	9694	0.323	0.148	32085	0.382	0.155	25461	0.353
21-Mar	2306	0.258	4049	0.369	0.154	20378	0.723	0.126	14492	0.541
22-Mar	4553	0.249	5217	0.365	0.153	4942	0.838	0.175	19910	0.541
29-Mar	1545	0.261	5110	0.403	0.151	12600	0.558	0.174	10662	0.414

4. Development of Protocols for the Use of High-Definition Imagery Techniques in Aerial Surveys

4.1 High Definition Imagery Parameters

Prior to the workshop, technical and survey design parameters that could lead to potential protocols were provisionally identified.

Potential Technical Parameters

- Survey height – Typically the surveys have used heights between 457 and 609 m. These have been on the grounds that such heights minimise disturbance to individuals, being much higher than visual survey methods (80 m). Heights as low as 210 m in early trials undertaken by HiDef reported some disturbance to common scoter.
- Image resolution – Surveys have been conducted with resolutions between 2 and 10 cm but a limit to coarseness should be determined. Higher resolution may not always be necessary, and standardisation would allow comparable identification.
- Duration of time each bird is visible (video only) – Needs to be standardised and has been recommended by HiDef Ltd as 5-10 images of a bird spanning 0.5 s.
- Image width – Surveys have been conducted with image widths of 25-300 m; summed image width for the four cameras used in video high definition imagery by HiDef has been 200 m.

Further technical considerations

- Overall transect width – this is equivalent to image width if one camera is used, but equates to the sum of image widths and strip spacing if more than one camera is used (Table 4.1).
- Airspeeds – These are also variable between surveys typically ranging from 219 km.hr^{-1} to 350 km.hr^{-1}, faster than visual surveys (185 km.hr^{-1}).
- Error in identification – Are particular digital surveys more or less prone to error in species/family identification?
- Labour costs and automation – If further automation can be applied then this would reduce costs
- Equipment – Particular technology probably should not be prioritised as this would be counter-productive to further developments.

Considerations relating to survey design and analysis

- Coverage and transect spacing – In comparison to visual methods, high definition imagery based surveys provided less precise population estimates mainly due to lower coverage, hence potentially increasing the number of lines and reducing spacing (thus increasing the coverage) could increase precision. Typically, coverage (the proportion of the target area painted by camera images) has ranged between 10-20%; NERI have achieved 100% coverage over a smaller area in mosaic still images. A coverage of 75% of Carmarthen Bay would enable changes in population to be determined comparable to that for other protected species.

- Survey effort – For digital methods, a greater precision could be gained by a better spread of lines throughout the survey region, allowing more reliable extrapolation to the whole survey region
- Cost – Further costs would clearly be incurred through increasing the number of transect strips, however a segmented approach may also be possible enabling and equi-distant grid layout, but must be weighed up against costs
- Edges – Equal sampling must take place across the survey area and consideration given that edges are not over- or under-surveyed
- Gradients – Typically this should be perpendicular to animal distribution to avoid the over- or under-estimation of populations
- Analysis – Further analytical consideration must be taken in estimating population size, for instance estimating systematic sample variance arising from non-random spacing of transect strips, and use of a finite population correction for variance estimation

Table 4.1. Summary of some technical parameters used in recent high definition surveys.

Type	**Video**	**Still Image**	**Still Image**
Survey	**HiDef Defra**	**NERI**	**APEM**
Location	Carmarthen Bay, UK	Kamfers Dam, SA	Carmarthen Bay, UK
Altitude (m)	609	600	457
Resolution (cm)	2	10	7
Coverage (%)	10-20	100	15
Duration of time bird visible (vid only)	>0.5 s		
Image width (m)	50	25	300
Total image width	200	25	300
Overall Transect width (m)	200 (385)[a]	na	300
Transect separation (m)	300	na	1700
Airspeed knots	150	190	118
$km.h^{-1}$	278	350	219
Area covered (km^2)		5.25	53.2

N.b. [a]Transect width for HiDef survey: four cameras covered strips of 50 m equally spaced at 55 m, giving a total image width of 200 m over an overall transect width of 365 m.

Currently there is a specific need to develop protocols in order to facilitate the potential use of High-definition Imagery in the surveys required of Round 3 wind farm zones. During the workshop, discussion was centred around feasibility of setting protocols for a number of parameters. However the consensus amongst all parties was that protocols depended on the specific aims of the survey being conducted and the individual species being targeted.

Thus flexibility should be maintained over and above a baseline set of protocols giving minimal requirements. The following points form a discussion with some suggested lower limit protocols that should be adhered to, and where applicable, circumstantial protocols that we can suggest at this stage.

4.2 Summary of Main Workshop Findings

a. Protocols depend on the aim of the particular survey. For instance, species may vary in their detectability and parameters required, and hence it is important to understand what level of survey is being conducted prior to survey.

b. Levels of survey that are likely to be required are as follows:

- Characterisation: A survey to investigate what species assemblages are present, e.g. of a Round 3 development zone prior to Environmental Impact Assessment (EIA). Typically for biotic factors, these are traditionally through extensive preliminary surveying in order to characterise the site in terms of spatial and temporal distribution of habitats and species, most notably those of conservation concern, allowing identification and mapping.

- Baseline Environmental Impact Assessment (EIA): The Environmental Impact Assessment Directive 85/337/EEC, requires an EIA to be carried out in support of an application for wind farm developments. The current approach uses a matrix approach of cross-tabulating sensitivity of species with the magnitude of the impact of the development. This is a tool used to assess, understand, and take account of a wind farm's likely environmental impacts, before a development is given consent to proceed. This also includes a buffer zone around the wind farm, based on evidence that Common Scoters, Red-throated Divers and auks avoid areas up to 4 km from the boundary of the wind farm (Petersen 2005; Drewitt & Langston 2006). Although experience from Denmark (Petersen & Fox 2007) indicates that several years after commissioning, common scoters may occur within wind farm areas at similar densities to those elsewhere, divers tend to remain displaced. See Maclean *et al*. (2009) for further details.

- Purposes of meeting Appropriate Assessment (AA): As part of the EIA process, where a 'likely significant effect' upon a Natura 2000 site (Special Protection Area [SPA] or Special Area of Conservation [SAC]) is identified, the developer needs to provide sufficient evidence so the competent regulatory authority can conduct the AA. Information provided in the EIA should also be in a form and format that allows an AA to be undertaken. Baseline surveys will be required in order to understand and predict the effects within, or adjacent to, a classified Natura 2000 site. Note, processes operating outside SPAs may have an impact on birds within a SPA, hence an AA is not restricted to developments lying within a SPA. Where significant negative effects are identified, alternative options should be examined to avoid any potential damaging effects. Within a SPA the impact on the bird's habitat is usually interpreted in proportion to the relative bird density in the potentially affected area. For such an assessment, good quality distribution and abundance data are required at a relatively fine spatial scale, together with highly accurate species identification. However, it is likely that other supporting information will be needed to allow an AA to be made, and high definition surveys will not, in general, be suitable as the sole survey methodology when undertaking surveys for EIAs and AAs.

