Approaches to marine mammal monitoring at marine renewable energy developments

Final Report

Project Name:	Approaches to marine mammal monitoring at marine renewable energy developments
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Date:	Wednesday, 11 August 2010	

Table of acronyms

Acrconym	Description
AA	Absolute Abundance
AAM	Autonomous Acoustic Monitoring
AOC	Air Operators Certificate
ARC	Atlantic Research Coalition
BACI	Before-After-Control-Impact
CAA	Civil Aviation Authority
CI	Confidence Interval
CODA	Cetacean Offshore Distribution and Abundance in the North Sea
CRRU	Cetacean Research and Rescue UnitCVCoefficient of Variation
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DP	Double Platform
DP LT	Double Platform Line Transect
EAR	Ecological Acoustic Recorder
ECS	European Cetacean Society
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EPS	European Protected Species
ESAS	European Seabirds at Sea
FCS	Favourable Conservation Status
GAM	Generalised Additive Model
GIS	Geographical Information System
GLM	Generalised Linear Model
GPS	Global Positioning System
GSM	Global System for Mobile communications
HD	High Definition
HR	Habitat Regulations
IFAW	International Fund for Animal Welfare
JCD	Joint Cetacean Database
JNCC	Joint Nature Conservation Committee
LT	Line Transect
MCA	Maritime and Coastguard Agency
MMO	Marine Mammal Observer
MSFD	Marine Strategy Framework Directive
NERC	Natural Environment Research Council
NMEA	National Marine Electronics Association
OMR	Offshore Marine Regulations
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAM	Passive Acoustic Monitoring
PBR	Potential Biological Removal
PCAD	Population Consequences of Acoustic DisturbancePhoto-IDPhoto-Identification
POD	POrpoise Detector
PoOP	Platform of Opportunity
R3	Round 3
RA	Relative Abundance
RhIB	Rigid hulled Inflatable Boat
RSPB	The Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SAMS	Scottish Association for Marine Sciences
SAST	Seabirds At Sea Team
SCANS and SCANS-II	Small Cetacean Abundance in the North Sea and Adjacent Waters
SCOS	Special Committee on Seals
SLR	Single-Lens Reflex
SMRU	Sea Mammal Research Unit
SP	Single Platform
SP LT	Single Platform Line Transect
SPA	Special Protected Area
SRDL	Satellite Relay Data Logger
UAS	Unmanned Aerial Systems
UKMMAS	UK Marine Monitoring and Surveillance Strategy
VHF	Very High Frequency
WDCS	Whale and Dolphin Conservation Society

Definitions of technical terms

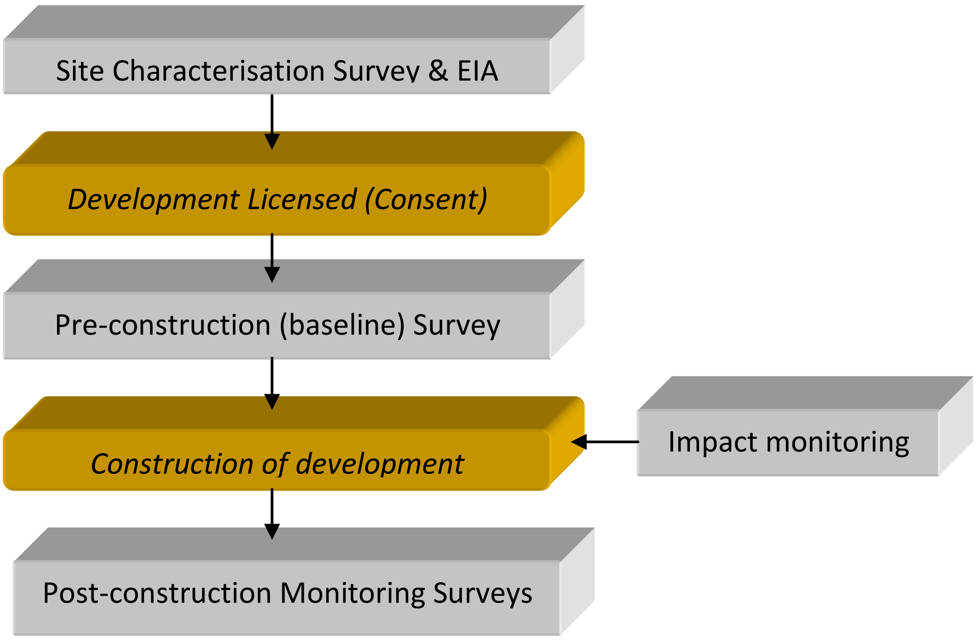
Biological significance: An effect that may change a population trajectory or the structure and function of an ecological system.

Characterisation : A process, usually involving data collection, to provide an assessment of the major ecological features of a location of defined region, including documentation of those features that that are defined as protected under current legislation, or that may require protection.

Developer: Any commercial or non-commercial body that is applying to construct a marine renewable energy device, system, array or complex (inclusive of supporting infrastructure) on the sea bed or on the water column.

Effect: An impact (but not necessarily with negative outcomes) on the individuals, species or ecological systems involved.

Environmental assessment: The following diagram shows the structure of an environmental assessment as referred to in the present report, together with some of the terms used within the document:



Impact: Impacts are the responses of individual animals, species or ecological systems to human disturbance. An impact is often viewed as a negative effect.

Industry: The collective commercial developers involved in the installation of renewable energy capacity, including The Crown Estate.

Marine mammals: These include all seals, whale, dolphins and porpoises. Seals are also known as pinnipeds and whales, dolphins and porpoises as cetaceans.

Monitoring: Measurement of the variation in a pre-defined environmental feature, or variable, especially through time but also spatially in some cases. Monitoring is usually considered as operational measurement to provide information that assist with decision-making.

Regulator: A Government body (e.g. Marine Scotland, Defra) that has the responsibility under legislation to issue licences for offshore renewable energy developments. The Regulator also ensures that are appropriate controls by placing conditions on the licence and by undertaking appropriate inspection to ensure compliance.

Scientific Advisers: In general, scientific Advisers are practicing scientists who have specialist knowledge of particular fields of science. They are usually employed by Government (e.g. Marine Scotland) but may also be independent of Government and can be drawn from the Research Councils (e.g. NERC) or academia. NERC has a formal role as a scientific Adviser on the management of seal populations and this function is devolved to SMRU at the University of St Andrews. *De facto*, this role for SMRU also often extends to cetaceans.

Statistical power: The ability to detect an effect from data collected when it is present. Low statistical power can lead to the belief that there is no effect even when there is an effect which could be significant. Low statistical power can also lead to detection of an apparent effect but without the ability to determine whether this was caused by chance variation in the data.

Statutory Consultees: Also known as Statutory Nature Conservation Agencies (SNCAs), these are bodies that can include SNH, CCW, Natural England and JNCC, as well a local authorities whom the Regulator must consult about a development and who are often specialists in particular areas of the statutory requirements.

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1 Executive Summary

This report seeks to address the issues around marine mammal environmental compliance and provide options for the development of a consistent UK-wide strategic approach to marine mammal monitoring. The focus of this study is on assisting developers to meet their consenting requirements. The report assessed (1) the data required in order to assess the risks to sensitive and legally-protected species from construction, (2) the relative costs of different technical solutions, and (3) examples of how approaches might be applied based upon a number of scenarios.

The report distinguishes between two different groups of measurements that may be required. One of these, called characterisation, provides basic information about the ecological features within a region, especially those that might have specific protection under current legislation. The other, known as impact monitoring, involves measuring the effects that the disturbance due to the development is having and takes place coincident with different phases of the development. Both are essential components because the first defines the ecological value whereas the second provides information about how this is being changed as a result of the development. Nevertheless, there are difficulties defining to what extent disturbance should be allowed; clearly no disturbance is impractical but the main issue is what methods can be used to define damaging (or significant) levels of disturbance. The report raises the issue of Potential Biological Removal (PBR) as a possible mechanism. While this remains an issue for fundamental research there is a very real practical need to build a mechanism for providing clear, concise and biologically-defensible advice to Regulators about the levels of disturbance that are likely to be sustainable. The onus is upon the Scientific Advisers to provide this advice.

In general, data that characterise the likely regions for offshore energy development are available from recent and ongoing research. However, these are generally collected at spatial and temporal scales that are much greater than are likely to be needed. It is almost certain that some form of measurement of population trends of the more abundant and sensitive species (it would be impossible with the rarer species) will be required if there is to be effective measurement of impacts.

Detailed methods have been developed to characterise marine mammal populations and these could be adapted to allow measurements at the spatial and temporal scales required for impact monitoring. However, the power to detect changes in population trends that could be significant is usually very low. There tends to be a direct relationship between statistical power and the amount of data collected. Even very significant changes in abundance are difficult to detect reliably without considerable effort and cost. Emerging technologies may provide partial solutions to this but these are mostly still at the early stages of being tested and many, such as HD photography, have significant potential difficulties attached to them and need rigorous testing.

Overall, aerial surveys are more cost-effective than ship-based surveys but aerial surveys may not be appropriate in all situations. It appears to be wise to design surveys for particular regions specifically to suit the problems associated with each region. This could include the expected type of sensitive species to be detected, exposure, distance from land,

and whether it is necessary to measure relative versus absolute abundance to detect trends. Because of the many different variables that have to be taken in to consideration, it was difficult within this report to provide a template for survey design. We recommend that the design of monitoring procedures should be bespoke for each situation but that there should be open consultation on these designs before they are implemented.

Given the general difficulties there are with providing the kind of information needed by Regulators to ensure that developments in marine renewable energy are legally compliant, we recommend a licensing procedure that initially includes precautionary assumptions within the licensing conditions. These conditions may then be relaxed if and when evidence is provided that disproves the precautionary assumptions.

Given the scales of offshore renewable energy development envisaged together with the predicted spatial extent of some impacts, there is the potential for a strong interaction between adjacent developments. This means that the activities of individual developers cannot be seen in isolation and some level of co-design of marine mammal monitoring, including implementation, needs to be considered. Such co-design has further advantages in that this could occur at scales that have better congruence with the natural spatial distribution of marine mammal populations and also with current data resources, as well as the current methods that are available for determining distribution and abundance. If this is to be implemented most effectively it will require a radical change in the current vision, on the part of both Regulators and Developers, for compliance monitoring of marine mammals around renewable energy developments with a move towards an increase in the spatial scales for monitoring to cover large sections of the UK regional seas.

2 Introduction

2.1 Preamble

This scoping study seeks to address the issues around marine mammal environmental compliance and provide options for the development of a consistent UK-wide strategic approach to environmental monitoring. The study includes generic recommendations for approaches to marine mammal monitoring for offshore wind and other marine renewable energy, defined in the present report as wave or tidal energy.

The initial objective of the study undertaken by SMRU Ltd, and reflected in this report, was to attempt to bring greater clarity to the problem of ensuring that Developers of offshore renewable energy knew what was expected of them by Regulators. Up to a point the report has achieved those objectives but probably falls short of the original intention – which was to solve the problem. The reason for this is mainly because all those involved are faced with an extraordinarily difficult problem for which there may be no clear solution. This problem is that, on the one hand, Regulators cannot provide clear guidance about the limits to environmental disturbance that can be tolerated as a result of marine renewable energy developments while, on the other hand, Developers need to know these limits in order to design the developments and constrain their financial risk. The scientific community is also unable to close the gap between these two positions by providing the essential information needed on both sides.

In advance of publication of this report, The Crown Estate chose to circulate the draft text to Regulators, industry and some other stakeholders. This produced comments about the report and most of these have been responded to by changing the body of the text or through additional work. This work was carried out by Ian Boyd on behalf of both The Crown Estate and SMRU Ltd and was done under his role as Director of SMRU, which is one of the Scientific Advisers to Government about the management of marine mammals. This section, the Executive Summary, Research Recommendations and some other significant parts of the text have been produced following comments from those who are most likely to use this document.

Perhaps the largest single change made to the report during revision, which was partly a response to the comments made by the stakeholders but has mainly emerged by synthesising across all the information within the report, was to recommend a fundamental shift in the approach taken to measuring the effects of offshore developments upon marine mammals. This change is now reflected in the Executive Summary, Research Recommendations and the Conclusions of the report. It involves the need to undertake monitoring in a co-ordinated fashion over the whole of the UK regional seas that are affected by renewable energy developments. This emerges from an appreciation built from the report that the success of compliance monitoring for marine mammals depends upon several critical factors:

1. Monitoring needs to take place at spatial scales that are appropriate to the biological problems. This means that for large mobile species like marine mammals monitoring must take place over very large spatial scales. Without doubt the areas covered by

the leases held by individual developers are probably, even in the case of the largest areas involved, at least an order of magnitude too small to be effective in this respect. What is clear from this report and the comments from stakeholders is that the effects of adjacent developments may overlap and area-wide, large-scale monitoring may be the only feasible way to detect and manage cumulative impacts.

2. Current data resources are actually already collected at these larger scales (e.g. SCOS and SCANS data) and the designs of these monitoring activities has evolved in this way for exactly these reasons, i.e. it makes little sense in many cases to monitor at smaller scales. However, this also means that current data resources (for both seals and cetaceans) become much more useful to Regulators and Developers for establishing the effects of offshore renewable energy development.
3. Such a shift in thinking also brings the monitoring of renewable energy development in to line with the scales of management defined by legislation (the system of SACs and EPSs) and with the definitions of Biological Significance that are likely to emerge as research improves our knowledge of marine mammal populations.
4. This approach also makes the assessment of the limits to disturbance of marine mammals by renewable energy development much more feasible. If information is being collected at the spatial scales that reflect the natural meta-population structure then there will be greater biological realism embedded in these estimates. How licences for disturbance are then allocated by Regulators to Developers is then a matter for negotiation but is not a question that needs further information about the populations themselves.
5. This approach lends a strong dose of feasibility to an otherwise increasingly unworkable set of scenarios. It allows renewable energy developments to combine resources across the full range of wind, tidal and wave power sectors. The unfeasibility of alternatives is particularly the case when the financial implications of marine mammal monitoring are considered, because if we were to truly deliver what the Regulators appear to be asking for the costs would be astronomical and would probably render most renewable energy developments commercially insolvent. We need to take a major step away from this approach. The approach suggested here will not be cheap but it will probably be considerably (perhaps many times) less expensive than the alternative, fragmented, expensive, inefficient approach to compliance monitoring and data delivery.
6. A major question, however, is whether the Industry has the capacity to self-organise to the extent that it can pool its resources and set aside commercial competitiveness to find the most advantageous route through the Regulator's needs, to meet this common goal. There is probably a role for The Regulators and The Crown Estate in addressing this issue.

In their reviews of the draft document, the stakeholders presented a number of issues that could not be dealt with by appropriate editing or additional work. These can be summarised as follows:

1. <u>Many saw a need for the report to provide more specific examples so that Developers could have a template to follow</u>. For example, some were very focussed upon the immediate problems faced in specific zones/with specific projects. While it is easily understood why this has been requested, reading this report will provide a

rapid sense of how technical this field is. The number of parameters required to be taken into consideration when designing compliance monitoring for offshore development is so large that providing templates or closely worked examples is simply impractical. Each offshore development will require to have its monitoring activities individually designed taking account of constraints associated with the level of background information available, the design and purpose of the offshore development, location relative to access and exposure, and the set of marine mammal species considered to be of greatest significance to the Regulator.

2. Some of those who commented were very focussed upon offshore wind. It was clear, for example, that the wind farm Developers saw some of the text relating to methods that might be applied to wave and tidal devices as of little relevance to them and they questioned why that text were present within the report. However, the report attempts to cover wave, tidal and wind. This was reflected particularly in some of the comments about the analysis of the cost-benefit trade-offs associated with different survey options. The analyses provided were very general in their intent and were designed only to provide a guide as to the costs involved. Clearly, individual Developers would need to undertake similar analyses should they wish to understand the cost-benefit tradeoffs of different specific options in each specific case.
3. Some saw high definition (HD) photography as a method that could be exploited more fully for marine mammal monitoring than has been the case and the examples from apparent successful use in seabird surveys have been used to provide impetus to this suggestion. Developers are particularly keen to see this being developed because it promises to reduce costs. Nevertheless, there were strongly polarised views about this, and comments from individuals who are experienced in this field suggest that this is not currently a useful method for marine mammals and, at least, needs to be approached with more care than might be suggested by some of the Developers. One Developer commented that it "must" be an improvement on boat based surveys – this is not necessarily the case and further work is required.
4. There was an understandable wish from Developers for more clarity on whether surveys for birds and marine mammals could be combined. In general, one would wish to design surveys around the variable being measured that has the highest variance so as to constrain this variance as much as possible. The report has been modified slightly to reflect this need. Unfortunately, the current approaches appear generally to involve adding marine mammal surveys to those that have been optimised for seabirds (e.g. see discussion above about using HD photography). This approach to the problem is incorrect if the variance around seabird surveys is lower than the variance around marine mammal surveys, which is almost certainly the case.
5. There was a tendency to view some problems from a slightly unrealistic perspective. This is evident in three different ways:
    a. Although it is recognised that there is a need to simplify and focus upon the main issues, the wish from many (both Statutory Advisers and Industry) to find simple solutions – for example by carrying out collision risk or habitat modelling (presumably with no new data!) – could waste a lot of time and resources needlessly.

b. There is a need to think carefully before acting because the costs of not doing so are more serious in terms of tying up scarce expertise in these areas of work on needless activity than they are in terms of their financial cost. For example, a potential conclusion from this report is that carrying out marine mammal surveys to detect trends in absolute abundance around renewable energy development is a hopeless pursuit because these surveys are unlikely to provide the statistical power required to detect population change let alone sufficient information to provide an assurance that any change has been caused by the renewable energy development. Surveying marine mammals may only serve to satisfy the Regulators that as much as possible is being done to detect population changes even if they are very unlikely to detect those changes in the time scales required in order to be useful for making decisions.
c. Regulators probably need to begin thinking in terms of using simple indicators of compliance that represent variables that can be easily and cheaply measured, even if they may be rather poor indicators of the actual effects of renewable energy developments upon marine mammals. The Scientific Advisers need to support the development of these indicators. A disadvantage of such indicators will be, inevitably, that they will not always lead to the correct decisions being made by Regulators and, if this results in the assumptions made by the Regulators being very precautionary, this may mean that some Developers will incur high costs for no good reason. Nevertheless, the advantage of using these types of indicators is that the probability of the Regulators making the wrong decision can be modelled in advance and the possibility of incurring high financial costs (through delay, additional survey work or complete withdrawal of a licence) will be more transparent, thus making the financial risks easier to predict.