- Before and After / Control and Impact Analysis (BACI): This survey is required for a detailed assessment and monitoring before and after a development (Smith *et al*. 1993) and requires specific technical and survey design parameters. Specifically, this requires additional baseline data for monitoring purposes, and strict survey design methodology for repeatability and the detection of change.

- Common Standards Monitoring: More detailed monitoring might also be required for Common Standards Monitoring of feature species of protected sites. This process is intended to be a, simple assessment for protected sites such as Special Protection Areas (SPA)s, Ramsar sites, and SSSIs, but requires accurate identification of species and reliable, precise and repeatable estimates of population size.

Within each level, surveys will also need to distinguish between the requirements of estimating populations and determining distributions. Characterisation, for example, may be more focused on distribution rather than obtaining precise estimates of populations, and such an approach would then feed into informing subsequent survey design at other levels. However, it is important to also note that the data from characterisation surveys may potentially be used for baselines in EIAs and before-after assessments, and if this is the case it is important that the differing requirements of these assessments (notably those related to survey design) are born in mind from the start.

c. Parameters for which protocols could be developed include technical parameters, parameters on survey design and parameters on data analysis. Some potential parameters are outlined above in section 4.1, and are discussed in more detail below.

4.3 Discussion on Recommended Protocols

The following represents a discussion of potential protocols and recommendations where appropriate rather than an exhaustive comprehensive list of guidelines. The protocols here represent minimal conditions, though it should be noted that they may need to be altered or improved on depending on survey aims. Recommended protocols are summarised in section 5.

4.3.1 Technical Parameters

a. Minimum flight height to avoid disturbance: 450 m. This recommendation should apply for all levels of survey. An advantage of high definition imagery is that excellent resolution of images can be achieved even with high heights, thus eliminating the need for lower flight heights. HiDef have flown trials as low as 210 m with some disturbance noted to scoter and initially suggested 270 m as a lower limit; however, a more reasonable flight height minimum may be 450 m, above which APEM Ltd noticed no disturbance to common scoter. Scoter are ranked as the seabird species most susceptible to disturbance in northwest European waters (Garthe & Hüppop 2004), and hence are particularly suitable for setting this baseline figure. These heights are still far higher than those conventional aerial surveys. Where disturbance is not noted for particular species, a lowering of flight height below 450 m may be feasible where necessary. For instance, a lower flight height can both increase resolution of images and increase strip width, hence if particular species ID is necessary using higher resolution images, and one is confident lower flight heights do not cause unnecessary disturbance, then it would be beneficial to reduce the 450 m limit. However until such data are available we recommend 450 m as the lower ceiling. Note, clear justification is necessary for changing survey methods between pre- and post-construction, and where the same methodology cannot be used, the contractor must demonstrate that equivalent precision of estimates of populations can be achieved (see later survey design section 4.3.2 a). This is notably due to the difficulties of comparing the different data collected. However, it should also be noted that changing flight heights may result in differing levels of disturbance and thus different population estimates, thus wherever possible it is important to maintain the same flight height through BACI assessments regardless of the survey method being used.

b. Accuracy in species identification. There is a need to be match the level of identification and observer error currently achieved by traditional aerial surveys with those used in high definition imagery approaches. This is necessary to enable comparisons of the data from high definition surveys to be drawn with existing conventional datasets and to maintain minimum standards (see Survey Design section below for discussion surrounding observer error, and the relationships with image resolution and flight speed).

Species groupings. It was not always possible to identify all species using high definition surveys – for instance, gull species proved difficult (Table 4.2). However, the species or species groupings that could be identified matched existing groupings from JNCC boat-based surveys (A. Webb Pers. Comm.).

The level of species identification has to match the aim of the particular survey. Full species identification will therefore require this level of identification be set as standard for the survey. However, in conjunction with the recommendation below, it is recommended as a minimum requirement that the resolution used should allow the identification of the same species or species groupings used as standard by JNCC (Table 4.2, Appendix 1).

A note should also be kept also detailing the reasoning behind why species could not be determined and a comparison between observers, and also if precision could be narrowed to species within the groupings. Three further categories of species have also been recorded under high definition imagery methods, including waders (all species), migratory flock formations, and crow sp. These were most likely recorded incidentally and are thus below minimum standard for species groupings, and are thus not recommended as additional categories here. Increases in technology may also allow further refinement and identification of species beyond the taxa levels reported in Table 4.2, and should be updated accordingly.

Table 4.2. An example of those species or species groupings that have been recorded under High Definition Imagery methods at sea and equivalent groupings according to those used as standard by JNCC in conventional surveys (note full JNCC groupings are shown in Appendix 1); NERI have also trialled high definition imagery for Tern and Gull colonies in Denmark, cliff-nesting seabirds in NW Greenland, and for Lesser Flamingos in South Africa.

JNCC Code	JNCC Species / Species Grouping	HiDef	APEM	NERI
40	Great Northern Diver	1		
220	Fulmar	1		
710	Northern Gannet	1		
720	Cormorant		1	
2060	Common Eider	1		1
2130	Common Scoter	1	1	1
2150	Velvet Scoter	1		
5690	Great Skua	1		
5780	Little Gull	1		
5900	Common Gull	1		
5910	Lesser Black-backed Gull	1		
5920	Herring Gull	1		
6000	Great Black-backed Gull	1		
6020	Kittiwake	1		
6110	Sandwich Tern	1		
1520	Mute Swan	1		
1730	Common Shelduck	1		
4500	Eurasian Oystercatcher	1	1	
5410	Eurasian Curlew	1		
95003	Diver sp (All Gaviidae)	1		
95009	Shag / Cormorant	1		
95037	Tern sp (All Sternidae)	1		
95040	Auk sp (All Auks, including Black guillemot)	1		
94003	Small Gull sp (Common, Black-headed, Mediterranean, and Little Gull, plus Kittiwake)		1	
95034	Large Gull sp (Lesser Black-backed, Yellow-legged, Herring, Great Black-backed, Glaucous, and Iceland Gull)		1	
	Additional Imagery groupings			
	Wader sp (All)	1	1	
	Migratory Flock Formation		1	
	Crow sp (All)		1	

c. Resolution. The resolution of the surveys varied between trials of different equipment between 2 and 10 cm. However, more recent developments are enabling the use of smaller resolutions. Following discussion at the workshop, we recommend that a *minimum resolution of 5 cm is maintained with further increases in resolution encouraged*. However, if the level of species identification required by surveys (see above) can be shown to be made accurately at a resolution coarser than 5 cm, then such resolutions should also be permitted. The total width of the transect strip is partly dependent on resolution, but in accordance with the minimum high definition imagery transect width trialled, we would recommend a minimum transect width of 200 m be used as a minimum protocol. It is imperative that the resolution used should allow the same level of identification as used in conventional aerial and boat survey methods for comparability of results.

Further increases in resolution are inevitable through technical developments and so long as they agree to the above criteria, should be actively encouraged. If further improvements in resolution allow targeted species surveys where previously they did not, then resolution should be increased accordingly.

d. Colour. Colour images should always be used as opposed to black and white or specific colour bands, due to superiority of species identification.

e. Video survey. *The duration of time each bird is visible* to enable reliable identification should be maintained, according to HiDef, is *a minimum of 5 images (suggested range 5-10) of a bird spanning 0.5 s*. This should be standardised throughout all survey levels as a minimum requirement for reliable identification.

f. Exposure. It is preferable that exposure be optimised for the species of investigation where surveys are for specific species, for instance in lower tier surveys. However, for more general surveys, a suitable exposure level should be determined at the discretion of the developer so that as many species and taxa can be identified as possible.

g. Automation. Automation software, such as that used by NERI, is freely available and is also being trialled in-house by APEM. Automation will improve post-processing effort and time of observers, and should be explored further. Nevertheless, initial trials, such as those carried out by NERI are needed comparing manual counting and automated procedures so that a suitable level of accuracy, e.g. *ca*. 90% or above is reached between observer and automation, using a dissimilarity matrix across different species and using different observers. Results from surveys undertaken across varying conditions of sunny vs cloudy days should also be compared to ensure the criteria set are applicable across different conditions. Thus, while it is viable to explore automation, until a suitable level of identification is achieved for many species, in the short to medium term, manual inspection of film/images should be the default for high definition imagery surveys. For instance, HiDef reported that suitable identification from expert reviewers of footage was achieved manually within an acceptable time cost limit. (See also Quality Assurance section below).

h. Speed of travel. Slower speed can give clearer pictures and may prove useful in assisting identification of species, but current speeds in the range of *ca*. 220 – 350 $km.hr^{-1}$ (*ca.* 120-190 knots) are suitable for a baseline parameter range, and images at these speeds are suitable in many instances for identification of birds to the species level. This parameter is also closely related to costs and area covered. Speed should be modified accordingly where there is no detriment to any of the above minimum requirements, and/or there is a clear benefit in identifying a species that was not previously identifiable, e.g. splitting of auk species. Flight speed will therefore be a trade off between the desirability for minimising the time taken to cover an area with acceptable image resolution to enable species identification.

i. <u>New technology.</u> All companies involved with high definition methods reported improvements either in place or under development. New technology should be incorporated to improve on the minimum criteria outlined in this document. Incorporation of infra-red technology to increase survey time during the day (and at night) and mitigate the effects of low cloud, for example, may also enhance the current technology being used.

j. <u>Conditions.</u> *We recommend avoiding surveying through low cloud with the current technology available*. During early trials from HiDef (Mellor *et al*. 2007; Mellor & Maher 2008) flight heights were lowered to overcome problems of low cloud, although this was at the expense of disturbance to common scoter. Surveys should thus be maintained above the minimum flight height recommended above unless conditions do not allow this. Following Camphuysen *et al*. (2004) *we also recommend avoidance of undertaking surveys in conditions of Beaufort Scale 4 and above in order that birds are not missed and that they are correctly identified*. It should be noted that sea state is less of an issue for video surveying since white caps of waves move, whereas in still images they could be confused with birds such as gulls. Thus, *undertaking surveys in higher wind speeds should be permissible but only if it can be demonstrated that birds are not missed and that species identification is not adversely affected in these conditions with the technology being used*. Clearly with all survey techniques there will be a maximum limit on the wind speed where technologies can be used, but this is yet to be determined

k. <u>Additional information.</u> The sex and age of birds should always be recorded where possible for the species. Additional data on windspeed, direction, survey date and time are typically recorded during high definition surveys. If the unlikely event of creating disturbance to birds at the specified flight height, the original location prior to disturbance should also be recorded.

4.3.2 Survey Design and Analysis

This section discusses several issues surrounding survey design and analysis using high definition aerial technology. A number of recommendations are presented here as separate bullet points, but it should be noted that these points are strongly inter-connected. Consequently, a synthesis of survey and statistical design issues and guidance is provided at the end of this section.

The aim of the surveys discussed here is usually to derive population estimates of the numbers of birds using an area. A further aim (e.g. of the BACI analysis described above) may be to detect change, and this may be achieved either through a comparison of the population estimates (and their confidence limits) or by a statistical comparison of raw count data. Unless stated otherwise, the following recommendations assume that the surveys' main aim is to produce population estimates and that it is these estimates will be used for detecting change.

The comparison of the estimates of common scoter in Carmarthen Bay produced by different methodologies indicated that visual surveys were more precise than high definition methods, due to the wider strips surveyed (e.g. 2000 m rather than 300 m). As such, if precision of estimates is important, then more appropriate consideration needs to be given to survey design, notably for EIAs and BACI surveys.

Digital surveys are a form of plot sampling, with numbers scaled up according to the proportion of the total area covered by transect strips to provide population estimates. However, variance is often overestimated in doing this, arising from the assumption that the survey is a random sample whereas in fact it is a systematic spacing of transect strips. The following discussion points were raised at the workshop and we suggest recommendations where appropriate for each.

a. <u>Consistent survey methods.</u> There is a general need to maintain the same survey methodology between high definition surveys, but it is especially important that the exact criteria are followed for before and after comparisons (BACI). Survey methods should clearly allow comparability with past datasets collected using conventional survey methods. A good knowledge of the biological system is required, together with a strict sound survey design (Smith *et al*. 1993). This is a particular issue also with marine mammals and diving seabirds (see discussion below on detectability issues).