2.2 Objectives

The study had three objectives:

1. Assess the data required to enable Regulators to issue an informed, risk-based consent in advance of construction;
    - Relevant legislation and regulatory requirements
    - Requirements pre- and post-consent
2. Identify the most cost efficient methods of data collection, without compromising the quality of the data;
    - Scoping: is further data collection needed?
    - Established methods for monitoring marine mammals
    - Choosing the appropriate method for monitoring:
        - Power analysis
        - Cost-benefit analysis
3. Propose and agree the most appropriate marine mammal survey methods for a variety of generic scenarios.

The focus in this scoping study was on assisting Developers to meet their consenting requirements. Specifically, this report will provide Developers with options for the methods they may require to monitor marine mammal populations. The data collected will be necessary to carry out informed risk assessments; however it is not within the scope of this study to provide the tools for such assessments. In addition, we note that the establishment of long-term surveillance regimes to monitor Favourable Conservation Status of marine mammals is the Regulators' responsibility and is out with the scope of this study. Our report will therefore include some discussion about Regulator responsibilities, but the goal of this study is not to provide a detailed outline of how these responsibilities should be met.

3 Objective 1: Assessing the level of detail required for consent decisions

Summary

- European and UK legislation provide a clear impetus through the Habitats Directive, Habitats Regulations and Offshore Marine Habitats Regulations for characterisation surveys and impact monitoring of marine mammals.
- For Developers, requirements differ for European Protected Species and those listed as Annex II species; the former probably requiring an EPS licence and an assessment of likely disturbance or injury, the latter requiring the more rigorous Appropriate Assessment and test of likely significance.
- Monitoring can be split into characterisation surveys and impact monitoring
- Population trends need to be measured as part of the assessment of Favourable Conservation Status and is therefore of concern to the Regulators of marine renewable energy developments.
- The significance of impacts of marine renewable energy projects on marine mammal populations will need to be assessed separately.
- Options for monitoring to detect effects include collecting data throughout all phases of the development to examine trends or to test for statistically significant differences between consecutive surveys.
- Monitoring can have an important the design and implementation of mitigation plans and monitoring will assess the effectiveness of those plans. Monitoring programmes can provide Developers with data about the level of disturbance to marine mammals at the site and about the numbers displaced. Nevertheless, monitoring for effects and the effectiveness of mitigation will always be subject to uncertainties caused by other stressors on marine mammals that are unrelated to renewable energy developments.

3.1 Legislation

The most important wildlife legislation affecting Regulators of offshore wind and the marine renewable energy industry is the European Habitats Directive. All cetacean species are European Protected Species (EPS) listed in Annex IV of the Directive and, Under Article 12, member states are required to take the requisite measures to establish a system of strict protection for species in their natural range prohibiting (a) all forms of deliberate capture or killing of specimens of these species in the wild, (b) deliberate disturbance of these species, particularly during the period of breeding, rearing, hibernation and migration and (c) deterioration or destruction of breeding sites or resting places.

For Annex II species, which include the harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus),* grey seal (*Halichoerus grypus)* and harbour seal (*Phoca vitulina*), Member States are required to designate Special Areas of Conservation (SACs) in order for their habitats to be maintained or, where appropriate, restored at a favourable conservation status in their natural range. To date, both species of seal are qualifying features at several designated SACs; twelve for grey seals and eleven for harbour seals. The bottlenose dolphin is a qualifying feature of three sites; the Moray Firth, Cardigan Bay and the Llyn Peninsula. Data on harbour porpoise are under review and there are no sites currently designated in UK waters for this species. Consideration also needs to be given to instances where SACs span the jurisdictions of Member States, or where activities within one jurisdiction are likely to affect an SAC within the jurisdiction of another Member State.

EU Member States are also required to undertake surveillance of the conservation status of species referred to in the Annexes of the Habitats Directive, which includes all cetaceans and seals in UK waters.

The Habitats Directive has been transposed into the law of England, Wales and Scotland by the Conservation (Natural Habitats &c.) Regulations 2010 for inshore waters of England and Wales and in Northern Ireland by the Conservation (Natural Habitats &c.) Regulations 1995 (as amended); these are referred to as Habitat Regulations (HR). Additionally, the Habitats Directive has been transposed into UK law for all offshore activities in the Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2010 for UK offshore waters (including off Scotland). The OMR cover marine areas within UK jurisdiction, beyond 12 nautical miles.

In the context of offshore wind and marine renewable energy in territorial waters of England and Wales and UK offshore waters, the potential for an offence arises under the HR and OMR which prohibit:

- The deliberate capture, injury, killing or disturbance of any wild animal of a European protected species (EPS).

Under The Conservation (Natural Habitats, &c.) Amendment (Scotland) Regulations 2007, there is a slightly different and expanded wording for Scottish territorial waters. Specifically, it becomes an offence to deliberately or recklessly disturb. These regulations are given in detail in Text-box 1.

Text-box 1

The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended)
Protection of certain wild animals

39.—*(1) It is an offence–*

(a) deliberately or recklessly to capture, injure or kill a wild animal of a European protected species;

(b) deliberately or recklessly–

(i) to harass a wild animal or group of wild animals of a European protected species;

(ii) to disturb such an animal while it is occupying a structure or place which it uses for shelter or protection;

(iii) to disturb such an animal while it is rearing or otherwise caring for its young;

(iv) to obstruct access to a breeding site or resting place of such an animal, or otherwise to deny the animal use of the breeding site or resting place;

(v) to disturb such an animal in a manner that is, or in circumstances which are, likely to significantly affect the local distribution or abundance of the species to which it belongs;

(vi) disturb such an animal in a manner that is, or in circumstances which are, likely to impair its ability to survive, breed or reproduce, or rear or otherwise care for its young; or

(vii) to disturb such an animal while it is migrating or hibernating;

(c) deliberately or recklessly to take or destroy the eggs of such an animal; or

(d) to damage or destroy a breeding site or resting place of such an animal.

(2) Subject to the provisions of this Part, it is an offence to deliberately or recklessly disturb any dolphin, porpoise or whale (cetacean).

Furthermore, in relation to marine SACs designated under the Habitats Directive, it is stipulated in the Nature Conservation Guidance on offshore wind farm development produced by DEFRA (2005) that "where a Special Protected Area (SPA) is involved, either directly or indirectly, and it cannot be concluded that there will not be an impact (i.e. where it is uncertain whether an impact will occur or not), it should be assumed that there will be an impact (Precautionary Principle). If there are insufficient data to identify whether an impact is likely or not, it will be necessary to collect additional data through the use of surveys, thus a lack of data is not sufficient justification for concluding that there will not be an impact where there is an SAC designated at or near the location or whether there are any marine mammals in the area. If the desk study highlights that certain species may be present in an area in significant numbers there can be a presumption that it is likely that an impact will occur (Precautionary Approach). It is then necessary to *consider* whether the impact is significant".

These conditions are very challenging for mobile species like marine mammals and, if applied in a truly precautionary manner would lead to no licensing of offshore development or activity of any sort (let alone renewable energy). In essence, any activity within the North Sea, for example, could have an effect upon SACs for marine mammals within the North Sea (and in some cases beyond the North Sea) even though these SACs are themselves very small (e.g. an island that is a breeding colony for seals). However, in practice, the capacity to link the effects of an activity at a location remote from an SAC to changes in the favourable conservation status of the species within the SAC is very limited. Simple, univariate cause and effect relationships between an activity and a change in the abundance of a marine mammal are often difficult to establish at whole population scales let alone at the scales of SACs unless there is direct evidence of the number of deaths caused by a particular activity, such as could be the case with fisheries by-catch. The impacts of marine renewable energy would probably need to be very obvious, in terms of deaths or injuries to marine mammals, before there could be a case for constraining the development or operation of marine renewable energy on the basis of this affecting the good environmental status of and SAC. This is because there are few other situations in which the additional data collection required under the guidance from DEFRA would have sufficient statistical power to demonstrate an effect.

3.2 Regulatory requirements[1]

Using the legislation as outlined above, it is possible to summarise the questions that Regulators would need Developers to answer in advance of consenting a particular development.

1. For European Protected Species (all cetaceans in UK waters), construction of a wind farm (using foundation methods such as pile driving) or the deployment of wave and tidal devices, are likely to require an EPS licence since (1) the local abundance and distribution of certain species could be significantly affected by the noise produced or by creation of a barrier to natural movement, or (2) an EPS could be injured or killed (see the relevant regulations for England, Wales, Scotland and the UK offshore marine area).
    a. As part of the Environmental Impact Assessment (EIA) the **Developer** will need to assess the likelihood of a disturbance or an injury offence (guidance for the waters of England, Wales and the UK offshore marine area is provided in the JNCC draft guidance on the protection of EPS from injury and disturbance). There will also be a need to explain how the impacts associated with different developments, or other marine activities are likely to interact and whether they will be cumulative. In this case, Developers will need to be able to describe how their own activities interact with those of other Developers.
    b. In order to issue licences, **Regulators** will need to determine whether there could be a risk of a significant negative impact on population levels and/or a significant reduction in natural range or habitat use in order to ensure that favourable conservation status (FCS) is maintained (FCS test).

[1] Regulatory requirements were provided to the Crown Estate (and copied to SMRU Ltd) via a joint letter of statement (dated 12 November 2009) from Joint Nature Conservation Committee (JNCC), Countryside Council for Wales (CCW), Natural England (NE) and Scottish Natural Heritage (SNH).

2. For SACs (bottlenose dolphin, common seal, grey seal), wind, tidal and wave developments have the potential to cause significant disturbance to the qualifying features (including species) and/or the deterioration of the habitat of the qualifying features (see European Commission guidance on "Managing Natura 2000 sites").

    a. As part of the EIA the **Developer** will need to provide the necessary information to allow an assessment by the competent authority (as specified by the Habitats Regulations) of whether the development is likely to have a significant effect (Test of Likely Significance) and, if so, whether the development will adversely affect site integrity with relation to the conservation objectives for the site (Appropriate Assessment). Developers will also need to consider cumulating impacts.

    b. The **Regulator** will undertake the Habitats Regulations Assessment comprising a test of likely significance and subsequently an appropriate assessment, should that be required. They will need to assess how much impact can be allowed before the possibility of an adverse effect can no longer be discounted. However, as described above, there are many questions around how this can be achieved for mobile species like marine mammals and there are still no clear objective guidelines about what the limits of impact should be.

3.3 Translating legislative requirements to guide data collection

Ultimately, the aim of pre- and post-consenting monitoring for offshore wind and marine renewable energy developments should be to ensure that regulatory requirements (as determined by relevant legislation) are met. There are three basic questions that need to be answered in order to design appropriate monitoring programmes:

1. What is the metric of interest?
2. What is the most cost-effective and practical way to obtain robust estimates of this metric?
3. What threshold in this metric would result in unacceptable risk?

In practice, the third of these is a consideration for the Regulators, rather than the Developers. For both EPS and SACs, the Developers will need instead to focus on:

1. Pre-consenting: **Local characterisation** (species presence, densities and habitat use). This information will be used to estimate the potential impact (numbers disturbed/displaced, numbers injured, reduction in densities; see JNCC Draft Guidance on the Protection of marine EPS).

2. Post consenting: **Impact monitoring**

    a) Wind (numbers displaced/injured, reduction in densities);

    b) Wave/tidal (numbers displaced/injured/killed, barrier effects).

Importantly, characterisation surveys may not be required in all cases. One role of detailed scoping studies (ahead of consenting) is to determine whether sufficient data already exist to characterise the site. In those cases where a scoping study identifies a lack of baseline data, the next step would be to design an appropriate monitoring programme to address this deficiency.

Characterisation surveys may take place well before construction actually begins. In this case, Developers would also need to carry out a shorter pre-construction survey to establish a baseline for impact monitoring. Such surveys would likely take place immediately before construction and over a timeframe of weeks, rather than months or years.

The focus of monitoring requirements for the Regulator will be based mainly on national strategies for long-term assessment of Favourable Conservation Status, although the international nature of offshore renewable energy developments will also require consideration of SACs that span multiple national jurisdictions. Similarly, it is also the responsibility of the Regulator to carry out an Appropriate Assessment (if required: for example if there is an SAC within or near the development site); but the Developer will need to provide sufficient information for this to occur as part of their Environmental Impact Assessment.

This distinction between the Developers and Regulators is important in terms of determining required levels of significance from monitoring. Specifically, the onus of defining and determining biologically significant changes in populations falls to the Regulators. In the case of the Developers, they need to demonstrate that the predictions made with regards to impacts were correct, which will require some level of statistical power and a measure of the uncertainty associated with the estimates. This becomes a question of resource availability: the smaller the expected change, the greater the effort required.

We therefore focus our efforts in the remainder of this study on determining the most practical and cost-effective monitoring options for Developers to use during characterisation (pre-consenting) surveys and impact (post-consenting) monitoring.

3.4 Monitoring for mitigation

The results of monitoring play a key role in the design and implementation of a mitigation plan; and continued monitoring will assess the effectiveness of that plan. At the consenting stage of a renewables development, monitoring surveys will provide spatial and temporal information for marine mammals within the licensed areas. These characterisation survey data would be used to predict likely impacts; but such information may also be used to design a seasonal programme of pile-driving (the activity likely to cause the greatest disturbance) that would avoid peak times and areas for marine mammals. Whilst this approach may be adequate for some areas, an alternative may be required for large developments where the installation period may be extended. In light of monitoring data and the characteristics of the proposed farm, alternative technologies or engineering solutions (such as the use of bubble curtains, gravity based foundations or floating platforms which could reduce noise disturbance; see Nehls *et al.* (2007) for a full review) may need to be considered.

During the installation and operational phases, a properly designed impact monitoring programme is important to provide Developers with data on the level of disturbance to marine mammals at the site. Noise is one of the key concerns during construction and this should be monitored as should barrier effects and other forms of disturbance or injury. However, the precise nature of such monitoring will depend upon circumstances and it is beyond the scope of this report to provide a design for each circumstance. Specific impact monitoring designs will be required for each development and site.

A monitoring programme during installation should be able to provide Developers with data on the numbers of marine mammals disturbed/displaced, thus allowing assessment of local changes in abundance and distribution (important consideration for obtaining an EPS licence). Such an approach could be informative to the Regulators when undertaking the 'FCS test' as part of the licensing process for disturbance of European Protected Species. The levels of displacement will need to be put into context of population abundance, and up-to-date abundance estimates (from SCANS-type surveys) will be required.

3.5 Establishing limits of disturbance

Abundance estimates and installation monitoring data could be part of a management strategy with the aim of assessing and monitoring the potential impact of the renewable energy developments on a marine mammal population so that the conservation status of that population is not negatively affected. A considerable amount of additional work will be required in order to establish such a management strategy.

The Potential Biological Removal (PBR) is one approach that has been used, primarily in the USA, to assess impact of fisheries bycatch and direct harvesting on populations. It may be possible to adapt this concept to the needs of the marine renewable energy industry. It requires an estimation of the size of the population concerned together with an estimate of the intrinsic rate of increase. A safety factor is then introduced and, in recent work done by SMRU for the UK Special Committee on Seals (SCOS), a procedure has been devised for setting the safety factor according to the uncertainty around the estimate of the population size and the rate of increase. The PBR is a simple way of setting appropriate levels of impact where there are likely to be detectable deaths of animals (e.g. because of by-catch in fisheries or because of deliberate shooting) but if applied to renewable energy development it is not clear how the level of deaths could be measured. Since there is almost no useful information about the population sizes of many species, it seems most likely that the method for setting levels of impact would result in levels being established that would be so low that they could not be measured with any reliability.