Note, different methodologies can be used to calculate population estimates and distributions/densities for before-after assessments provided that no one method is more biased than the other, and a statistical comparison will be possible provided both have confidence limits. However, such assessments would be made far more robust if raw data were used, which would only be possible if the same methodology (and same survey design, i.e. transect strips) were maintained throughout. This would also allow the incorporation of covariates into analyses (see below). For BACI assessments, for instance, if no statistical comparison can be made between the results of two different survey methods, we recommend adhering to the methodology carried out in the original survey, which may thus mean a repeat visual survey instead of use of high definition imagery. It should be noted that maintaining visual aerial surveys post-construction may be problematic because low flying within an operational wind farm is not possible. Where a change in methodology is unavoidable, we would also recommend collecting new pre-construction data using high definition imagery, or running visual and high definition approaches in parallel for comparisons to be drawn. These steps would help minimise the likelihood that changes occurring post-construction are due to a methodological change rather than changes in numbers occurring to wind farm construction.

b. <u>Pseudoreplication.</u> Pseudoreplication may have been an issue for some previous analyses of high definition images, since the images or frames within the transect strips are not strictly statistically independent sampling units. However, the transect strip itself can be considered independent, thus all analyses should be conducted at the level of transect strips. Transect strips are also recommended to be perpendicular to environmental or animal distribution gradients that might exist in the study region, to minimise between-sampler variability and to reduce violations of the assumption that distributions are uniform with respect to the line. For instance abundance may decline with distance from the coast (e.g. Strindberg *et al*. 2004), and thus perpendicular transect lines are frequently employed in aerial visual surveys. Although this gradient may be difficult to predict, it should be incorporated into the survey design wherever it can be anticipated.

c. <u>Detection of change and covariates.</u> To date, it has been extremely difficult to be able to detect changes in seabird numbers between surveys, and this is a central problem in assessing the displacement effects of wind farms on birds (i.e. BACI approach, Smith *et al*. 1993). This issue is partly because of the natural variability in seabird numbers, but also because of low levels of coverage and small numbers of surveys (MacLean *et al*. 2006, 2007, Bradley *et al*. 2009a; Rexstad & Buckland 2009). We therefore also recommend the use of covariates such as oceanographic and hydrographic variables (MacLean *et al*. 2006), to be incorporated within "BACI" analyses, in particular those surveys using raw counts from high definition surveys, to reduce background noise that otherwise impede reliable assessment of change due to wind farm construction. This may require recording of additional factors during surveys such as wind speed and direction, as recorded by boat-based surveys, but most importantly incorporating detailed oceanographic variables (such as flow gradients and currents) collected independently to the aerial survey. It is important that surveys are designed to allow this.

d. <u>Statistical certainty.</u> High definition imagery gives a very accurate count of the number of birds in the strips imaged, which should be more precise than visual observers can achieve. However, there will still be some error in the estimates produced from these raw counts for the region as a whole.
For BACI analyses (and the EIA surveys that often form their baseline) which use population estimates and confidence limits to detect change, there should be a general

recommendation for being able to detect a certain level of change with a certain degree of accuracy. Thus surveys should seek to obtain a predetermined level of statistical power to detect change.

The power to detect change is not necessarily based on the percentage of the region covered and for larger survey regions, it is generally preferable to increase the number of samples (i.e. transect strips) rather than coverage *per se* (see below). Note, for smaller regions, where transect strips may cover a larger proportion of the area, a finite population correction should also be included in the variance estimate (S. Buckland pers. comm.). Studies including biota other than birds, such as fish and invertebrates, have suggested that the minimum sample size should be one that allows the detection of a halving or a doubling of the population at an acceptable predetermined level of statistical precision (e.g. Bohlin 1990). Surveys by APEM at Carmarthen Bay (Bradley *et al*. 2009b) have found that for a population change factor of 2 (i.e. halving or doubling in population) a coefficient of variation (CV) not larger than 16% would achieve a minimum acceptable estimate for clumped common scoter (Bradley *et al*. 2009a) and would be acceptable for statutory agencies. *Following these studies, detecting a halving or doubling of the population is therefore suggested as a minimum benchmark for all surveys*.

e. <u>Survey design and precision.</u> If the survey region is large, then precision depends not on the percentage of the area covered, but the number of flight lines flown (i.e. number of transect strips). Therefore, a fuller spread throughout the region would decrease standard error (Rexstad & Buckland 2009). Species with clumped distributions, such as seaducks, may require a greater number of lines to increase the chances of hitting one of those "clumps" (Fig. 4.1) and this could be informed by a priori knowledge from characterisation surveys. Under visual aerial survey methods, the exact relationship between precision of population estimates and transect spacing is not known (Camphuysen *et al*. 2004), and was previously recommended as a further area of research (Maclean *et al*. 2009). Most conventional methods have used the lower 2000 m spacing limit suggested by Camphuysen *et al*. (2004); however, a minimum of 20 transect lines within the region was also suggested for visual surveys (Camphuysen *et al*. 2004). *We would recommend that the same spacing and minimum number of transect lines also be considered for digital surveys, provided this can be achieved in one survey flight* (see 4.3.2 f).

The number of transect lines is of greater importance than spacing and, clearly, in certain circumstances it will not be possible to maintain a spacing of 2000 m and still survey the entire area in one flight or to maintain an acceptable number of transects. Thus, we refer back to what the initial objectives of the survey are, and what level of precision is needed to meet those objectives (see 4.3.2 d). For instance, if the desired level of precision for the area surveyed can be achieved through strips separated by more than 2000 m, then such procedures should be taken. Likewise, for smaller regions, 20 transect lines may not be achievable unless spacing is reduced. However, provided that there is no risk of double counting or disturbing birds, this spacing could be lowered for high definition imagery surveys to meet the desired level of precision. As always, start points of transect strips should be randomised if using a constant transect separation distance throughout the zone. Contractors are best placed to make these judgements. *We therefore suggest the spacing and number of transect strip parameters to be retained as flexible around the recommended minimum protocols, determined by survey practicalities, precision and survey objectives.*

It should also be noted that utilising the same criteria of spacing used in visual aerial methods, coupled with treating each strip as a sampling unit, resulted in reduced precision of population estimates for digital methods (as transect strips were narrower and the proportion of the area surveyed was therefore less). Decisions will ultimately also depend on costs. Consequently, for larger areas, adjustments may also be needed to balance costs of surveying and the precision of population estimates. Therefore, *if* *image processing is costly relative to aircraft time, then we recommend flying more lines, and creating a post-flight subsample within strips* (Fig. 4.1). This design should be set up so there is equal distance separation between the transect strips, and the subsequent subsample from the same strip (Fig. 4.2). This structure will increase the number of samples also within the region and increase precision of population estimates. *However, if aircraft time is more costly, then one should sample wider transect strips to increase precision*, either through using multiple cameras, or increasing individual image width (though under the latter, note the influence on resolution). Until more data are available, it would not be prudent to put an upper maximum on transect spacing due to its dependence on area surveyed, costs incurred, and the species investigated under the level of the survey. In agreement with Maclean *et al*. (2009) we would recommend further research into the effects of the number of transects and spacing on population estimates for both visual and high definition methods.

Note, for BACI surveys comparing raw count data instead of population estimates, it is important that the same transect strips are used throughout to enable comparisons pre- and post construction.

f. Area surveyed and costs incurred. Repeated surveys over different days will allow more precise estimation of actual numbers and distributions, and will increase the power for detection of change. Thus, it is recommended that whenever possible, *the whole study area needs to be covered in one single day*. Single day surveys will give a truer representation of an average distribution during the multiple days of survey, whereas sequential survey of different transects over several days is more likely to be biased by net shifts in distribution over time both throughout the season, and on a daily basis due to individual movements. This increases the risk of double counting or missing birds considerably and thus of over- or underestimates of populations, and is also an issue for simply assessing distributions. An appropriate averaging of population estimates would then be required over the multiple survey days. Costs of air time are also a factor here.