Alternative methods based upon, for example, the Revised Management Procedure developed by the International Whaling Commission may be possible to implement. However, all of these methods have important problems associated with them, one of which is that they require some sort of estimate of the environmental carrying capacity, which is impossible to estimate with any useful level of certainty. On balance, while far from ideal the PBR has a number of desirable characteristics, at least if applied in the form developed by SMRU for the UK Special Committee on Seals. Its simplicity makes it transparent and it makes fewer assumptions than most other methods. Consequently, we recommend that additional work should be carried out to provide PBR-type estimates of the levels of mortality that could be sustained by marine renewable energy developments across all species of concern. Nevertheless, modification will be required in order to account for non-lethal effects. It should be the role of the statutory Scientific Advisers to undertake this work.

4 Objective 2: Identifying the most cost-effective methods of data collection

Summary

- Characterisation survey data are needed to adequately describe the current environment and to allow impact predictions to be made. If such data do not currently exist, further data collection will be required.
- Available data comes primarily from the SCANS surveys and the ESAS and Joint Cetacean databases. All sources have shortcomings with respect to characterisation of sites for marine renewable energy projects.
- Detailed scoping studies will be required to assess if, and to what extent, further surveys are required; however in most cases it is likely that such work will be needed.
- The resources needed for monitoring depend on the methods to be used. Selecting one method over another will ultimately be based on a number of factors, including objectives, availability of infrastructure and staff, cost and logistical restrictions.
- Systematic sightings surveys are the standard for estimating density and abundance of marine mammal populations. The most commonly used method for cetaceans and pinnipeds are line-transect surveys and aerial photography, respectively.
- Power to detect changes increases by increasing sampling effort.
- Power is also better for relative abundance measures; abundant species; smaller areas; and higher rates of population change.
- In most cases, SCANS-II data should not be considered a replacement for characterisation survey data because SCANS-II data were collected with the purpose of characterising much larger areas than are defined for renewable energy developments.
- The question of whether (and to what extent) characterisation surveys will be required will need to be answered during site-specific scoping studies.
- Generic cost-benefit analysis to compare various monitoring techniques showed, in general, that aerial surveys were more cost effective than ship-based methods.
- The difference in cost between double and single platform aerial surveys is negligible when considered in the context of data quality. Double platform surveys should be given preference as data will generate absolute abundance estimates.
- Passive acoustic monitoring during line-transect surveys can be useful for augmenting visual observations.
- Autonomous acoustic monitoring is a cost-effective technique for generating long-term, seasonal information on presence of cetaceans; however these methods are unlikely to generate absolute abundance estimates.

- New and emergent technologies, such as high definition photography or new passive acoustic monitoring systems, are still being improved. Development of high-definition photographic techniques is occurring rapidly, but further assessment is needed to validate the robustness of the data and results.
- The overall efficiency of surveys for some R3 sites will almost certainly be improved through collaboration between Developers. Many sites will require similar surveys, with similar requirements and planning.
- Combining resources should cost less than carrying out a number of separate, but essentially identical, surveys; and may provide more biologically meaningful results.
- The most costly survey methods (double platform, ship-based surveys) also tend to produce the highest quality data over a range of species. In comparison, autonomous acoustic monitoring (AAM) is financially efficient, but comes with a number of caveats regarding data quality and usefulness.
- Aerial surveys are cost-efficient compared to boat surveys because they cover large areas relatively quickly, but may not be feasible at all sites.
- The best choice of monitoring technique is determined by the objectives of the study, the characteristics of the area, the species of interest and the resources available. More than one technique used in combination may provide the best possible outcome.
- Platforms of opportunity, photo-ID, acoustic data loggers, fixed-point surveys, and telemetry are also widely used methods.

4.1 The role of scoping: making use of existing data to replace characterisation surveys

Characterisation or baseline data must adequately describe the current environment. In the case of marine mammals, the data would need to describe the species present, their temporal and spatial distribution and density to a level of detail that would allow a change from this base line to be detected during impact monitoring. Once the baseline has been established, the data can be used to make impact predictions (e.g. what is the chance of disturbance or injury?), although for these predictions to be useful additional information will be needed about the reaction of sensitive species. Thus, in the absence of suitable data, regular surveys will be required to satisfy characterisation requirements and focussed studies of the species of greatest concern will be needed.

Such data are distinguishable from impact monitoring data, in that they may be collected well before construction begins. In this case, baseline data for impact monitoring will also be required, but probably over a much shorter time frame (although the time frame will be dictated by the need for statistical power).

The key to both characterisation and baseline impact data is in thinking carefully about how the potential impact might manifest in the population, and how this could be measured. For marine mammals, the most important baseline data will centre on some measure of density, as well as distribution.

For most sites, the amount and quality of existing baseline data is hugely variable. Thus each site will require an individual and thorough scoping study, in part to determine if and to what extent further characterisation survey work is needed. In most cases it is likely that some sort of additional characterisation survey work will be required. Such surveys should also include some seasonal survey work. While it is accepted that marine mammal populations can be highly variable, there is strong scientific consensus supporting the value of seasonal surveys as part of characterisation studies.

Following characterisation surveys, the emphasis should be on impact monitoring, including a survey immediately before construction activities begin to establish whether the past baseline remains relevant. This should also include a seasonal element to the pre-construction baseline. The type, timing and duration of these pre-construction surveys to confirm the baseline will depend upon the specific circumstances.

In cases where the pre-construction baseline cannot be confirmed or differs from the baseline then there will be a need to reassess the overall design of the survey and monitoring, although this does not imply that it should necessarily be changed. However, it will have shown that some of the assumptions within the EIA were incorrect and there will be a need to revisit the EIA taking this additional information in to account. This iterative approach to the EIA will be required throughout the construction and operational phase because, for reasons that may have nothing to do with the development, it is possible that the baseline could change and information about this will be needed. It should be anticipated that this type of information will be forthcoming from low-level background monitoring associated with impact monitoring or operational monitoring.

4.1.1 Description of existing data

Data that characterise the marine mammal populations within the coastal waters of the UK take many forms. In general, most can only provide an indication of the species composition, although doubts about species identification do not mean that they are all reliable even in terms of this basic characteristic. An improvement on the basic presence/absence information for particular species that might be available from, for example, strandings data, are data that provide a location and time of observation. These data have utility when providing general assessments of species that could be found in particular regions and they may provide a broad indication of relative abundance (although this can be very misleading if not treated with considerable caution because some of these data sets can say more about where observers tend to go and how observable some species are than they do about actual distribution and abundance). It is often data of these types that are used in EIAs because there are usually no better alternatives at small spatial scales. For data about distribution and abundance to be truly useful it needs to include an assessment of observation effort within a formal statistical framework. Apart from a few specific coastal surveys for porpoises and bottlenose dolphins the principal source of these types of data in UK waters are the SCANS surveys.

The SCANS datasets

Existing data describing cetacean abundance in continental shelf waters of the UK are limited to the SCANS (Small cetacean abundance in the North Sea) and SCANS-II (Small cetaceans in the European Atlantic and North Sea) surveys. SCANS-II (completed during July 2005) provides the most precise broad-scale estimates of cetacean abundance in UK waters.

To consider whether SCANS-II data can be used as characterisation survey data for offshore developments, such as Round 3, it is necessary to consider the objectives of the SCANS-II survey; the survey design; and the resulting data. Note that we are only considering SCANS-II data, as these are more up-to-date and cover a wider geographical area than SCANS.

SCANS-II fieldwork was conducted over a one month period in July 2005. Part of the project objective was to estimate small cetacean abundance in the North Sea and European Atlantic continental shelf waters. Thus, the survey was broad scale, covering over 1,350,000 km^2 and over 35,000 km of survey trackline (boat and aerial surveys combined).

SCANS-II data have limited use as characterisation survey data for offshore wind farms. These data were never intended to inform managers about small scale distributions and abundance; rather the primary objective was to assess abundance of *populations*. Thus it is more relevant to the types of monitoring required of Regulators to monitor (for example) favourable conservation status. Both the amount of effort and number of sightings in each of the round 3 Zones are too little to be informative as baseline data or for impact assessment (Table 1).

Table 1. Survey effort and sightings of harbour porpoise during the aerial and shipboard SCANS-II surveys.

Region	Area (km2)	Effort (km)	Aerial sightings	Ship sightings
1 Dogger Bank	8535	110	0 (no aerial effort)	9
2 Bristol Channel	956	0	0	0
3 Moray Firth	524	11	0	0 (no ship effort)
4. West of Isle of Wight	772	18	0	0 (no ship effort)
5. Norfolk	5858	252	0	0 (no ship effort)
6. Irish Sea	2172	169	2	0 (no ship effort)
7. Hornsea	4735	60	0 (no aerial effort)	8
8. Hastings	272	0	0	0
9. Firth of Forth	2865	45	0 (no aerial effort)	5

SCANS-II sightings data for harbour porpoise and minke whales were sufficient to produce modelled density surface plots, which give a visual representation of the distribution and densities of these species as indicated by SCANS-II data. This approach used Generalised Additive Models (GAMs) to model a response variable (i.e. density) to a series of environmental predictor variables which can then be used to generate an abundance estimate and fit a density surface to the entire survey area, not just within the searched strip (Hedley *et al.,* 1999; Hedley *et al.*, 2004).

GAMs have been widely used to generate density surfaces for cetaceans (e.g. Cañadas and Hammond, 2006) and have also been applied to land based monitoring data from renewable energy developments in the UK (e.g. DMP Statistical Solutions Ltd., 2008). Density surface maps make it easy to visually compare densities of animals in different areas and between years. The advantage of a GAM approach is that the technique does not rely on data that has been collected during a systematic survey; it can be applied to platform of opportunity data. Also, the precision of abundance estimates generated using GAMs (model-based estimates) tends to be better than conventional design-based estimates which means they are better able to reveal temporal changes or trends (e.g. Gómez de Segura *et al.,* 2007). The surface also allows estimates of abundance to be obtained for smaller areas within it; however the estimates are only as good as the prediction model selected and so design-based estimates are still considered more robust. A significant disadvantage of using GAMs to estimate density is that they can generate fine-scale maps of distribution and abundance and, in the hands of those who do not fully understand the uncertainty associated with these plots, they can be over-interpreted.

It is tempting to use the SCANS density plots as a way of characterising likely densities in Round 3 zones – at least for harbour porpoise and minke whales. However, the survey data from SCANS-II are too coarse to be analysed at such a fine scale level (P. Hammond, pers. comm.). Taking this approach would strongly rely on the assumption that the relationship modelled between density and the environmental variables at the large scale still holds when applied to much smaller areas.

Cetacean Atlas (Joint Cetacean Database)

The JNCC-produced Atlas of cetacean distribution in north-west European waters (Reid *et al*., 2003) is based on the Joint Cetacean Database and incorporates sighting data from a number of sources (including SCANS, European Seabirds at Sea, and Sea Watch Foundation) spanning some 25 years. Included in the atlas are numerous sighting plots, which depict sightings of animals per hour. In many cases sighting rates have been corrected for sea state (individuals/standardised hour). The spatial and temporal patchiness of the data will limit the usefulness in terms of characterisation survey data. Furthermore the current available atlas is somewhat out of date. There is also the Atlas of Marine Mammal of Wales by Baines, M.E. and Evans, P.G.E. (CCW Marine Monitoring Report No.68).

Seal telemetry data

Pinniped tagging programmes are included as part of regular population monitoring programmes (e.g. SCOS 2008). The telemetry data allow usage of coastal and marine areas to be examined, and are therefore of relevance to marine renewable energy projects. Scoping studies will need to carefully consider available telemetry data from relevant areas, particularly those data which have not yet been fully analysed.

4.2 *A review of methods available for monitoring*

4.2.1 Introduction

Common objectives of marine mammal monitoring programmes are to characterise species distribution and density in an area, monitor the status of a population, monitor the impact of an anthropogenic activity or biological event, or to examine the spatial and temporal habitat use to identify important areas for marine mammals, such as for feeding or breeding. Here, we focus on distribution and abundance techniques as part of pre-consenting (characterisation) and post-consenting (impact) monitoring.

The design of monitoring to be undertaken will depend upon the environment being monitored. For example, distant offshore sites may need to employ a different suite of techniques from nearshore sites because of the distances involved and different levels of exposure, including how MCA and CAA regulations apply in each circumstance. Near-shore, tidal sites where water column energy levels are a particular challenge to any monitoring equipment and a hazard to shipping, will require special attention, although there is already a well developed track record of monitoring at the Falls of Warness (EMEC) site in Orkney and the SeaGen site at Strangford Lough. However, some of the monitoring methods used at those sites cannot be applied as the sites are scaled up. Consequently, overall, the design of the monitoring system will have to be specific to the location.

Abundance estimates can be absolute or relative. Absolute abundance estimates require an estimation of the detection probability of the target species. Detection probability (often termed *g(0)*) for marine mammals is rarely equal to one (i.e. all animals are seen). Therefore, we must either provide an empirical estimate of this detection probability (i.e. based on field data), in which case we can estimate absolute abundance; or in the absence of this, assume the probability to be one. In this case, abundance estimates will be negatively biased and relative.

Abundance estimates for determining local impacts can be relative; if methods are kept consistent, estimates can be used to examine changes over time. However, interpretation of such data is generally aided by availability of periodic absolute abundance estimates (such as those that would be derived from a national monitoring strategy).

Ultimately, the best choice of monitoring technique for any given situation will be determined by the objectives of the study. Only then can the different methods be evaluated taking into account the characteristics of the area, species of interest and resources available. In many cases more than one technique used in combination may provide the best possible outcome.

4.2.2 Established marine mammal monitoring methods

There are numerous methods used to study marine mammal distribution and abundance and the choice of method depends on the desired outputs of the study. Table 2 summarises the outputs from commonly used field methods and pros and cons for each method are discussed.

Traditional techniques for monitoring marine mammals have centred on using visual observations either from land, boat or aircraft to obtain both population (e.g. abundance estimates) and individual based (e.g. behaviour) information. For estimating absolute abundance, visual surveys remain one of the best and most statistically robust choices.

The use of incidental sightings data is not considered as a monitoring technique in this study. Such data generally cannot be analysed in any quantitative manner because they contain no record of effort or detection probability. They are usually collected outside a well designed protocol that makes them unreliable to varying (and unknown) degrees. However, recognising that they may be collected alongside some other types of data, such as seabird surveys, there is clearly an opportunity to gather this information for little additional cost.

There is often an assumption made that some information is better than no information at all. Although generally true, unless it is clear what biases exist within the information being collected, such information can be highly misleading. While we would encourage the continued collection of such information we are unsure what, if any, useful purpose it can have without appropriate calibration of potential biases. Collection of the data may well be useful at some later time if it is decided to allocate resources to validate the information collected in the past by, for example, collecting it alongside a fully validated survey design.

Similarly, stranding data are not often effort related and the data collected do not easily lend themselves to a quantitative analysis of population trends. The location of stranded animals may not necessarily be within their normal distribution range, and consideration needs to be given to oceanographic currents that will have influenced the animals' final resting place.

A basic description of how each methodology works will be given, but detailed field protocols will not be included. For additional reviews of monitoring methods see Evans and Hammond (2004) and SCANS-II (2008).

Table 2: Outputs from field techniques commonly used for studying marine mammals. Please refer to text above for description of abundance. Habitat use is related to distribution, describing where animals are found, but also for what purpose (e.g. feeding, breeding, etc). Life history may relate to survival rates, reproductive data (age at first reproduction, calving interval etc), maximum age etc. Behaviour encompasses physical (feeding) and acoustic (vocalisation) types.

	Pinnipeds (P) and/or Cetaceans (C)	**Presence/ absence**	**Relative abundance**	**Absolute abundance**	**Habitat Use**	**Movement/ migration**	**Life History**	**Behaviour**	**Ancillary data[2]**
Strandings	PC	•					•		
Incidental sightings	PC	•						•	
Autonomous acoustic monitoring	C(P)	•						• (P)	•
Fixed-point surveys	PC	•	•		•	•		•	
Platform of opportunity at-sea survey	C	•	•		•	•		•	•
Dedicated at-sea or coastal* **and** aerial sightings surveys	P*C	•	•	•(not P)	•	•		•	•
Towed hydrophone surveys	C	•	•	•[3]	•			•	•
Photo-identification	PC	•		•	•	•	•	•	
Telemetry	PC	•			•	•		•	•

[2] Refers to data collected on other species sighted and/or the environment at the same time as the main survey was conducted.

[3] Only for sperm whales.

Dedicated surveys

Systematic sightings surveys are the standard for estimating density and abundance of marine mammal populations. The methods differ for pinnipeds and cetaceans; as pinnipeds haul-out periodically, their surveys focus on counts of animals at these sites rather than when the animals are at sea.

One issue that is often overlooked when designing surveys or general data collection from marine mammals is that the process of data collection itself may cause some level of disturbance. Consequently, survey designs need to consider this as a potential problem. This has become a particular issue when considering how to design systems for monitoring marine mammals around tidal turbines using active acoustics. In this case, the marine mammals have the capacity to hear the sonars (even though the manufacturer's specification says that they cannot be heard) and experiments have shown that the sounds can be aversive. This illustrates a need to carefully consider all survey methods for their potential impact on marine mammals.