It should be noted that it may not be possible to cover the very large areas in one day with the minimum number of transect strips recommended, particularly in mid-winter when day-length is short. Therefore, the number (and consequently the spacing) of transect strips should reflect the desired precision of the survey offset against practical needs of the contractor (e.g. costs of survey time versus image interpretation), and may be reduced due the overriding need to complete the survey in a single day. It is also considered more important to carry out surveys in a single day, than to maintain a constant transect separation. If one day of effort does not give adequate precision, then the whole area can be covered in a repeat survey, or several repeat surveys, allowing the mean population size during the survey period to be estimated to whatever precision is required. In the event that precision cannot be met under the resources available, even with repeated survey days, then a less preferred option is to survey sections on *consecutive* days to meet the desired level of precision, under the tentative assumption that distributions will be similar between consecutive days. However, this option is primarily not recommended.

Quality Assurance. We recommend that *two or more independent observers should assess images independently after the survey*, for quality control, and a confusion matrix should be provided to show the degree of agreement and which species might be confused with each other. In particular, comparisons should be made in the identification of similar species pairs such as guillemots and razorbills. However, *validation must also be carried out on a subset of the original data by both an independent consultant or expert in addition to "in-house" experts as part of the quality assurance process*. This should also prove useful in assessing the level of error surrounding identification of particular species. Although APEM reported an 80% agreement between five observers using 20% of the images generated, species specific assessment is still required. A recommendation for *a minimum 90% agreement between observers* would concur with the levels of accuracy used in training observers by WWT.

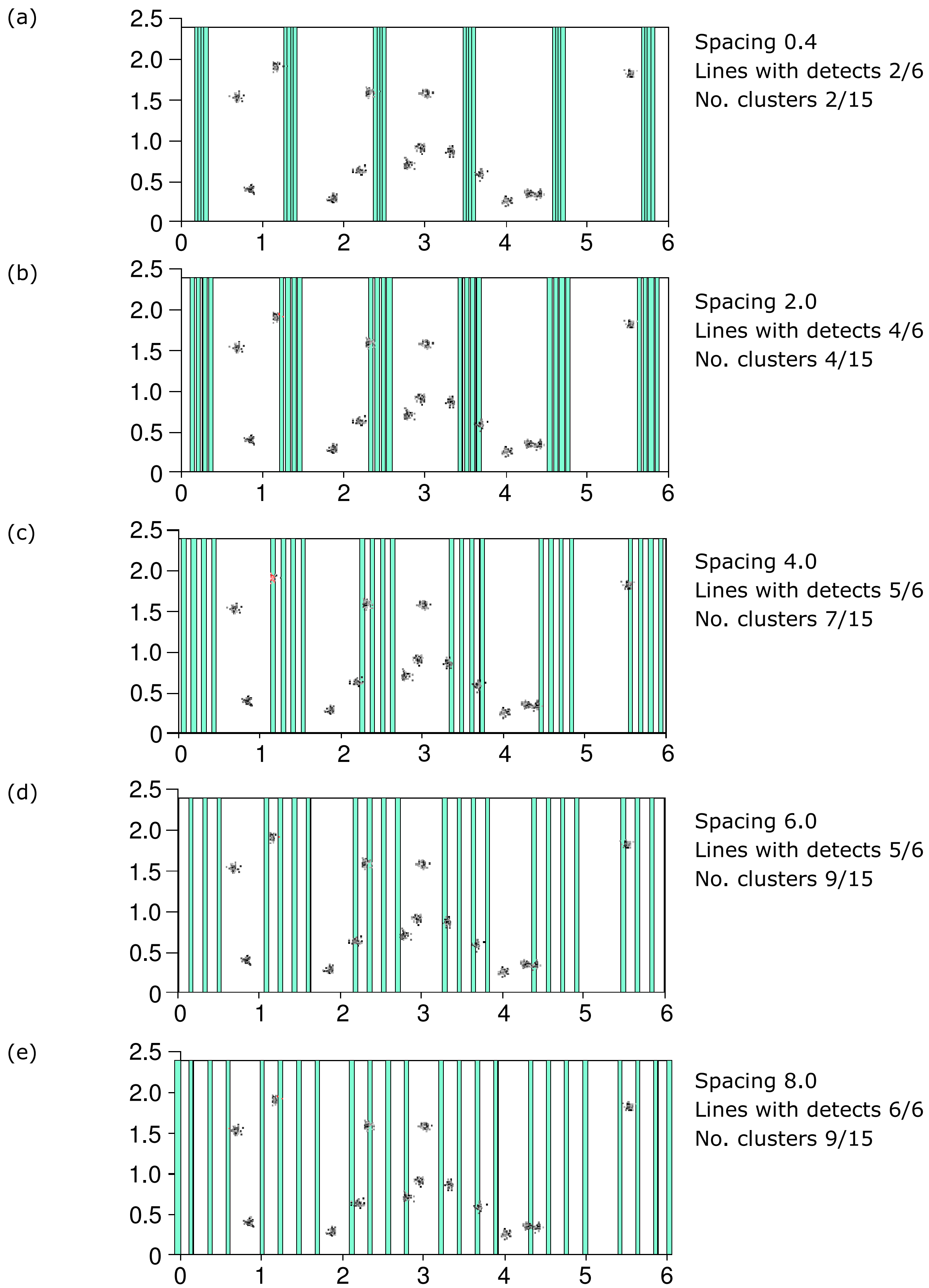

Figure 4.1. Illustration of the effect of increasing number of transect strips from HiDef surveys across a hypothetical survey region for common scoter (x and y axes are arbitrary values); a-e represent progressive increasing of transect spacing and registering the number of lines containing detections of scoter and the number of clusters in total detected (Figure from Rexstad and Buckland, University of St Andrews unpublished).

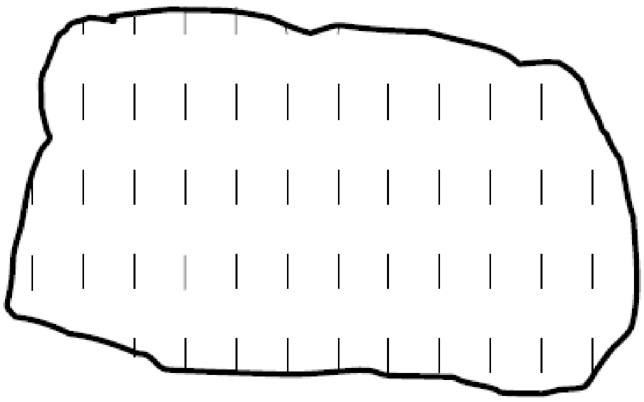

Figure 4.2. Systematic grid of line segments equally-spaced through the survey region (Figure from Rexstad and Buckland, University of St Andrews unpublished)

Survey design issues should therefore be tailored towards:

1) The level of survey and whether distributions or precision on population estimates or the prediction of population change are most important

2) The species being investigated, i.e. if the species typically has clumped distributions then more sampling strips will be required

3) Balancing the costs of aircraft time vs image processing

Synthesis on Guidelines for Survey Design

What are the objectives of the survey and what precision is needed to achieve those objectives?

The objective of the surveys and the precision required should determine the effort needed. A target precision should be set for priority species, and at a minimum we recommend detecting a halving or doubling of the population; for instance this corresponded to a CV of ≤16% for common scoter (Bradley et al. 2009). However, greater precision than this may be required depending on the level of survey, and species targeted. Use of power analysis from pilot data for the area concerned would also be highly recommended for determining the precision, and the contractors are best placed to achieve this.

What spacing allows an area to be covered in a day?

The number of transect strips used and their spacing are interconnected parameters that should reflect the level of precision required to meet the objectives of the study, whilst giving flexibility to contractors to design the survey around maximising efficiency and reducing costs. The number of transect lines is of greater importance than spacing and a minimum of 20 transect lines is recommended. However, depending on the different sizes of areas to be surveyed, the parameters of transect spacing and number of lines may need to be adjusted, provided precision and objectives of the survey are met. The spacing of lines may need to be greater than 2000 m in order to cover large areas in one day. Alternatively, spacing may be reduced to maintain sample size in small areas. If a single day's survey cannot achieve the desired precision we recommend covering the whole area in repeated surveys, allowing the mean population size to be estimated to whatever precision is required.

Additional information of movements of birds between survey days would also aid design of future surveys. Consideration should also be given to the sub-sampling methodology outlined above (Fig 4.2) based on balance of costs of flight with precision needs of the survey. For larger areas, if image processing is costly relative to aircraft time then we recommend flying more lines, and creating a post-flight subsample within strips (Fig. 4.1). However if aircraft time is more costly, then one should sample wider transect strips to increase precision.

Survey parameters also need to be tailored to the species surveyed; for species occurring in clusters, increasing the number of lines will give a greater chance of hitting a cluster of birds, hence reducing variance in the estimate.

Why not simply survey in piecemeal fashion, splitting the region up?

If an area cannot be covered in a single day, a temptation arises to survey neighbouring sub-areas several days apart, depending on weather conditions. For calculation of population estimates, this should not be done. Estimates from different sub-areas surveyed on different occasions should not be summed together, even if the gaps between surveys are anything up to weeks apart, due to local bird movements and/or seasonal migration. For instance, a lower estimate in one area than another could simply reflect birds moving between locations. If covered in piecemeal fashion, it is not possible to later assess the effect of windfarms using population estimates due to these confounding effects. If covering the whole area in one day does not give adequate precision, and repeat surveys cannot be undertaken due to the availability of resources, then a less preferred option is to survey sections on *consecutive* days to meet the desired level of precision, assuming distributions are more likely to be similar. However, this option is primarily not recommended.

Final considerations

These protocols are all highly interlinked, and adjustments should be carried out at the discretion of the contractor bearing in mind the need to maintain the precision requirements for the survey, whilst maximising efficiency, overcoming practical constraints and offsetting relative costs of survey time versus image interpretation.

Please refer back also to the addition recommendations made under points 4.3.2. a, b, c, and g.

4.3.3 Further Provisos

a. Species targeted. As alluded to above, different requirements will be needed for different species. Although strict guidelines are important for informing the forthcoming surveys ahead of round 3 developments, further data for new species, for instance on error in post-processing images, should be incorporated as and when it becomes available.

b. Observer training. Adequate time for training new observers should be allowed, for instance in operating equipment or in processing images, to achieve the required level of precision as specified above in “d”.

c. Marine mammals. Thus far, focus has been placed on examples using seabirds. However, marine mammals may also be surveyed using high definition imagery, in particular through video images from HiDef. There are some issues surrounding use of high definition imagery for marine mammals and diving seabirds such as auks and divers, as for both visual and digital surveys detection is <1. To account for this, the proportion of time spent on the sea surface could be measured and estimates corrected accordingly. However a further complication arises from the initial detection of these species, since within a pod of cetaceans (for instance), deeper animals may be noticed only when others are more visible in the image. While these may be detected through examination of a stored image, such individuals may be missed during conventional aerial surveys.

A final consideration is that *for Common Standards Monitoring and for Appropriate Assessments (for example, of Natura 2000 sites), a greater degree of accuracy may be need in species identification*, for instance splitting auks into guillemot, razorbill, and puffin. This will require development of technology and more assessment of whether survey height can also be lowered for specific species. The issue of whether flushing occurs on a species by species approach is relevant to mixed flocks where collective decisions are made by birds in the decision to flush.

At present, no particular high definition technology was found to be superior for sole use, thus further development by other organisations in the use of high definition equipment should be encouraged in accordance with minimum criteria supplied here. However, there is a case to be made for comparing the relative ability of video versus stills for particular species identification, as one method may give a more reliable assessment of a particular species for future targeted surveys.

5. Conclusions: Summary of Recommended Protocols

5.1 Technical

a. A current minimum flight height should be set as 450 m to avoid disturbance to birds, but this value could be lowered where increased resolution and species identification is required, and no disturbance is noted to species being surveyed.

b. The level of identification and observer error must be comparable between visual aerial surveys and high definition imagery to enable reliable comparisons, and standardised JNCC taxa groupings should be adhered to, including JNCC taxa groupings where species cannot be reliably determined.

c. A minimum resolution of 5 cm is suggested for all survey levels, with further increases encouraged so long as other minimum parameters are not jeopardised. However, if the level of species identification required by surveys (see above) can be shown to be made accurately at a resolution coarser than 5 cm, then such resolutions should also be permitted. A lower limit of transect width is recommended as 200 m, and should allow the identification of the same species or species groupings used as standard by JNCC.

d. Colour images should be used in all surveys.

e. For video methods a minimum of 5 images (suggested range 5-10) of a bird spanning 0.5 s is necessary for reliable identification.

f. Exposure should be optimised for specific species if conducting species-specific surveys, such as darker birds or gulls, with an acceptable exposure chosen for general characterisation surveys that maximises the number of species groupings obtained.

g. Use of automation should be encouraged but with consideration of costs incurred. However, manual inspection can still give reliable identification at adequate costs and speed, and should remain the default protocol with full quality control, until there is appropriate evidence that a species can be detected more reliably and at increased speed and efficiency under automation.

h. A slower speed of travel of aircraft can result in clearer images and should be given consideration, for instance where species-specific surveys are concerned, but typical speeds of *ca*. 220 – 350 km.hr^{-1} (*ca.* 120-190 knots) are suitable for a baseline parameter range. Speed, however, will be a trade off between reducing travel time and image resolution appropriate for species identification.

i. Advances in technology should be trialled, explored and incorporated where they do not compromise the above criteria and provide improvements in species recognition, and increasing diurnal survey time.

j. Avoid surveying in low cloud or adverse weather conditions of Beaufort force 4 or above in order that birds are not missed and that they are correctly identified. However, undertaking surveys in higher wind speeds should be permissible but only if it can be demonstrated that birds are not missed and that species identification is not adversely affected in these conditions with the technology being used. Clearly with all survey techniques there will be a maximum limit on the wind speed where these technologies can be used, however this is yet to be determined

k. Additional information on the sex and age of birds should be recorded where possible.