Cetaceans

The most commonly used method for systematic visual surveys of cetaceans are line-transect surveys; where a survey area is defined and a set of pre-determined transect lines are surveyed. During the survey, observers record the perpendicular distance to each of the sightings (a technique known as distance sampling) together with data on the species and group size. In this way, a detection function[4] can be fitted and an effective width of the strip that has been searched estimated; this corrects for animals missed by observers further away from the transect line. The method generates unbiased estimates of density and abundance providing that the key assumptions are met:

1. Distances and angles from the observer to points of interest are measured without bias;
2. Animals are detected at their initial location, prior to any responsive movement to the survey platform; and
3. Animals on the transect are detected with certainty, i.e. the detection function $g(0) = 1$.

Attempts to meet assumption (1) are made through use of reticle binoculars and inclinometers during ship and aerial surveys, respectively. Whilst not completely error-free, these methods should at least be bias-free. Video-range techniques (Leaper and Gordon, 2001) have been developed and are an improvement on reticle estimates but the equipment is more expensive and more difficult to use.

Assumption (2) is a particular issue for boat-based surveys. Many cetacean species are known to respond to the presence of boats. Attraction results in positively biased abundance estimates whilst vessel avoidance results in negatively biased estimates. These are not insurmountable problems, but generally require auxiliary data collection involving

[4] A detection function is a curve fitted to perpendicular distance data which models the decrease in detectability of animals as they are further away from the trackline.

some sort of double-platform experiment (Hammond *et al.*, 2002) or record of animal heading for each sighting (Palka and Hammond, 2001).

Assumption (3) is almost never satisfied, irrespective of species or survey platform. However, some field methods (e.g. double-platform or double-observer methods) allow for empirical estimation of *g(0)*.

A constraint common to all visual line-transect surveys, regardless of platform choice, is that surveys need to be conducted in fair weather conditions. The detection of cetaceans is heavily dependent on weather conditions, particularly Beaufort sea state[5] since an increasing number of white caps or breaking waves tends to obscure the most common sighting cues (most sighting surveys are discontinued when sea state reaches Beaufort 4). Obviously surveys can only be conducted during daylight hours, which further impose time-restrictions.

Line-transect methods have been successfully used from both boat and aerial platforms to estimate density and abundance (e.g. Hammond *et al.*, 2002; Macleod, 2004) and are considered by many to be the standard for marine mammal abundance estimation (Buckland *et al.*, 2001). Free and increasingly sophisticated software[6] facilitates data analysis and also includes some useful survey design tools (see Strindberg *et al*., 2004).

Boat-based line transect surveys

Boat-based surveys require an elevated and stable platform. Boat surveys to estimate *g(0)* need to have two survey platforms, each being able to accommodate up to four observers (Hammond *et al.*, 2002; SCANS-II, 2008). Consequently the ships need to be large and tend to be expensive. When two platforms are available for visual observation on the survey vessel, responsive movement can also be accounted for by using the “BT method” (Buckland and Turnock, 1992). One platform must be higher than the other and the observers on this platform (tracker) search farther ahead than the other platform (primary) using binoculars, while the primary team search with the naked eye.

Aerial line-transect surveys

It is often assumed that aerial surveys do not suffer from problems associated with responsive movement, although this depends upon the aircraft type and the species concerned. Some marine mammals are highly sensitive to the kind of low-frequency pulsed sound from aircraft (which can propagate through water as well as air) such as helicopters and while “responsive movement” is often considered mainly in terms of lateral movement of animals away or towards the track line, marine mammals have the capacity to submerge in response to aircraft noise that can reduce their apparent abundance. Aerial surveys are less sensitive to weather conditions and considerable ground can be covered quickly. Compared to ship surveys, charter costs for aircraft are cheap. Logistical considerations include proximity of suitable facilities (air-strips, refuelling stations) and finding appropriate craft. For aerial surveys to be effective and safe, planes must be twin-engine and high-winged, and ideally have bubble windows. Survey sites that are further offshore or a long way from airports may not be accessible to planes.

[5] http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html, page viewed July 14, 2009.

[6] http://www.ruwpa.st-and.ac.uk/distance/

In the past, single aircraft with enough seating to carry two observer teams (four observers in total) have been used. These teams need to work independently, thus requiring a carefully thought out field protocol and disciplined observers. The advantage of such methodology is that the resulting mark-recapture distance sampling analysis is incorporated into recent versions of DISTANCE (Thomas *et al*., 2010).

Two other methods have been established for estimating *g(0)* during aerial surveys; data are collected by two aircrafts surveying the same track line in tandem or by one aircraft circling back (the “race-track” method) after a sighting to simulate the second aircraft (Hiby and Lovell, 1998; Hiby, 1999). Unfortunately, methods for analyzing these data have not been packaged in user friendly software and an experienced analyst is required.

The pros and cons of boat and aerial based line transect surveys are shown in Table 3, below.

Table 3: Summary of pros and cons of visual line-transect surveys for cetaceans.

Pros	***Cons***
Line-transect surveys	
• Data allow for estimation of absolute or relative density & abundance • Can provide information on distribution • Can be long-term • Can cover entire range of population	• Often expensive • Restricted by weather conditions and to daylight hours • Variability often high – can be difficult to detect trends • Provide “snapshots” over relatively short time periods
Boat-based surveys	
Offshore and near-shore • Additional data can be collected • Well established and robust methods for assumption violations, especially for large vessels **Near-shore only** • Small boats can take advantage of good weather in some circumstances	**Offshore and near-shore** • Large vessels expensive • Responsive movement **Near-shore only** • Small boats range-restricted • Small boats reduced effective strip width and survey team size/effectiveness for line-transects • Small bots highly constrained by weather
Aerial surveys	
• Fewer issues with responsive movement • Can cover large areas quickly • Can take advantage more readily of good weather windows • May already be taking place to carry out bird surveys	• Logistical limitations • Responsive movement may be a problem for some aircraft types or some species • Height limitations around wind farms

Pinnipeds

The methods used to estimate abundance for harbour and grey seals differ because of fundamental differences in their life histories. Grey seals aggregate at traditional breeding colonies in the autumn to give birth to a single pup ("white coat") and mate; harbour seals breed during the summer months and tend to disperse, rather than aggregate, during breeding. Both harbour and grey seals come ashore for prolonged periods during their annual moult. In the UK this is during late summer (harbour seals) and spring (grey seals).

For grey seals the combination of traditional breeding aggregations and white coated pups mean that the number of pups is relatively easy to count, and therefore this is the main method for monitoring their numbers. Pup production is also the main rationale behind SAC designation for this species. In contrast, harbour seals are routinely surveyed during their annual moult.

Grey seal breeding season surveys

The majority of Britain's grey seal breeding colonies are surveyed annually to undertake pup counts. The most widely used method uses aerial photography as many of the colonies are remote offshore islands (although it should be noted that counts can also be made from boats or from the shore at some sites). Vertical aerial photographs are taken of the colonies and processed post survey to obtain accurate counts. These counts can be used to obtain estimates of pup production at individual colonies (Duck and Mackey, 2008). Currently these counts are aggregated to a regional level (North Sea, Orkney, Inner Hebrides, Outer Hebrides) before a model is applied to generate a population estimate (Thomas and Harwood, 2008). Because surveys are carried out annually, population trends can be examined. However, the approach is very time consuming, specialised and can be expensive.

Harbour seal moult surveys

Harbour seals are surveyed annually during their moult in August. Two different aerial survey techniques are routinely applied by the Sea Mammal Research Unit (SMRU; Duck *et al.*, 2008). Due to the cryptic nature of the seals' pelage and the complexity of the coastline in the Northern Isles, Hebrides, and west mainland coast of Scotland, most surveys are carried out using a thermographic aerial photography technique using a helicopter platform. This technique is expensive, which limits the surveying of the majority of the Scottish coast line to a 5 yearly cycle.

Major haul out sites on the east coast are surveyed more frequently. Seals hauling out on intertidal sandbanks can be more easily spotted, and thus surveyed using fixed wing air craft (twin or single engine dependant on the site). Oblique photographs can be taken using a hand held digital SLR camera, or vertical photography can be used (which requires more specialised equipment). At some locations routine monitoring can be carried out from shore based locations using telescopes. Historically many sites were counted from boats; coverage of the entire population is limited using this approach.

Estimates of harbour seals abundance are usually expressed in terms of minimum populations size (total number of animals counted) multiplied by a conversion factor for the total number not available to be photographed. Uncertainty in harbour seal estimates can be high because of the uncertainty about the proportion of the population in the water at the time of counting. Good survey methodology restricts the timing of the surveys to two hours either side of local low tide time, but a relatively large proportion of the population remains in the water during this time. The results of telemetry studies of harbour seals have helped to define the likely proportion of animals hauled out at any time, and it is estimated that between 40-70% of harbour seals are likely to be counted during surveys (Thompson *et al*., 1997). The number of harbour seals counted during dedicated surveys is therefore used as an index of population size, and provides a minimum estimate of the population within an area and nationally. The most recent minimum estimate for the British population is 40,000-46,000 animals.

Boat-based surveys may be required for pinnipeds in some regions where they are present in caves or gullies that are difficult to photograph from the air but these types of habitats tend to occur mainly in Shetland, they are most relevant for grey seals and they account for a relatively small proportion of the total population.

The pros and cons of aerial, boat based and land based surveys for monitoring pinniped relative abundance are summarised in Table 4.

Table 4: Summary of pros and cons of various methods for monitoring relative abundance in pinniped species in the UK.

Pros	***Cons***
Aerial surveys	
• Data allow for estimation of relative abundance (or absolute abundance in association with telemetry data) • Can provide information on distribution (on land) • Should have limited disturbance to haul out site • Can be long-term • Can cover entire range of population • Photographic or video records can be kept for verification after surveys	• Often expensive • Restricted by weather conditions and to daylight hours • Variability often high – can be difficult to detect trends • Time consuming and labour intensive • Land based information only • Health and safety • Responsive movement
Boat-based surveys	
• May be cheaper than air surveys • Data allow for estimation of local relative abundance (or absolute abundance is association with telemetry data) • May be more flexible to local weather conditions	• Range-restricted (limited elevation) • Quality of counts may be poor • Responsive movement • May cause disturbance to site

Land based surveys	
• May cause disturbance to site • Data allow for estimation of local relative abundance (or absolute abundance is association with telemetry data) • May be more flexible to local weather conditions • Could be combined with other fine scale or individual based studies	• Logistical limitations – sites may not be accessible or only partly visible • Quality of counts may be poor

Platforms of opportunity (PoOPs)

Opportunistic cetacean surveys (Table 5) can be carried out on any vessel with a forward facing, relatively high platform from which to make observations. The difference between opportunistic (or incidental) data and data from platforms of opportunity is that in the case of the latter, while the platform is opportunistic, data collection can still happen in a dedicated, rigorous manner (Williams *et al.*, 2006). Because the platforms are opportunistic, however, the cost of such data collection can be a fraction of that of a dedicated survey. The main disadvantage of using platforms of opportunity is that it is not possible to influence where and when the vessels goes.

Popular platforms of opportunity are ferries, cruise ships, cargo ships and yachts. Surveys may also be carried out on vessels being used for other research projects, such as fisheries or seabirds.

Because of the spatial limitations of the data collected onboard many platforms of opportunity, abundance estimates cannot be generated using design-based line transect distance sampling methods; the success of these methods relies on an equal coverage probability of the transects within the survey area. However, providing a survey from a platform of opportunity provides representative coverage of an area then generalised additive models (GAMs; see section 4.1.1) can be used to model abundance. GAMs can generate easily interpretable surface-density maps and provide abundance estimates in areas where funds are not otherwise available for dedicated marine mammal surveys (e.g. Williams *et al*. 2006). These are termed model-based estimates.

While such analyses should not be seen as replacements for well designed, systematic surveys, they can nonetheless provide an excellent means of using opportunistic data to design future surveys or indicating effort should be focused for other field work such as photo-ID or biopsy sampling. In particular, if opportunistic data are collected carefully and can be combined from several sources, then it may be possible to acquire useful contextual data over a large area. It is important to remember however, that data collection from PoOPs requires the same careful attention to field protocol and data quality as any other dedicated survey project. Poor field methods can render data useless, and this applies to PoOPs in the same way as it does to dedicated line-transect survey projects.

Table 5: Summary of pros and cons of data from platforms of opportunity.

Pros	*Cons*
• Cheap way of collecting data • Can provide good temporal coverage • Data can be used to investigate relative abundance and habitat preference • May be possible to generate density surface maps	• Generally not possible to estimate absolute abundance • Not good for pinnipeds • Effort is generally restricted spatially • Un-calibrated responsive movement • No control over the area/region surveyed

Photo-identification

Photo-identification (photo-ID) and mark-recapture techniques started to gain widespread recognition as powerful cetacean research tools in the 1970s, and more recently have been applied to pinniped populations. However, the application of these techniques is generally species- and location-specific. One benefit of photo-ID and mark-recapture is that studies are relatively non-invasive, since no physical handling of animals is required. But the major advantage of these individual-based studies is that they can be long-term and the resulting data can be used in the estimation not only of abundance but also of life history parameters (e.g., survival and reproductive success), home range and habitat utilisation.

Drawbacks are that generally only a portion of the population is sampled using photo-ID i.e., it is area based. Thus, interpretation of cetacean abundance from photo-ID mark-recapture estimates is not as simple as from line-transect estimates. In line-transect studies, area is explicitly defined, and the estimate is of the number of animals in that area at a given point; i.e. a “snapshot”. In contrast, photo-ID mark-recapture estimates are typically gained over a much longer time-frame, and will likely include animals that stray into the area only occasionally. Therefore, photo-identification is optimised to measures the number of animals that use an area, though they may not all be present at any one time, rather than density, or distribution.

Acoustic techniques

Towed hydrophone array

Passive acoustic monitoring (PAM) relies on detecting vocalisations of cetaceans (i.e. it does not emit acoustic signals – rather it “listens”), and is gaining increasing popularity for monitoring cetacean populations. Acoustic data can be collected round the clock and are less dependent on weather conditions. Also much of the data collection can be automated and is not limited by the skill of the “observer”. However, the method depends on species having vocalisations with a useful detection range and that are species-specific. Since pinnipeds do not vocalise underwater in the same way that cetaceans do, this section is only relevant to cetaceans.

There are currently two systems in use for carrying out passive acoustic monitoring of cetaceans: towed hydrophone arrays and static autonomous acoustic data loggers (AAM; Table 6). Towed arrays can be deployed from most boats and by hand; although a winch can be useful for larger arrays. Their use can be restricted by water depth, although this is dependent on the length of the array and speed of the vessel. A minimum water depth of 10m is generally required for these surveys. The array developed for the SCANS-II surveys (SCANS-II, 2008) consisted of a 200m tow cable with three hydrophone elements and a depth sensor at the end. Multiple hydrophone elements were used to allow bearing to the detections to be estimated which could form the basis of a distance sampling analysis to obtain relative abundance. The spacing between the first and second hydrophones was optimised to detect harbour porpoises and that between the first and third was optimised for other odontocetes (dolphins and toothed whales), which tend to vocalise at a lower frequency.

The harbour porpoise and sperm whale lend themselves very well to acoustic detection as their vocalisations are readily discernable from other marine noise. Vocalisations from delphinids are more complex and not easily recognisable to species, and a reliable system to automate their identification has yet to be established.

There are a suite of sound analysis packages which are widely available. A new software development, PAMGUARD[7] (Gillespie *et al.*, 2008), can collect data on most species and is able to differentiate vocalisations from harbour porpoise, sperm whales, pilot whales and some beaked whales.

Autonomous acoustic data loggers

There are several autonomous acoustic data loggers available, all of which will record raw data and some which will also carry-out real time data analysis. Of the recording only type, the Cornell Pop-Up has been widely used. Pop-Ups are intended for deployment on the ocean floor, up to depths of 6,000m, and are designed to "pop up" for retrieval. The Ecological Acoustic Recorder (EAR) monitors biological activity in the water column for periods of one year or longer. They are anchored to the sea-bed and released, just like a Pop-Up. However, while they are easier to use than Pop-Ups, they cannot be deployed as deep. Recently colleagues at the European Marine Energy Centre (EMEC)[8] and the Scottish Association for Marine Sciences (SAMS)[9] have been involved in the development of drifting EAR technology, although this has not been designed to detect marine mammals and is optimised for measuring the general acoustic environment.

Within Europe, the most commonly employed form of acoustic data logger that stores raw data and performs basic analysis is the POD[10] or POrpoise Detector – an autonomous acoustic data logger that detects presence/absence of vocalising cetaceans. PODs are a useful tool for looking at behaviour of animals in response to marine activities and have been used extensively to monitor the impact of wind farms on harbour porpoises in Denmark, Germany and Holland (Carstensen *et al.*, 2006; Tougaard and Henriksen, 2009).

PODs are programmable and can be set to record within the frequency range of interest. The most recently developed POD, the C-POD, can detect all toothed cetaceans which vocalise within the 20-160kHz range (except sperm whales). A deep-water C-POD (up to

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[7] http://www.pamguard.org

[8] http://www.emec.org.uk/index.asp

[9] http://www.sams.ac.uk/research/research-themes/marine-renewable-energy-research/the-renewables-team

[10] http://www.chelonia.co.uk/

2,000m) is being developed but currently PODs are limited to water depths of about 500m (Trengenza *pers. comm.*).

Common metrics derived from POD data are ‘porpoise positive’ time units (e.g. months, days, hours; e.g. Verfuß *et al*., 2007). This indicates, for example, the number of days in a month (or hours in a day, etc) for which some porpoise activity was recorded. Another useful metric is waiting time between encounters (e.g. Carstensen *et al*., 2006), which can also provide a measure of porpoise activity (i.e. an increase in waiting time between consecutive encounters would be suggestive of lower density). However, and while PODs have several strengths (see Table 6), perhaps the greatest weakness is that they measure acoustic activity, rather than numbers of animals. Thus, changes in the level of acoustic activity may be due to differences in behaviour, rather than true changes in density of animals.

Table 6: Summary of pros and cons of using acoustic data from towed hydrophones and autonomous acoustic data loggers.

Pros	***Cons***
Towed hydrophone array	
• Data are independent of daylight and most weather conditions • Can provide high spatial resolution data	• Methods to estimate abundance are only developed for harbour porpoises and sperm whales; species identification is currently difficult for other species • Performance is dependent on the noise level of the vessel • High frequency vocalisations have a limited detection range of approximately 200m
Autonomous data loggers	
• Stationary click detectors provide high temporal resolution • Data collection can be relatively inexpensive • Long-term data sets can be collected • Data can be used to monitor relative abundance if click rates are assumed to be constant over time	• Methods to estimate abundance are not well developed • High frequency vocalisations have a limited detection range of approximately 200m • Devices require retrieval to obtain the data • No background noise compensation • Limited ability for most designs to provide detection range

Fixed-point surveys

Fixed-point visual observations (Table 7) for marine mammals can be from both land- and sea-based points, but more commonly the former. Land-based observations are often carried out from cliffs or headlands i.e. elevated points with a good view of the adjacent coastal waters covering constrained migration pathways of narrow channels. With a few notable exceptions, fixed-point observations in isolation cannot produce estimates of absolute abundance. However, with auxiliary data to model detectability, it is possible to establish relative abundance and therefore trends over time.

Fixed-point observations are often used in behavioural studies for coastal cetacean species as researchers can observe behaviour of animals (e.g. reactions to tour vessels) without themselves being a potential impact. A significant limitation however is the small area over which observations can be reliably made. Fixed point observations will only ever be viable for those sites which are contained within roughly 5km of proposed observation points, but can provide useful supplementary data for monitoring movements of animals near sites that are close to shore (or some other fixed and elevated platform). Observations are commonly made with a surveyor's theodolite, which – when placed in a known, geo-referenced position – can provide accurate positional information of sighted animals, and allow researchers to plot and track animals in real time.

Table 7: Summary of pros and cons of fixed-point surveys.

Pros	*Cons*
• Inexpensive (compared to boat based or aerial methods) • Observers not influencing behaviour of animals • Can provide spatial and temporal data on usage and distribution • Can collected data for pinnipeds, cetaceans and sea birds using the same approach • Established analysis frameworks • Can be extended to assess long-term trends	• Generally not possible to estimate abundance • Experienced observes are required • Weather restricted • Need to find a suitable site/vantage point • Often confined to coastal strips or channels

Telemetry

Telemetry is a widely used method for studying marine mammals and can help identify important habitats, migration routes and define boundaries between populations (Table 8). There are three over-riding challenges about using telemetry that constrain when, where and the purpose of the application. These are (1) the attachment of a device; (2) recovery of the data; (3) power supply. There are trade-offs between all of these and in many application there may be no suitable telemetry device available (e.g. for most cetaceans). Consequently obtaining data from marine mammals using telemetry is technically challenging and almost all examples of data collection from this type of activity are still classified as experimentation and fall within the Animals (Scientific Procedures) Act 1982. There are still relatively few examples of operational monitoring using telemetry of marine mammals.

There are several different types of tags: VHF, satellite, GPS mobile phone and data loggers[11]. Data collected by satellite tags are transmitted intermittently to an earth based

[11] http://www.smru.st-andrews.ac.uk/Instrumentation/pageset.aspx?psr=339; http://www.wildlifecomputers.com/Products.aspx?ID=-1

station via satellite, whereas GPS tags transmit data via the global GSM mobile phone network. Such tags allow tracking of animals over very long distances and for many months (up to 212 days for harbour porpoise, Read and Westgate (1997) and Johnston *et al.* (2005); up to 143 days for bottlenose dolphin, Corkeron and Martin (2004); up to 65 days for killer whales, Andrews *et al.* (2008); 23 days for Risso's dolphin, Wells *et al.* (2009)) without the need to retrieve the tag.

By comparison, VHF transmitters allow the animal to be tracked over much shorter ranges and time periods, but can provide high-resolution data on diving behaviour if a time and depth recorder (TDR) is also fitted (e.g. Baird *et al.*, 2002). However the tags have to be retrieved to get the data. Data loggers are usually only deployed for short periods (hours) and they too have to be retrieved. These tags are primarily used to obtain high-resolution dive data in cetacean.

Behavioural data from tagged harbour seals can be used to generate a correction factor to be applied to counts of animals at haul outs in order to estimate population size (Thompson *et al.*, 1997; Sharples *et al*., 2009). Recently, tagging studies of grey seals have been used to create relative habitat usage maps (Matthiopoulos *et al.*, 2004, McConnell *et al.*, 2009), providing an invaluable picture of where animals go when they are at sea.

In general, only a few animals can be tagged at a time and so the number of individuals in a sample is small. This limits the inferences that can be made about the population as a whole (Aarts *et al*., 2008).

Table 8: Summary of pros and cons of telemetry.

Pros	***Cons***
• Can provide information on movements, migration and range of individuals • Can provide information on behaviour • Can provide information on habitat preferences and areas of special importance • Detailed information on animals without human disturbance (after release)	• Many individuals need to be tagged to make general conclusions • Invasive - potential animal welfare issues from tagging process • Equipment is relatively expensive

4.2.3 New and emerging technology

High definition photography

Use of high definition (HD) photography seeks to achieve a number of advantages over traditional aerial line transect survey methods, such as reducing labour costs, gathering fully-auditable field data, and increasing accuracy of counts (Mellor *et al*., 2007).

HD aerial photography has recently been pursued as a viable alternative for marine bird surveys at current or potential wind farm sites (Mellor *et al*., 2007; Mellor and Maher, 2008). Experienced observers were able to identify various different species. Subsequent feasibility surveys have been undertaken using the HD aerial photography system (Hexter, 2009a; 2009b). During one of these surveys (Hexter, 2009b), a total of 121 sightings of marine mammals were also made using HD photography. Most were identified as harbour porpoise, with a smaller number of dolphins (not identified to species level) and seals. Interestingly, the cetacean sightings during this survey generated a larger local population estimate than had been indicated by previous surveys (Hexter, 2009b; though note that it is not explained in the report how the population estimates from the HD data were obtained).

HD photography as a viable method for wildlife surveys is a rapidly developing field; and one that has considerable potential for marine mammal surveys. This will be particularly true for offshore wind farms, where the height of the turbines is expected to preclude the use of traditional aerial surveys. However even quite recent reports (Thaxter and Burton, 2009) caution against relying fully on HD surveys until at least some of the remaining issues are resolved. Species identification continues to be an issue, and although porpoises seem distinguishable from dolphins (e.g. Hexter, 2009b; 2009c) species-ID beyond "dolphin" seems more difficult. There are also acknowledged difficulties in accounting for animals not at the surface (availability bias) and while these issues are not insurmountable, they do not appear to have been resolved yet (Thaxter and Burton, 2009). In the case of seabirds, recent comparisons with traditional visual surveys have shown that, as a result of greater variability, the power to detect change from digital surveys is poorer than for visual surveys (Burt *et al*., 2009).

Further work is therefore needed before HD-photography can be recommended as a preferred and primary monitoring technique. In particular, we recommend the following issues are pursued:

i) As yet there has not been any comparison of HD techniques with conventional surveys for marine mammals. Similar work has been done for birds (Burt *et al*., 2009; Thaxter & Burton, 2009) and should be done for marine mammals also.

ii) There is currently no way of dealing with the availability bias of marine mammals surveyed using HD techniques. This is seen as a key requirement for these methods.

Availability bias is a component of *g(0)* – the probability of detecting an animal on the survey trackline. In effect there are two probability components to *g(0)*: 1) the probability of detecting an animal, given that it was *available* for detection; and 2) the probability of an animal being at the surface and available to be detected. HD video techniques effectively remove the first component, since theoretically anything within frame will be detected *if* it is available. But currently there are no field or analytical techniques that have been developed around HD methods that can account for the second component. What this means in practice is that it is not possible to compare counts from different surveys of the same area; or indeed to compare amongst different areas and biases may differ between species. Imagine two surveys of harbour porpoise are compared (these could be across space or time). The counts from each survey could be quite different, but if (for example) water visibility was poor during one survey, perhaps resulting in a lower animal count, we would have no way of knowing whether observed differences were a true reflection of animal distribution and density, or merely an artefact of water conditions at the time. There are well developed methods to deal with these same issues during traditional, visual surveys, and there is no reason to believe the same will not eventually be true for HD methods. Development of such methods should now be seen as a priority.

Related to HD photography is the concept of using unmanned aerial systems (UAS) craft. These were recently reviewed by Koski *et al.* (2009). In general, the systems were too expensive, and/or did not meet basic requirements for offshore biological surveys. HD photography and image stabilisation were among the recommendations made to advance UAS, however the authors discussed several other impediments, including a lack of "see-and-avoid" systems, and uncertainties surrounding data quality (Koski *et al.*, 2009).

PAMBuoy

A new acoustic monitoring system, PAMBuoy, is currently being developed as a real time marine mammal detection system that uses embedded microprocessors to analyse acoustic data at high frequencies. The system is an autonomous, self-sufficient, moored surface buoy that is powered using a series of solar panels. Summary detection data can stored on board or transmitted to shore at user defined intervals using the GPRS 3G mobile phone system (it is anticipated that alternative communications systems could also be utilised).

Detection and classification algorithms are based broadly on those developed for the PAMGUARD software. By relying on software, rather than species-specific hardware, this system is highly flexible and can work with multiple species including many of those common around the UK (e.g. harbour porpoise).

Primary data that can be transmitted include timings of marine mammal detections, identification of species, and bearings to detections (subject to left/right ambiguities). Secondary data include buoy location (GPS), a summary of background noise levels (user defined frequencies and intervals), and system management data (e.g. battery levels).

Automated field data collection

A computer based system for the collection of line transect survey data was designed and built for the SCANS-II surveys of 2005 and used during the offshore CODA surveys in 2007 (Gillespie *et al.*, submitted). SCANS-II and CODA were large-scale double platform surveys designed to generate data for precise and unbiased abundance estimation. The data collection system was developed to automate data collection wherever possible.

This approach has been applied in particular to the measurement (rather than estimation) of distances and angles to sightings. Leaper *et al*. (2008) showed that both distance and angle errors make a substantial contribution to the variance of abundance estimates and may cause considerable bias. Also, the system provides accurate time-stamps for surfacing events which aids identification of duplicate sightings. Distance and angle measurements were made using established photogrammetric techniques. Collection of photogrammetric data from video was automated and included a system of data buffering so that several seconds of data prior to each observer sighting could be captured. An additional goal of the system was to eliminate the need for post-cruise data entry and validation through the use of on-board data validation software.

4.3 Choosing the appropriate monitoring method

4.3.1 Introduction to power analysis

Power analysis is a useful method for planning surveys and analysing time-series data to look at population trends (Gerrodette, 1987). For planning purposes, it can inform the user of the level of monitoring effort required to obtain the desired sample size and associated measure of precision, to detect a change of a given magnitude in a period of time, or how long it would take to detect a trend of a certain magnitude given the level of monitoring dictated by available resources. This approach has been applied to renewables developments in the UK, at Strangford Lough and EMEC, for analysis and interpretation of land based visual observation data (e.g. DMP Statistical Solutions Ltd, 2008). It is also useful for comparing the power of different monitoring methods to detect trends (Berggren *et al.*, 2008). For example, the technique was used to choose between the use of visual survey methods and T-PODs on a Danish wind farm site (Carlstrom *et al.*, 2006).

Power analysis allows us to estimate the probability of detecting a trend in abundance given a time-series of estimates, their associated precision and a given rate of population change. Power analysis can also be used to work out the number or precision of surveys required to detect change with a given degree of confidence (Gerrodette, 1987). Precision is usually expressed using the term coefficient of variation, or CV, which describes the variability of the data relative to the metric in question (i.e. a ratio; CV is usually given as a value between 0 and 1, or a percentage). A small CV is indicative of a precise estimate; whereas a large CV means there is considerable uncertainty as to the true value of the metric.

Surveys that generate precise density/abundance estimates are therefore preferable because: i) they will have lower uncertainty about the estimate; and ii) when repeated and subject to power analysis, will give greater power to detect a change. This is because even if two surveys of the same population (but at different times) provide quite different answers, if the CV (i.e. uncertainty) is large, there is a greater chance that the two values are in fact the same. In this case, the power to detect change is low. Whereas if the CV of the two estimates is small, we will have greater certainty that the differences (if any) observed are real, and the power to detect change is high.

Thus, surveys should be designed with a target precision in mind, especially if the aim is to use repeated estimates to investigate changes over time. The amount of survey effort or number of sampling occasions will influence the CV (and hence power) of density estimates and this relationship is explored in section 4.3. High statistical power means a high probability of detecting a change. Low statistical power means we may fail to detect change. SCANS-II data were available for analysis. Data were chosen from blocks with adequate sightings data for analysis and of geographical relevance to R3 sites.

4.3.2 Uncertainty and effort

In general, abundance estimates from surveys with a lot of effort and sightings tend to be more precise i.e. have a low CV. To date, the most precise population estimates for cetaceans in UK waters are from the SCANS-II survey. These data form an important baseline for consideration by marine renewables Developers. However, the data are poor for making temporal inferences and in a spatial context there is much variability in animal density and the uncertainty surrounding the estimates.

As part of this survey, model-based estimates of harbour porpoise and minke whale abundance were obtained by fitting a GAM-based density surface model (see section 4.1.1) to the survey data that included longitude, latitude, depth and distance to coast. The predictions from these models were used to obtain local density estimates (animals/km^2) on a 2 minute grid (i.e. ~8.15km^2). CVs for each grid cell were estimated from 200 bootstrap replicates made by re-sampling on transects. Maps were generated from this exercise for harbour porpoise and minke whale to look at the levels of uncertainty over the UK continental shelf and at the different R3 sites based on currently available data (Figure 1 and Figure 3).

Highest modelled harbour porpoise densities occurred off the east coast of the UK, particularly in the region of the R3 Dogger Bank site (Figure 1). The east coast of England also shows the highest densities of minke whales. The uncertainty associated with the estimates for both porpoise and minke whale in the Dogger Bank region is high (Figure 2 and Figure 4). The CVs in the regions of interest will be related to the error in the model which in turn will be locally affected by the amount of survey effort. Thus the CVs represent the uncertainty associated with each cell as a function of the underlying intrinsic uncertainty in the population size, mitigated by local effort if any. The data suggest that regions supported by large amounts of survey effort have reduced CVs. This is demonstrated by the Irish Sea zone, south of the Isle of Man (Figure 2 and Figure 4). This exercise demonstrates the importance of maximising effort within your survey area to ensure small CVs.

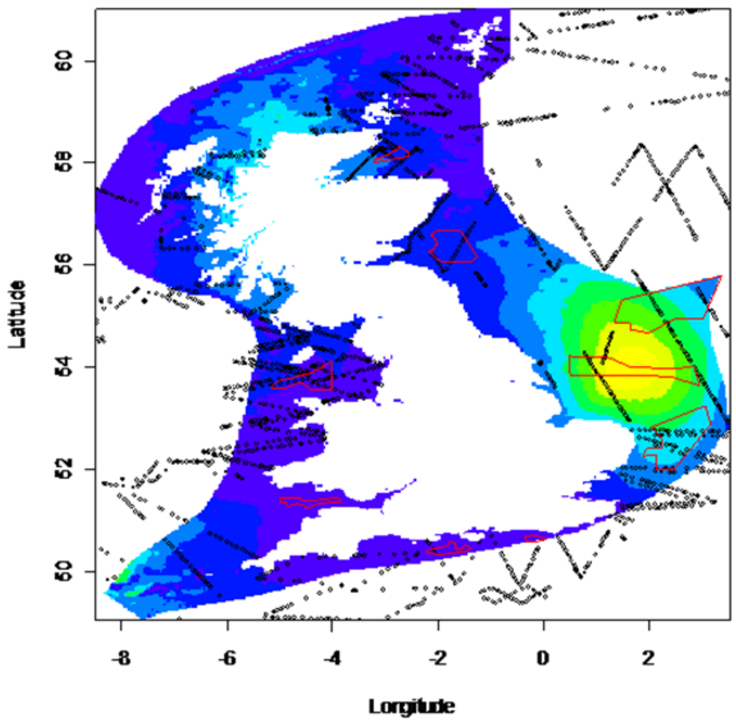


Figure 1: Estimates of local harbour porpoise density (animals/km^2) from SCANS-II at 2 min^2 grid resolution .Intervals: 0 – 0.2 violet, 0.2 – 0.4 deep blue, 0.4 – 0.6 medium blue, 0.6 – 0.8 pale blue, 0.8 – 1 blue-green, 1 – 1.2 green, 1.2 – 1.4 yellow. R3 zones are shown in red. Dots indicate survey effort.