5.2. Survey Design and Analysis

Protocols on survey design depend on the objectives of the survey. In most cases, surveys are primarily undertaken in order to produce population estimates; a further aim may be to detect change, and this may be achieved either through a comparison of the population estimates (and their confidence limits) or by a statistical comparison of raw count data. Unless stated otherwise, the following recommendations assume that the surveys' main aim is to produce population estimates and that it is these estimates will be used for detecting change. It should also be remembered that the recommendations are strongly interlinked and should not considered in isolation.

a. The same survey methodology should be maintained between consecutive surveys if the survey has the same purpose as the previous one, or a before-after assessment is required. Different survey methodologies should only be used if statistical comparison can be made and there is no bias in survey estimates from either survey.

b. Pseudoreplication can be avoided through using the transect strip as the level of analysis.

c. Where raw data are used for comparison of numbers before and after wind farm construction, covariates should be used in analysis to increase the power of detecting change.

d. For BACI analyses (and the EIA surveys that often form their baseline) which use population estimates and confidence limits to detect change, there should be a general recommendation for being able to detect a certain level of change with a certain degree of accuracy. The power to detect change is not necessarily based on the percentage of the region covered and for larger survey regions, it is generally preferable to increase the number of samples (i.e. transect strips) rather than coverage *per se*. Detecting a halving or doubling of the population is suggested as a minimum benchmark for all surveys.

e. The number of transect strips used and their spacing are interconnected parameters that should reflect the level of precision required to meet the objectives of the study, whilst giving flexibility to contractors to design the survey around maximising efficiency and reducing costs. Following the recommendations for conventional surveys, a spacing of 2000 m and minimum of 20 transect lines is recommended as a starting point for designing digital surveys, provided this can be achieved in one survey flight.

However, the number of transect lines is of greater importance than spacing and, clearly, in certain circumstances it will not be possible to maintain a spacing of 2000 m and still survey the entire area in one flight or to maintain an acceptable number of transects. If the desired level of precision for the area surveyed can be achieved through strips separated by more than 2000 m, then such procedures should be taken. Likewise, for smaller regions, 20 transect lines may not be achievable unless spacing is reduced. However, provided that there is no risk of double counting or disturbing birds, this spacing could be lowered for high definition imagery surveys to meet the desired level of precision. We therefore suggest the spacing and number of transect strip parameters to be retained as flexible around the recommended minimum protocols, determined by survey practicalities, precision and survey objectives.

Decisions will ultimately also depend on costs. If image processing is costly relative to aircraft time then fly more flight lines and create a sub-sample within transect strips; if aircraft time is more costly, then sample wider spaced transect strips, whilst adhering to the desired level of precision.

Transect strips should be perpendicular to the coast or an environmental gradient to reduce heterogeneity of counts within strips.

f. Whenever possible, *the whole study area should to be covered in one single day*. Population estimates from different sub-areas surveyed on different occasions should not be summed together, even if the gaps between surveys are anything up to weeks apart, due to local bird movements and/or seasonal migration. If one day of effort does not give the recommended level of precision then conduct repeat surveys of the entire survey region over different days to allow the appropriate precision to be obtained, and better estimation of actual numbers, distributions, and peak and mean population estimates.

   If covering the whole area in one day does not give adequate precision, and repeat surveys cannot be undertaken due to the availability of resources, then a less preferred option is to survey sections on *consecutive* days to meet the desired level of precision, assuming distributions are more likely to be similar. However, this option is primarily not recommended.

g. Two or more observers should assess images independently, but validation must also be carried out by an independent consultant or expert providing a minimum of 90% quality control. We also recommend producing a dissimilarity matrix of identification across species, to help assess the level of error surrounding identification of particular species and confusion between similar species pairs.

5.3. Further Provisos

a. Additional consideration should be given to the species being targeted and, where possible, an a priori knowledge of populations and distributions from previous surveys should be used. If the species has clumped distribution, then consider prioritising increasing the number of transect strips, or sub-sampling within each transect strip to meet the desired precision of the survey.
b. Adequate training should also be allowed for new observers processing images to achieve the required level of precision as specified in "Survey Design and Analysis d".
c. Correction of time spent at the sea surface within video images is needed for surveying marine mammals, and caution should be placed in fully using high definition imagery for mammals and diving seabirds until more work is undertaken.

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Appendix 1

JNCC species and taxa grouping levels of seabirds from boat surveys

Code	JNCC Species Grouping
20	RED-THROATED DIVER
30	BLACK-THROATED DIVER
40	GREAT NORTHERN DIVER
50	WHITE-BILLED DIVER
90	GREAT CRESTED GREBE
100	RED-NECKED GREBE
110	SLAVONIAN GREBE
120	BLACK-NECKED GREBE
220	FULMAR
260	SOFT-PLUMAGED PETREL SP.
360	CORY'S SHEARWATER
400	GREAT SHEARWATER
430	SOOTY SHEARWATER
460	MANX SHEARWATER
462	BALEARIC SHEARWATER
480	LITTLE SHEARWATER
500	WILSON'S PETREL
520	STORM PETREL
550	LEACH'S PETREL
710	GANNET
720	CORMORANT
800	SHAG
2040	SCAUP
2060	COMMON EIDER
2120	LONG-TAILED DUCK
2130	COMMON SCOTER
2140	SURF SCOTER
2150	VELVET SCOTER
2180	GOLDENEYE
2210	RED-BREASTED MERGANSER
2230	GOOSANDER
5640	RED-NECKED PHARALOPE
5650	GREY PHARALOPE
5660	POMARINE SKUA
5670	ARCTIC SKUA
5680	LONG-TAILED SKUA
5690	GREAT SKUA
5750	MEDITERRANEAN GULL
5780	LITTLE GULL
5790	SABINE'S GULL
5820	BLACK-HEADED GULL
5880	RING-BILLED GULL
5900	COMMON GULL
5910	LESSER BLACK-BACKED GULL
5911	Larus f. fuscus
5912	Larus fuscus graellsii
5920	HERRING GULL
5921	Larus a. argentatus
5922	YELLOW-LEGGED HERRING GULL
5980	ICELAND GULL