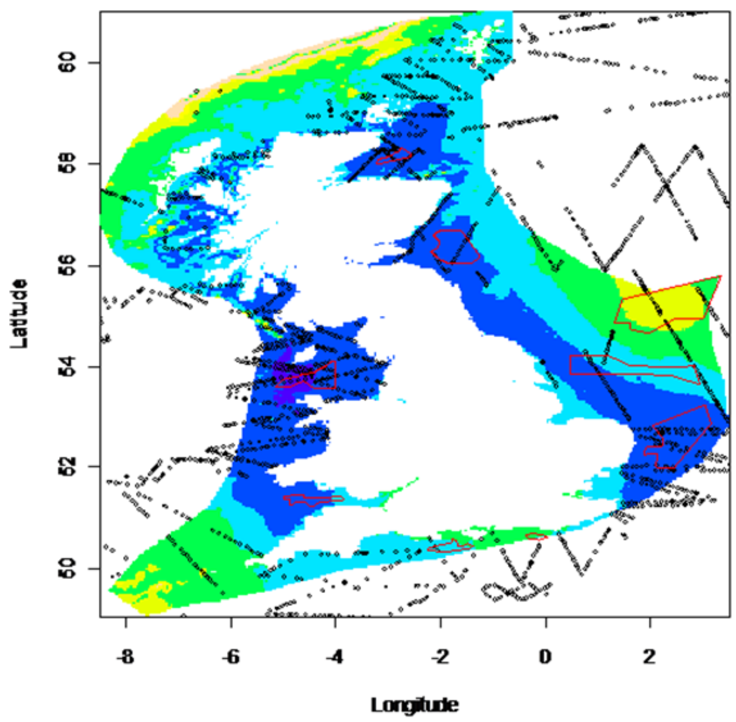


Figure 2: Estimates of coefficients of variation of SCANS-II harbour porpoise density estimates at 2 minute^2 resolution. Intervals: 0 – 0.16, violet, 0.16 – 0.30, medium blue, 0.3 – 0.5, pale blue, 0.5 – 1 green, 1- 2 green-yellow, 2 -3 yellow, 3+ beige. R3 zones are shown in red. Dots indicate survey effort.

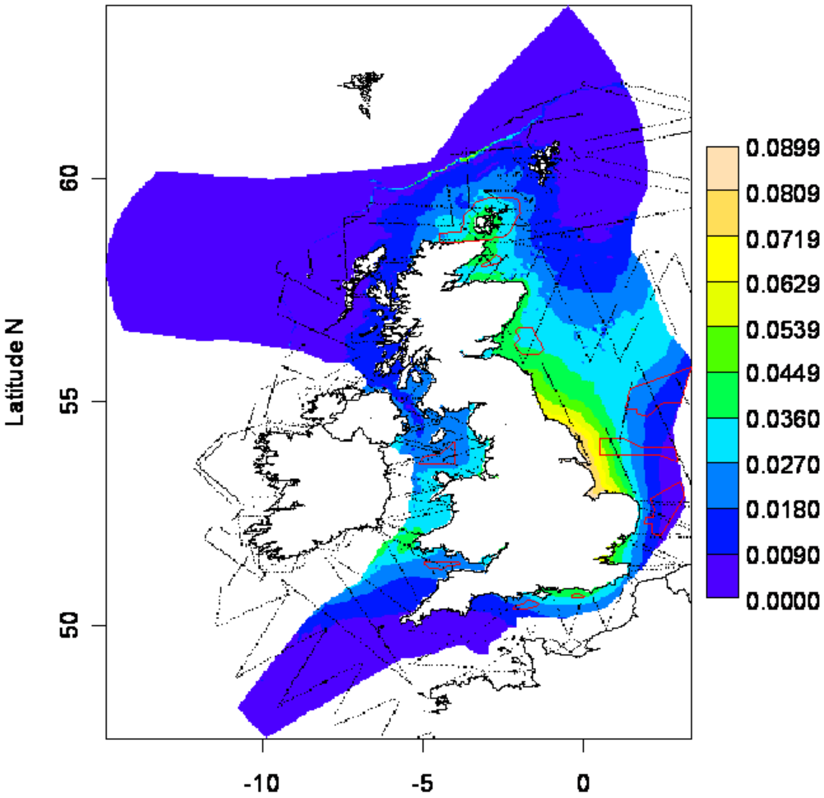


Figure 3: Predicted density surface for minke whales (animals/km^2) from SCANS-II at 2 min^2 grid resolution. R3 zones are shown in red. Dots indicate survey effort.

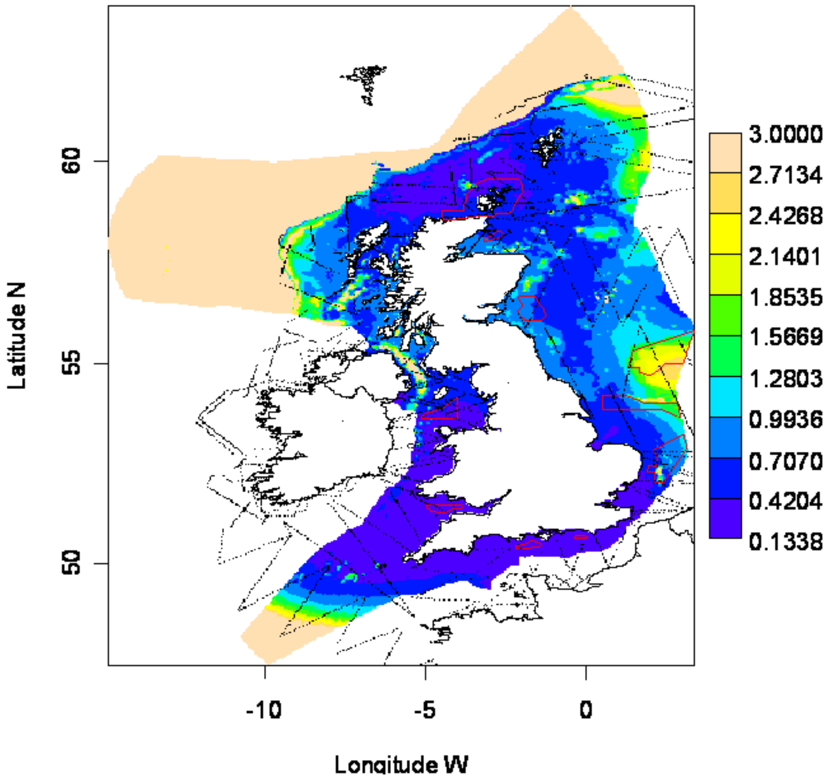


Figure 4: Coefficients of variation associated with the minke whale density surface. R3 zones are shown in red. Dots indicate survey effort.

4.3.3 Power analysis to inform survey design

Effort and survey method

Power analysis has been applied to the SCANS-II (SCANS-II, 2008) data to demonstrate its use at the planning stage of monitoring surveys in order to:

i) Determine how much effort is required to obtain a desired CV, and therefore power

ii) Compare the performance of methods to inform a decision on the best approach.

The details on the calculation of power are given in section 10. Power analysis has been performed on absolute abundance data from the SCANS-II ship and aerial surveys. The SCANS-II project also compared methods that generate relative abundance measures, and the results of this are used in this work.

Absolute abundance methods

The power of two absolute abundance methods, double platform shipboard surveys and racetrack aerial surveys, has been compared. Shipboard detections of harbour porpoise and minke whales made in three strata (V, U and P) (Figure 5) along with effort in those areas were used to approximate uncertainty in abundance for various amounts of ship-based effort. Similarly, harbour porpoise aerial survey detections in strata O, N, J and B (Figure 5) were subjected to the same power analyses as the shipboard data. There were insufficient minke whale data for analysis.

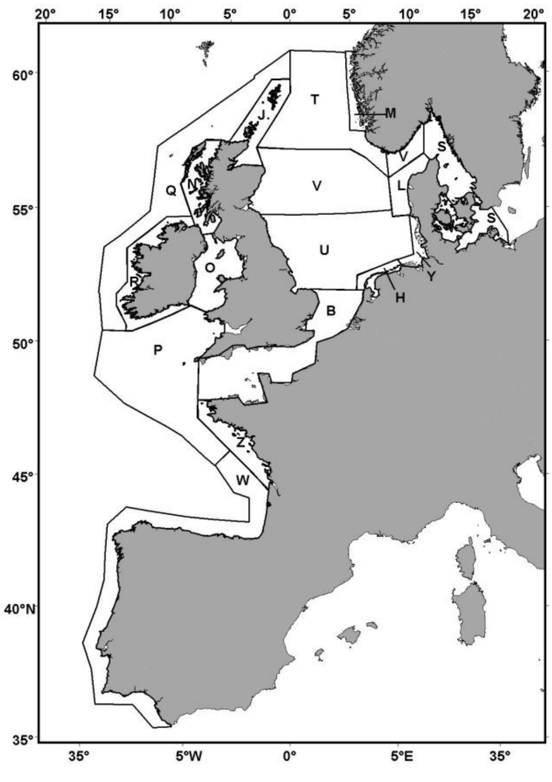


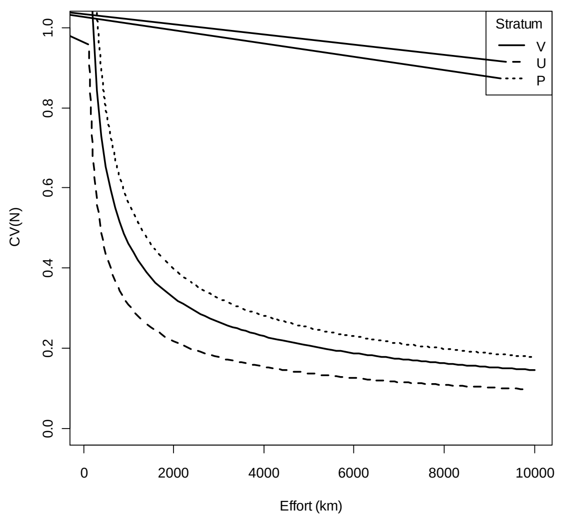
Figure 5: Survey strata covered by ships and aircraft during the SCANS-II surveys of July 2005. Taken from SCANS-II, 2008.

The relationship between the amount of survey effort and uncertainty is shown for harbour porpoise (Figure 6) and minke whale (Figure 7).

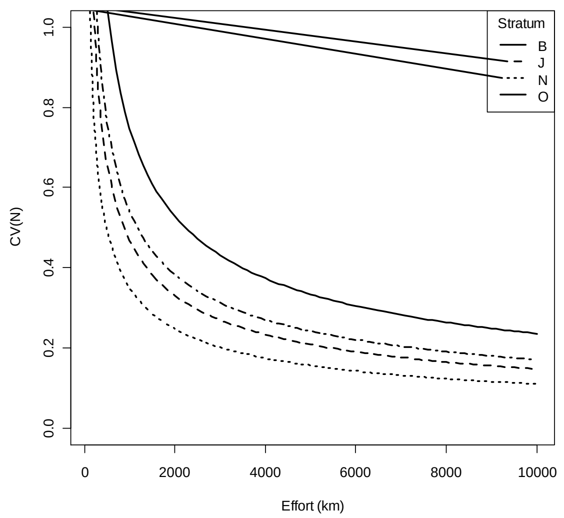
Regardless of survey method, the precision of estimates is best for the stratum with the highest density; in this case, U for the shipboard surveys and N for the aerial surveys. For example, consider Figure 6 (a): if 4,000 km of effort were achieved in each of the strata, then CVs of ~0.17, 0.21, and 0.30 for strata U (highest density), V and P (lowest density) respectively would be generated. High density areas will generate more sightings during surveys which in turn will generate more precise abundance estimates (i.e., with lower CV).

Comparing the curves for stratum U and N in Figure 6 (a) and (b), respectively (because they have comparable encounter rates of harbour porpoise), a CV of 0.2 can be achieved with less effort for shipboard surveys compared with aerial. This is due to the higher encounter rates that are generated with shipboard surveys compared to aerial in areas of comparable density because of the lower survey speed. More time spent searching is likely to generate more sightings, thus improving CV.

The effect of local density on CV is also highlighted when you compare methods across species; more effort is required to achieve a good CV for minke whales (Figure 7) than harbour porpoise (Figure 6 a) because they are less common e.g., for 4,000km, in stratum V, CV for minke whales is ~ 0.4 whereas CV for harbour porpoise is ~ 0.25.



(a)



b)

Figure 6: Amount survey effort (km) and associated uncertainty (CV) for SCANS-II harbour porpoise detections for two absolute abundance survey methods; (a) double platform shipboard surveys and b) race-track aerial surveys.

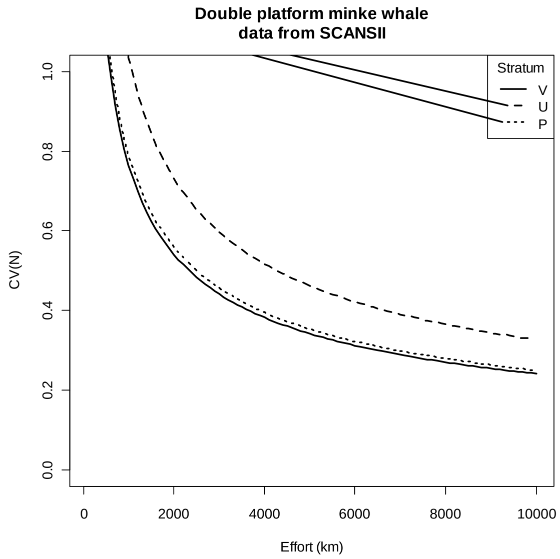


Figure 7: Amount of survey effort (km) and associated uncertainty (CV) for SCANS-II minke whale detections for double platform shipboard surveys.

Relative abundance

As part of the SCANS-II project, the relationship between CV and survey effort for four different monitoring methods that generate measures of harbour porpoise relative abundance was investigated. The four methods were: single platform aerial visual (2 cetacean observers), single platform ship visual (2 cetacean observers), ship visual seabird observer (as a proxy for a single cetacean visual observer) and towed acoustics. Figure 8 shows the result of comparison of effort and CV for the shipboard methods in block S and the aerial survey analysis (from block (L) located closest to those used in the shipboard analysis). The curves for the shipboard methods are almost identical but approximately twice the effort is needed for the aerial observers to obtain a similar CV.

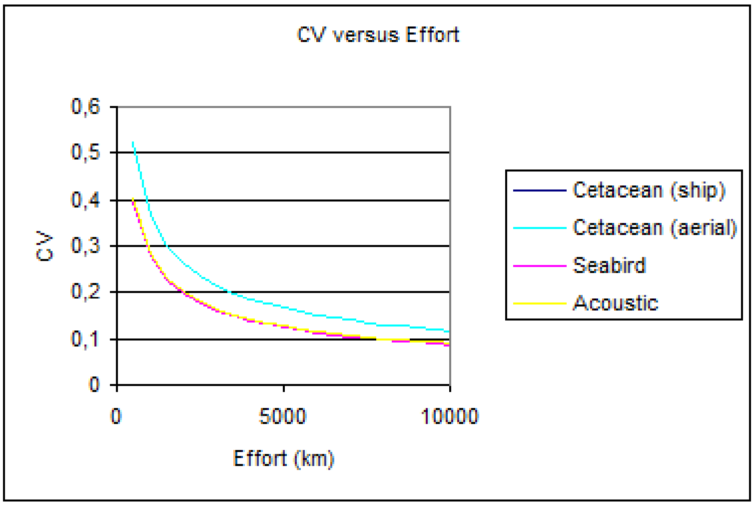


Figure 8: CV versus effort for four different monitoring methods. The data for cetacean (ship), seabird (proxy for single cetacean observer) and acoustic were collected on SCANS-II survey block S and the cetacean (aerial) data were collected in survey block L.

Generally, the amount of effort needed to achieve a certain power is less for relative than absolute abundance methods. For example, consider strata V (Figure 6) and S (Figure 8) which have comparable porpoise densities, the amount of effort required to achieve a CV of 0.4 is approximately twice for the absolute abundance shipboard method (block V) compared to the relative abundance shipboard methods (block S).

4.3.4 Power to detect change

The ability to detect population changes is an important consideration for an assessment of the Favourable Conservation Status (FCS) of marine mammal species. Population level monitoring is a concern for Regulators as a time series of precise population estimates will need to be assessed using power analysis to assist in FCS assessment. The monitoring work undertaken by Developers is not aimed at assessing populations, and their use of power analysis should primarily be to assist survey design by indicating a level of effort required to achieve an acceptable CV.

4.3.5 Longevity of monitoring schemes

A time series of precise abundance estimates will improve the power and shorten the period required to detect change within a population. A faster rate of change will also shorten the period it takes to detect a change. Therefore, careful consideration needs to be given to the frequency of surveys; they should be carried out more regularly if rapid changes are expected and less frequently if small changes are more likely. The resources required to sustain ongoing monitoring should be based on the likely length of time required to assess whether a change is occurring or not. Trends in populations are detected over a period of years, rather than months.

Figure 9[12] shows the number of years of monitoring needed to achieve a power of 0.8, for a range of annual rates of population change and coefficients of variation (CV). For example, with a relatively good CV of 0.2, it would take 10 years to detect a 10% annual change in the population; to detect an annual change of 50% within 5 years, the CV would have to be approximately 0.18.

[12]Graph was generated using freely available code at http://www.creem.st-and.ac.uk/len/software.html

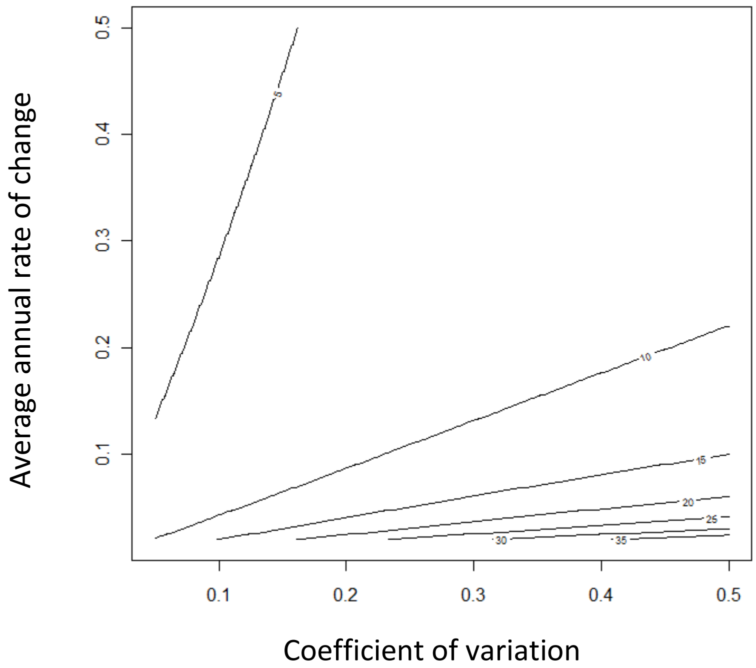


Figure 9: Time taken (in years) to detect varying rates of population change (with power of 0.8) given varying levels of precision (CV).

4.3.6 Detecting change pre- and post-consenting

Power analysis

A power analysis was carried out to investigate the power to detect a 50% change in abundance between two consecutive surveys within a two-year period. The two estimates were chosen to represent results from two surveys, one each in the pre and post consent phases of the development. Detecting the halving or doubling of a population has been suggested as a minimum benchmark (Maclean *et al.*, 2009); a 50% decline or increase in the local density around a wind farm is a considerable change. This level of change at several sites could have a significant impact at the population level and this would need to be assessed in an appropriate framework.

The SCANS-II absolute abundance ship and aerial survey data for harbour porpoise and minke whale were used to investigate the amount of effort needed to detect a change of 50% between the pre and post consent surveys within selected strata for which data were available. The graphs indicate that the probability of detecting the change for the harbour porpoise (Figure 10a, b) is greater than for the minke whale (Figure 10c), due to the former being more common. Power to detect a change is generally poor even with a large amount of survey effort (e.g. ~60% power for 6,000km of double platform shipboard effort for harbour porpoise in stratum U).

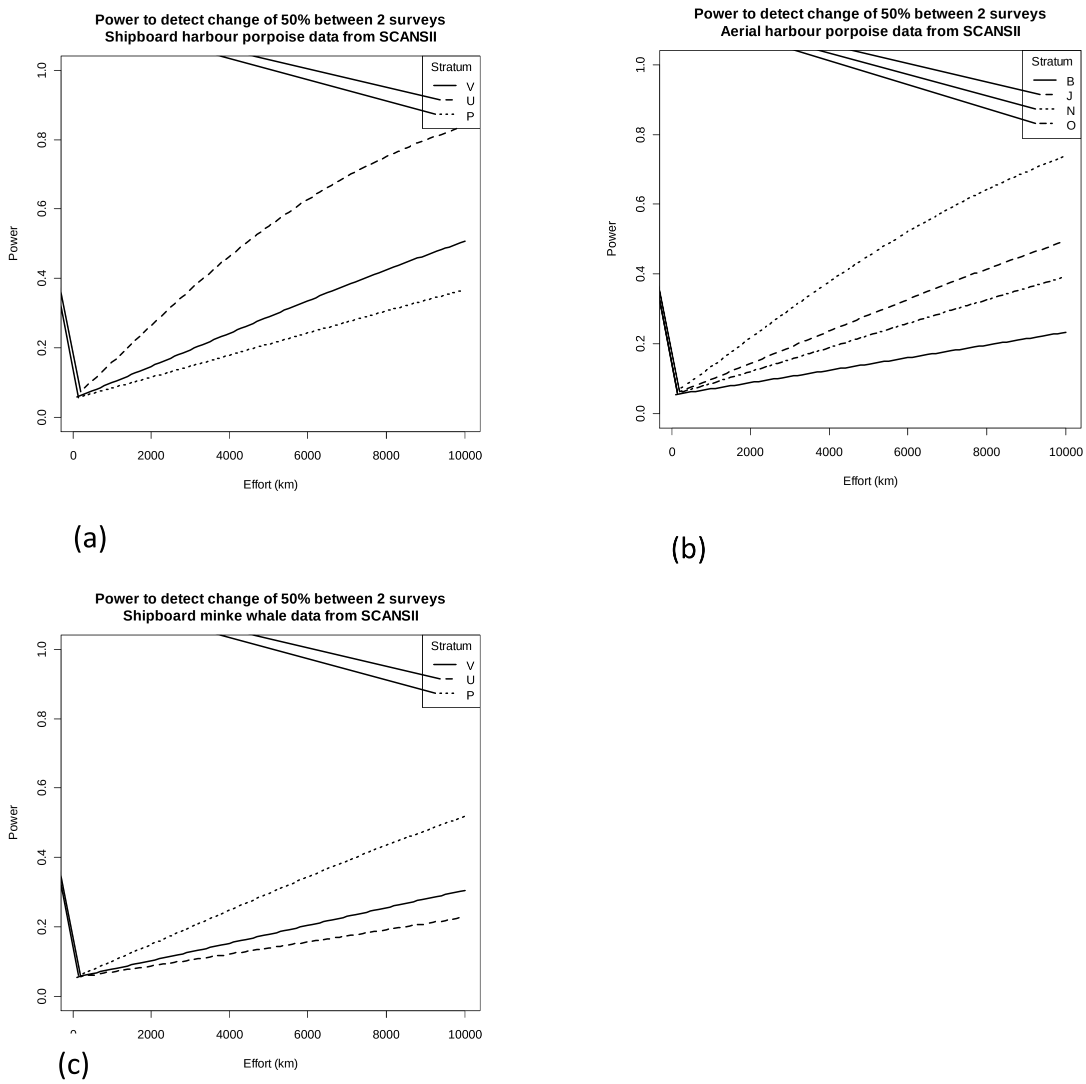


Figure 10: Power to detect change as a function of effort (km) for: (a) shipboard harbour porpoise survey data; (b) aerial harbour porpoise survey data; and (c) shipboard minke whale survey data.

Statistical significance

Developers will primarily be interested in any significant changes between local densities of animals during the pre and post-consent phases. Power analysis can be applied to a series of estimates to look at this; however, if there are few estimates on which to base the analysis the result will be poor (demonstrated previously).

Power analysis is more suited to detecting trends over long time periods. Within the time period of the consenting process, it is more realistic and meaningful for the Developer to test differences between abundance estimates within the pre and post consent phases for statistical significance. One approach is to use a Z-test (Buckland *et al.*, 2001). If a significant difference between consecutive estimates is detected, then this can prompt further investigation into the causes of it. Tests of statistical significance can be applied to compare temporal estimates within one site or spatial estimates across sites (either development or "control" sites).

4.3.7 Detecting long-term changes

As part of the SCANS-II project, an analysis was performed to look at the power required to detect a 5% per annum exponential decline over ten years with annual monitoring and a one-tailed alpha significance level of 0.05 (assuming that CV is constant and not related to abundance). The power of different methods to detect a change was investigated for harbour porpoises for methods that generate a monitoring index (e.g. relative abundance or detection rate) rather than absolute abundance: 1) single platform aerial visual (two cetacean observers), 2) single platform ship visual (two cetacean observers), 3) ship visual seabird observer (as a proxy for a single cetacean visual observer) and 4) towed acoustics. Data were used from four survey blocks (i.e. four different ships) (see Figure 5) where the methods (except aerial survey) had been used simultaneously during the SCANS-II surveys in July 2005. The data for the aerial survey analysis was chosen from a block (L) located closest to those used in the shipboard analysis. The results are shown in Figure 11.

The calculation of power for relative abundance data is based on a number of assumptions:

- changes in the relative abundance observed during the surveys are indicative of changes in absolute abundance (note this is a critical assumption that may not be valid if there is bias within the estimate of relative abundance and if that bias varies in time and space);
- logistical, biological and environmental factors stay the same between surveys;
- there is no additional variability affecting the index from e.g. ship's equipment, observers, weather etc.

Unless all these other factors stay the same between surveys, the calculations and resulting power will likely overestimate the power to detect trends.

The chosen change of 5% is relatively small, yet a ten-year series of annual surveys with approximately 2,500km of effort in the survey strata would suggest the change could be detected with reasonable power (>0.6). This analysis also shows useful comparisons between the powers of the different relative abundance methods to detect the same change. In all cases, the shipboard visual and seabird observer perform best. It is encouraging that the single cetacean (seabird) observer performed comparably with the two dedicated cetacean observers. The towed array performed poorly in all cases expect block S. This shows that the power of the method varies considerably between vessels, performing best for quieter ones (Block S).

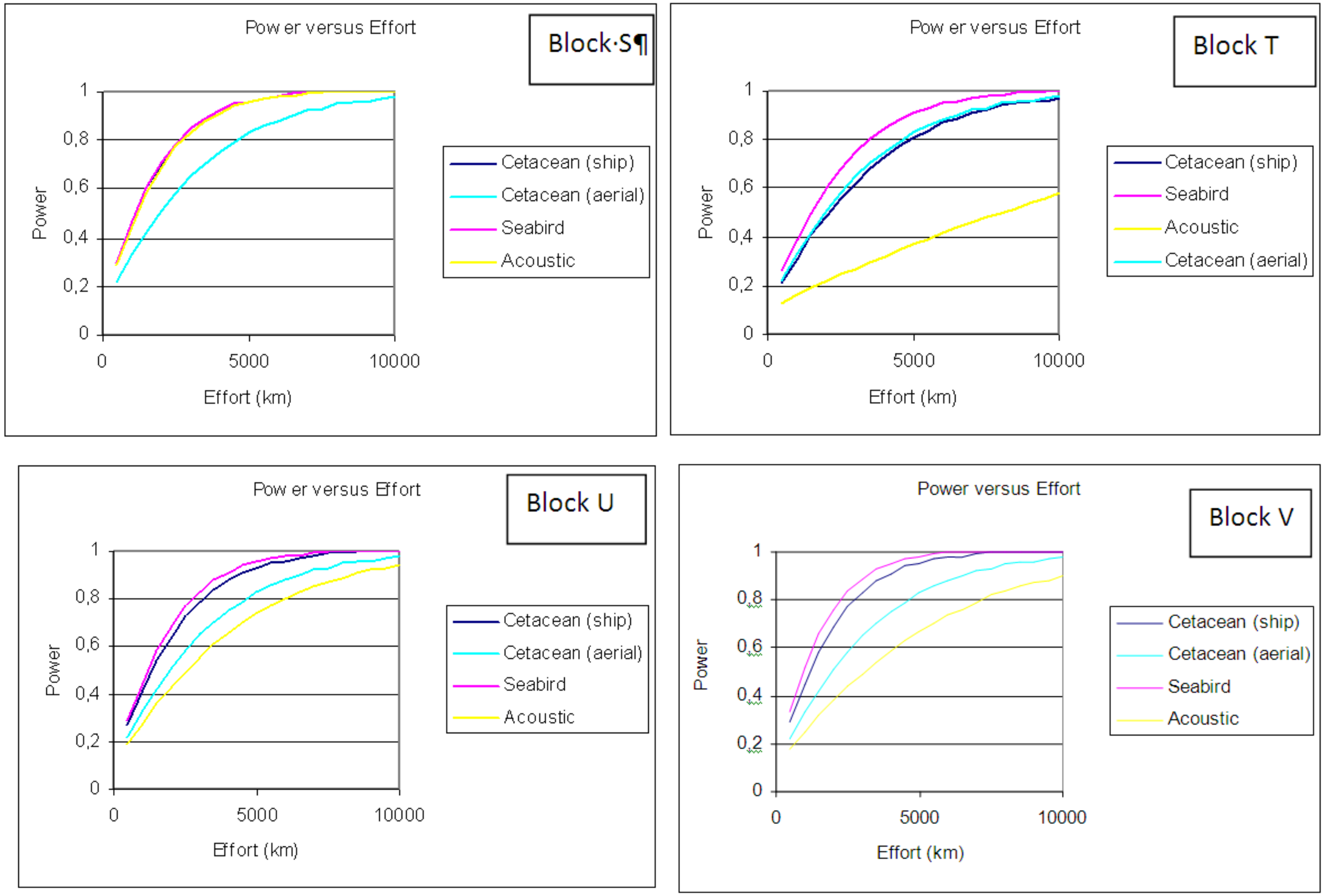


Figure 11: Power versus effort for four different vessel based monitoring methods. The data for cetacean (ship), seabird (proxy for single cetacean observer) and acoustic were collected on four vessels each operating in a different block. The cetacean (aerial) data were all collected in survey block L

4.3.8 The basic cost of monitoring: cost/benefit analysis

The cost of monitoring marine mammals is largely dependent on the method used. It is useful during the planning stages of a monitoring program to offset the costs against the benefits of the work. A cost/benefit analysis can often justify the work needed but also inform the decision about which method will be most cost effective in achieving the desired outcome.

Factors affecting cost

The choice of monitoring method used is often influenced by not only its suitability, but also its cost as finances may be limited. The cost of a monitoring program depends on many factors, including cost of equipment, platform hire, personnel, travel and analysis. In all cases, the costs of analysis will depend on the metrics required. The more complex the analyses, the more expertise required and generally, it will take longer to process. We have stopped short of providing actual costs due to the number of associated assumptions. Though note that in Table 9 we provide standardised costs (based on similar amounts of effort) to give an example of the scale of cost differences between some of the most common methods for cetacean surveys.

Dedicated cetacean surveys

In general, aerial surveys complete more survey effort in a given time period than ships because of the higher speed, and the benefits of this become apparent when the relative costs of the two platforms are compared (see Table 9). Aerial surveys require three (single platform - SP) or five (double platform - DP) observers (in each case, one person is acting as navigator; note also that these numbers will depend on methods being used). Similarly for ship based line transect surveys, double platform methods require a larger ship with two rather than a single observation platform, twice as many observers as single platform (8 versus 4), and the data processing/analysis is more complex for double platform analysis. Acoustics based line transect surveys require just a single operator. Equipment costs can vary considerably from high-tech automated systems to those requiring more manual input, but still meeting all requirements.

PODs are the most widely used autonomous acoustic data logger in the UK, and the exact number required will depend largely on the size of the survey area, and the desired degree of redundancy.

Dedicated seal surveys

The suggested sample size for a telemetry deployment is 12 animals based on best practice. Alongside the costs for core equipment, significant costs are also required for staff time and consumables during the deployment, and analysis of the resulting data. The costs for analysis would be comparable for cetacean telemetry data, although fewer staff may be required during the deployment of tags. It should also be noted time taken to deploy tags can be highly variable. Additionally, if relative maps of habitat usage are to be generated for the telemetry data, an index of the local population size is required. In the case of seals this information should be provided by undertaking dedicated aerial monitoring surveys concurrent with the telemetry deployment.

Costs for aerial surveys of pinnipeds can also be highly variable dependant on the aircraft and technique being employed. Helicopter based thermal image surveys are the most expensive and labour intensive approach when presented in this way. However, aerial techniques allow comparatively large areas of continuous coast line to be covered during a single day when compared to boat or land based counts.

4.3.9 Comparison of methods: cost *vs.* quality

Dedicated cetacean surveys

The cheapest method for cetacean monitoring is likely to be the use of autonomous acoustic data loggers in the form of PODs. Each POD is relatively cheap (~£3,000.00) and can collect data over a period of months, thus providing data on seasonal occurrence. However, the number of PODs required for a study is a factor of the size of the area surveyed. In addition, there may be greater costs than anticipated due to the loss/damage of PODS and expense in deployment and recovery. Bearing this in mind, subsequent loss of data also needs to be considered. Whilst the method is relatively cheap, the quality of data from them might also be considered "poor" (depending on objectives) as the acoustic detections can only be distinguished between "porpoise" and "dolphin", and there is currently no means to link the number of detections to the numbers of animals.