Code	JNCC Species Grouping
5990	GLAUCOUS GULL
5991	GLAUCOUS / HERRING HYBRID
6000	GREAT BLACK-BACKED GULL
6010	ROSS' GULL
6020	KITTIWAKE
6040	IVORY GULL
6110	SANDWICH TERN
6140	ROSEATE TERN
6150	COMMON TERN
6160	ARCTIC TERN
6240	LITTLE TERN
6270	BLACK TERN
6340	GUILLEMOT
6341	Uria a. aalge
6342	Uria aalge albionis
6350	BRUNNICH'S GUILLEMOT
6360	RAZORBILL
6380	BLACK GUILLEMOT
6470	LITTLE AUK
6540	PUFFIN
90000	NO BIRDS
94002	WHITE-WINGED GULL SP.
94003	SMALL GULL SP.
94004	GLAUCOUS / ICELAND GULL
94006	COMMON / HERRING GULL
94007	COMMON GULL / KITTIWAKE
94008	PUFFIN / LITTLE AUK
95003	DIVER SP
95004	GREBE SP.
95006	SHEARWATER SP.
95007	CORY'S / GREAT SHEARWATER
95008	PETREL SP.
95009	SHAG / CORMORANT
95016	DUCK SP.
95017	DIVING DUCK SP.
95018	SCOTER SP.
95019	AYTHA SP.
95030	PHARALOPE SP.
95031	SKUA SP.
95032	SMALL SKUA SP.
95033	GULL SP.
95034	LARGE GULL SP.
95035	BLACK-BACKED GULL SP.
95036	HERRING / LESSER B-B GULL SP.
95037	TERN SP.
95038	COMMIC TERN
95040	AUK SP.
95041	GUILLEMOT / RAZORBILL
95042	G'MOT / BRUNNICH'S G'MOT

Appendix 1 cont...

JNCC species and taxa grouping levels of mammals from boat surveys

Code	JNCC Species Grouping	Code	JNCC Species Grouping
50000	TURTLE SP.	80130	BLUE / FIN / SEI WHALE
50010	HARD-SHELLED TURTLE SP.	80140	MINKE / BOTTLE-NOSED WHALE
51010	LEATHERY TURTLE	80200	MEDIUM WHALE SP.
51020	LOGGERHEAD TURTLE	80210	BEAKED WHALE
51030	HAWKSBILL TURTLE	80220	PILOT / FALSE KILLER WHALE
51040	GREEN TURTLE	80230	LARGE FINNED WHALE SP.
51050	KEMP'S RIDLEY TURTLE	80300	SMALL WHALE SP.
51060	OLIVE RIDLEY TURTLE	80320	PATTERNED DOLPHIN SP.
51070	FLATBACK TURTLE	80330	LAGENORHYNCH. DOLPHIN SP.
60010	MACKEREL SHARK	80340	COMMON / EUPHROSYNE DOLPHIN
61010	PORBEAGLE	80350	COMM/EUPHRO/WHITE-S DOLPHIN
61020	MAKO SHARK	80360	UNPATTERNED DOLPHIN SP.
61030	BASKING SHARK	81000	WHALE SP.
61040	THRESHER SHARK	81010	RIGHT WHALE
61050	BLUE SHARK	81030	HUMPBACK WHALE
61060	TOPE	81040	FIN WHALE
61070	GREENLAND SHARK	81050	MINKE WHALE
62000	SUNFISH	81060	BLUE WHALE
63000	FISH BALL	81070	SEI WHALE
63010	SANDEEL BALL	81110	SPERM WHALE
63020	CLUPEID BALL	81120	PYGMY SPERM WHALE
70000	SEAL SP.	81130	NORTHERN BOTTLE-NOSED WHALE
70010	GREY SEAL	81140	CUVIER'S WHALE
70020	COMMON SEAL	81150	SOWERBY'S WHALE
70030	HOODED SEAL	81160	TRUE'S BEAKED WHALE
70040	BEARDED SEAL	81190	PILOT WHALE
70050	RINGED SEAL	81220	KILLER WHALE
70060	HARP SEAL	81230	FALSE KILLER WHALE
70070	WALRUS	82000	DOLPHIN SP.
71000	SMALL SEAL SP.	82310	RISSO'S DOLPHIN
80000	CETACEAN SP.	82410	HARBOUR PORPOISE
80100	LARGE WHALE SP.	82510	BOTTLENOSE DOLPHIN
80110	INDISTINCT DORSAL FINNED WHALE	82520	WHITE-BEAKED DOLPHIN
80120	DISTINCT DORSAL FINNED WHALE	82530	WHITE-SIDED DOLPHIN
		82540	COMMON DOLPHIN
		82550	EUPHROSYNE DOLPHIN

Notes on species excluded or included in specific taxa-level groupings:

94002: Glaucous, Iceland or Mediterranean Gull, 94003: Common, Black-headed, Mediterranean, and Little Gull, plus Kittiwake, 95003: All Gaviidae, 95004: All Podicepididae, 95006: All Puffinus, Calonectris etc., 95008: All Storm Petrels, 95016: All Anatidae, 95017: Aythya, Eiders, Melanitta, Goldeneyes, Long-tailed Duck, Mergansers, 95032: Not Great Skua, 95033: All Gulls including Kittiwake, 95034: Lesser Black-backed, Yellow-legged, Herring, Great Black-backed, Glaucous, and Iceland Gull, 95035: Lesser Black-backed or Great Black-backed Gulls; 95037: All Sternidae, 95038: Common or Arctic Tern, 95040: All Auks including Black Guillemot, 95042: Common or Brunnich's Guillemot

50000: All turtle species, 50010: All turtle species except Leathery, 60010: All surface-dwelling sharks, 70000: All phocids, 71000: All phocids except Walrus and Elephant Seal, 80000: All cetaceans, 80100: All whales except Minke and Beaked whales, 80110: All whales with indistinct dorsal fin (e.g. Humpback, Right, Grey, Bowhead Whales), 80120: All whales with distinct dorsal fin (e.g. Minke, Beaked Whales, Fin, Sei and Blue Whales), 80200: Beaked and Minke Whales, 80210: Beaked Whales only, 80230: Killer, False Killer Whales, 80300: such as Pilot, Killer and False Killer Whales, 80320: Any dolphin with a distinct pattern (i.e. not Bottlenose or Spotted Dolphins), 80330: White-beaked or White-sided Dolphin, 80360: Bottlenose, Spotted Dolphin etc., 81000: Any non-dolphin species.