The more costly methods tend to give more meaningful metrics of abundance. Double platform shipboard surveys are likely to be the most expensive method but the data generated from them will give precise, unbiased absolute abundance estimates. For long-term comparison of abundance estimates (trends), detectability must be estimated and incorporated into abundance estimates (i.e. estimates are absolute). This is because over time, the behaviour (and hence detectability) of the animals may change. If this was not accounted for then conclusions regarding observed trends in relative abundance may be erroneous. When considering short-term changes at a relatively local scale, it might be sufficient to use relative measures of abundance, which in the case of boat-based surveys for example are considerably cheaper. However, such estimates will still require periodic validation against absolute abundance estimates over longer time frames.

It should be noted that one-off shipboard and aerial surveys will not provide data on seasonal abundance and distribution; to use these methods to collect seasonal data would require seasonal surveys, and the costs would be significantly higher. However, most of the equipment will survive the life-span of the monitoring program and so these would be one-off costs.

The main difference between single platform and double platform aerial surveys is that double platform surveys require more observers; a plane carrying more observers may suffer increased fuel demand because of the extra weight and thus have more limited range and flight duration. Additional equipment may be needed and also more analysis time. The basic charter cost of the platform will not differ between single and double platform aerial surveys, because regardless of the survey methods being used, twin-engine planes are a legal requirement for offshore surveys. The price differential between aerial surveys of relative and absolute abundance surveys is not as substantial as that for ship-board methods.

4.3.10 Cost per unit effort – dedicated cetacean surveys

Absolute costs are difficult to evaluate in terms of "value for money" because each method generates different amounts (and quality) of data and metrics. An attempt to rationalise the costs of the different methods was done by creating an index based on cost per unit effort (CPUE; Table 9). In doing this, we have made a number of assumptions, and in order to realistically compare different methods (e.g. ship versus aerial) we have ensured that costs have been based on the same amount of total effort (e.g. kilometres of trackline surveyed). We have based costs on those from the SCANS-II surveys, with some updated figures where necessary.

In the first instance, this approach is used to compare platform-based methods. The index is based on daily costs which, for simplicity, include only charter costs and observers. The average number of hours per day available for data collection is derived from the SCANS-II survey, except in the case of aerial surveys where we have based our calculations on hourly charter rates and assumed the ratio of transit/survey time. The conversion from "cost per hour" to "cost per km" is made using average speed of the platforms (10 knots for ships, 185km/hr for aircraft). No actual monetary values are given; instead, costs for each method are expressed relative to the cheapest method – PoOP towed array. Thus when considering daily field costs, ship-based DP LT surveys are 51 times more expensive than PoOP towed array; whereas aerial DP LT surveys are 29 times more expensive; and so on. Similarly, when considering cost per kilometre of effort, ship-based DP LT surveys are 205 times more expensive than PoOP towed array; and so on.

Table 9: Standardised costs of visual and acoustic cetacean survey methods. Daily costs and CPUE figures are expressed relative to the cheapest method (PoOP towed array).

Method	Hour on effort	Daily field costs	Cost per hour of effort	Cost per km of effort
Ship-based DP LT	5.5	51	205	205
Aerial DP LT	4	29	158	16
Ship SP LT	5.5	26	103	103
Aerial SP LT	4	27	147	15
Towed acoustic array	22	6	6	6
PoOP visual survey	5.5	4	16	16
PoOP towed array	22	1	1	1

PoOP towed array survey gives the best value for money in terms of pounds spent per km of effort data returned. The cost effectiveness of this approach is due to there being no charter costs which is the biggest outlay for boat-based surveys; similarly, the cost of PoOP visual surveys is a fraction of the ship-based DP LT approach for this reason. Aerial surveys also perform well because they can cover a large amount of trackline in a relatively short-period of time which reduces charter costs. Again, the difference in cost per unit effort between SP and DP aerial surveys is minimal, and overall aerial surveys are far cheaper than boat-based surveys. The data collection period for acoustic methods is longer than visual methods as data can be collected during the night and in worse sea conditions.

4.3.11 Power vs. costs

The previous sections demonstrate the wide range in costs for conducting monitoring surveys. Using the approach used in the Power Analysis section, the SCANS-II data were used to compute power associated with various amounts of shipboard or aerial effort from the SCANS-II surveys. These effort values were then converted to monetary values with information regarding platform hire and labour costs (Figure 12).

There are several broad conclusions that can be taken from these results. The most obvious is that it is going to be difficult, expensive, and time-consuming to detect trends between absolute abundance surveys. In most cases, power to detect a 50% change between two surveys is very poor, even with significant expenditure. Precision improves with effort which means spending more money. However the results show here that for DP boat-based surveys of harbour porpoise (Figure 12a), even a total budget of £700,000.00 would only achieve power of between ~0.17 and 0.6 (depending on porpoise density). For minke whales the picture is even bleaker (Figure 12b). Thus for some species and in some areas, sufficient power will never be achieved to have confidence in the results, irrespective of budget.

The power/cost relationship improves dramatically for single platform (relative abundance surveys; Figure 12c, d). For boat-based harbour porpoise surveys, the same power is achieved with approximately half the budget. Given then the prohibitively expensive nature of DP surveys, and the improved power/cost ratio of SP surveys, this is further motivation to recommend relative abundance monitoring for short-term and localised effects.

A further recommendation from these results is that aerial surveys (Figure 12e, f) are significantly more cost-effective than boat-based surveys. While this provides strong motivation to use aerial surveys where possible, there are other factors that need to be considered; it is unlikely that aerial surveys will be suitable for all R3 zones and a more cost-effective and practical approach will be to collaborate across developments for a single, large scale boat survey. Where aerial surveys are a practical alternative, it makes sense to carry out absolute abundance surveys, since these are not much more expensive than relative abundance surveys. This is in stark contrast to differences in boat-based surveys. The extra costs reflect the additional observers and more complex analysis.

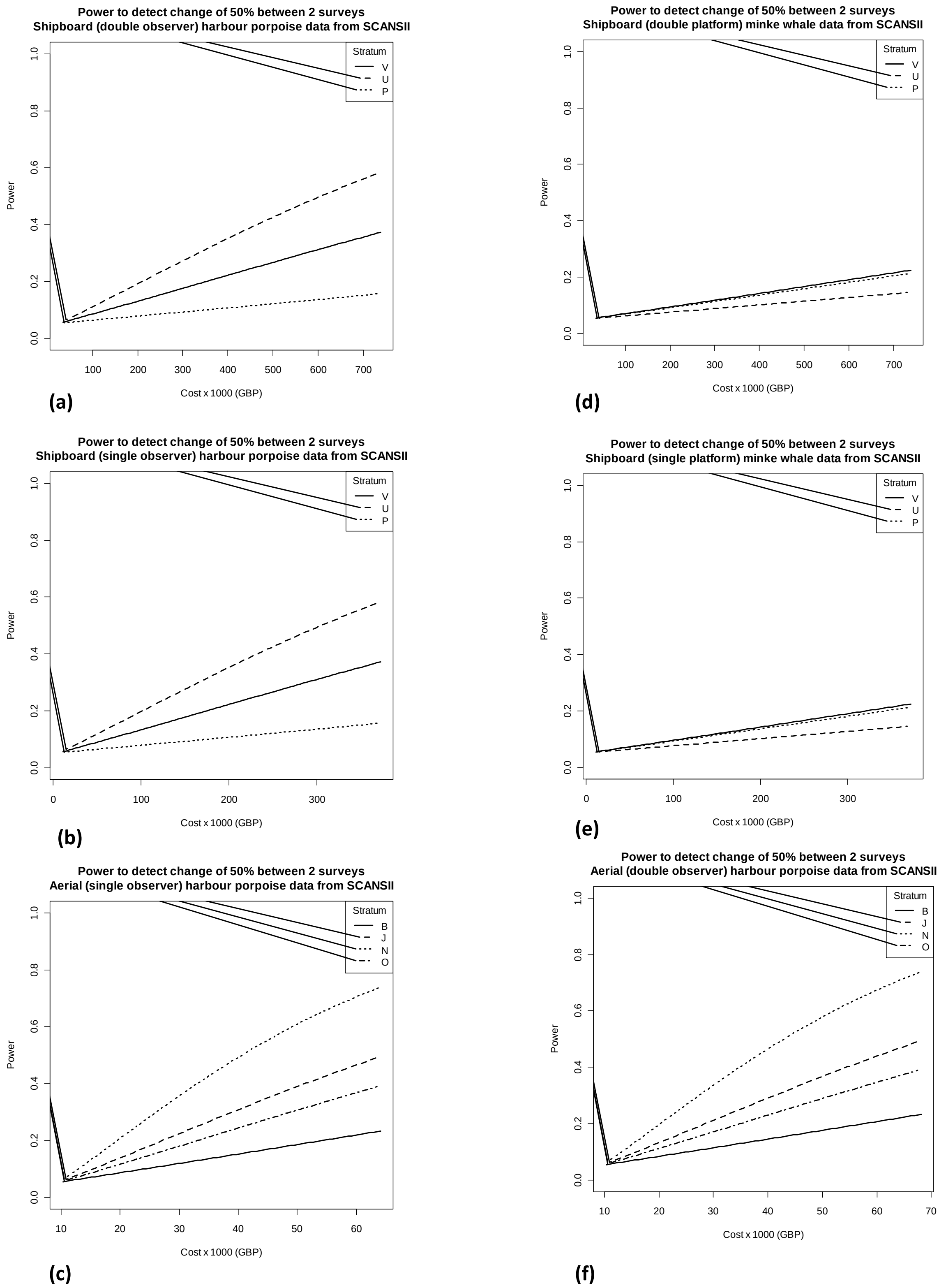


Figure 12: Power to detect a 50% change between 2 surveys and associated costs (x 1000 GBP) for harbour porpoises and minke whales; ship-board DP (a, b); ship-board SP (c, d); aerial SP and aerial DP (e, f).

5 Objective 3: Developing generic marine mammal monitoring scenarios for marine renewable energy projects

Summary

- In order to proceed rapidly to reduced levels of precaution, it is essential to develop a system for the co-design and sharing of data between the monitoring programmes for different developments.
- Attention to short-term impacts need to be given greatest attention at the early stages of development and the monitoring programme needs to be built around the need to eliminate certain activities (such as pile driving) as having significant impacts.
- Pre-consent monitoring focuses on site characterisation through baseline surveys and the facilitation of consenting through EIAs (for EPS) and Appropriate Assessments (for SACs).
- Post-consent monitoring focuses on impact assessment (animals displaced, injured, killed, and barrier effects).
- Method choices are driven by the survey objective and characteristics of the development site; target species, bathymetry, development phase, technology and scale.
- In general:
    - Aerial surveys may be impractical for long-distance offshore sites.
    - Aerial surveys are more practical in sites close to convoluted coastlines where ship navigation is difficult.
    - Fixed point surveys are restricted to small-scale, nearshore sites.
    - Pinniped haul out counts need to be concurrent with telemetry deployments to generate accurate at-sea distribution maps.
    - Post-consent survey design is complicated by the presence of renewable energy devices at the site; however, the pre-consent design should be maintained as closely as possible.
    - Photo-ID, strandings and opportunistic sightings have limited application in the context of marine renewable developments.
- Ship-based visual and towed-array acoustic surveys can be carried out concurrently.
- Combining surveys across sites is recommended where possible as a cost-saving measure and to mitigate resource limitation. Such surveys may also provide more biologically meaningful results.
- Marine mammal surveys could be combined with bird surveys, provided observer teams remain separate and independent.

5.1 Introduction

The choice of monitoring method is dependent on several factors relating to the physical and biological features of the area and the characteristics (scale and type) of the renewables development. A method appropriate to one development will not necessarily be suitable for another. Depending on the monitoring objective and constraints, the use of more than one method may be necessary and all approaches will need to be agreed with the Statutory Nature Conservation Advisers.

The most appropriate marine mammal monitoring methods have been developed under a range of different generic industry scenarios.

Whilst there are some generic rules with regard to which monitoring methods are best suited to what aim, there is no panacea. Specific monitoring surveys need to be designed on a site-by-site basis. This section advises the most appropriate method(s) given a particular scenario.

It should be emphasised that each location and each development will require to design its own purpose-made monitoring approach and this will need to be agreed in advance by the appropriate statutory nature conservation Advisory body.

An underlying function of the following approach is to encourage an adaptive approach to monitoring and measurement. This means that we need to learn as much as possible from each development. Adaptive approaches involve more than "deploy and monitor", a commonly used but slightly inaccurate term, because they require pre-deployment activity, including sufficient base line to be able to detect changes, and they also require the collection and dissemination of data to the wider community so that everybody can learn from the experience. There are significant barriers to adaptive approaches that need to be overcomes. In particular, these involve:

1. The tendency for individual companies to retain data from monitoring and measurement activities under the guise of commercial confidentiality and

The possibility that these approaches could demonstrate significant effects leading to licenses being withdrawn either temporarily or permanently. Consequently, we recommend that a condition on all licenses to Developers should be that

1. **All environmental data collected as a result of an approved monitoring programme should be deposited in a central database that can be accessed under an agreed protocol.**
2. **At an early stage of developments there should be greater consideration of the potential effects of short-term effects (e.g. such as pile-driving) and that these should be tested specifically relative to other effects, such as barrier effects or risk of collision**.

As experience of a particular development and generic development of a similar type builds it may be possible to become less precautionary but the rate at which precaution can be reduced will depend upon the experience being built by the whole industry so it is advantageous to all Developers to share data.

5.2 Monitoring objectives

Prior to choosing methods and designing a survey, the objectives of the monitoring programme must be defined. These will be determined by a number of factors, including site characteristics and relevant legislation.

Developers have to ensure that the local abundance and distribution of certain European Protected Species (EPS; all cetaceans in UK waters) are not significantly affected and that no EPS is injured or killed. Developers have to ensure also that no significant disturbance (see Text-box 1 in Section 4.1 concerning specific Scottish regulations) or habitat degradation is caused in SACs, which would have adverse effects on site integrity. The information gathered for EIA should be sufficient to assess the likelihood of an offence, the effectiveness of any mitigation and whether there is a need for a licence. A similar approach will be required to under the Marine (Scotland) Act 2010 for licensing any effects there might be upon seals. The monitoring programme needs to address the issues of protection of EPS and the need for licensing.

The following objectives should be set for monitoring programmes at each phase of development:

1. Pre -consenting; all technologies:

   Establishment of baseline, local characterization – collection of data on species presence/ distribution, abundance and habitat use (these data will inform impact assessment);
2. Post-consenting (construction and operation):
   a) Wind

      Impact monitoring – assess changes in animal distribution/ density, monitor number of animals displaced/ injured; collect relevant information on animal behavior and other relevant biological metrics, if possible;
   b) Wave and tidal

      Impact monitoring - assess changes in animal distribution/ density, monitor number of animals displaced/ injured/ killed; assess barrier effects; collect information on animal behavior and other biological metrics, if possible.

5.3 *Defining monitoring scenarios*

Scenarios have been defined by the phase (pre- and post-consent), scale (demonstrator and commercial) and technology (wind, wave and tidal) used in a development. In the development of monitoring methods, consideration of the species present also needs to be made (EPS and SAC). Some generalities about the best approach to monitoring marine mammals can be made but they are based on a number of assumptions, which are detailed below. These scenarios also relate to the regulatory requirements as outlined in section 3.2.

5.3.1 Phase-dependent monitoring

The purpose of monitoring marine mammals changes with the phases of the development. Early stage, pre-consenting monitoring is primarily aimed at site characterisation through baseline surveys, and the facilitation of consenting through EIAs (for EPS) and Appropriate Assessments (for SACs). A distinction can be made between (or baseline) surveys and *impact* monitoring. The former may occur over a number of months or years, depending on the data deficiencies identified during scoping, whereas pre-construction *impact* monitoring may therefore be relatively short-term. For example, a 3-4 week survey might in some cases provide enough data to enable a robust density estimate that can be used for impact assessment compared with subsequent estimates of densities during installation and operation.

Thus, during post-consenting stages (construction and operation), long-term periodic monitoring should be aimed at detecting and determining the level of any impact, and for contributing to mitigation procedures (for wave and tidal particularly) and monitoring their success.

As development proceeds, the resulting infrastructure may prevent design-based surveys and analysis. Post-construction monitoring of all technologies could be influenced by the infrastructure present, and this will need careful consideration in consultation with the Regulators at an early stage. Taking an offshore wind farm as an example; at the pre-construction phase it will be possible to design a line-transect survey and generate design-based density estimates. As the construction of the wind farm proceeds, positioning of line-transects will be influenced by the presence of infrastructure in the survey area and a randomised design will be difficult. Traditional line-transect sampling requires that lines are located according to a formal (and random) sampling scheme (resulting abundance estimates are referred to as design-based). Assuming it will be possible to plot survey lines through an operational wind farm, line-transect data can still be collected; and as long as representative coverage has been achieved, density and abundance estimates can be derived. However, the resulting analyses and subsequent results will be model-based[13]; generating surface density plots from which abundance can be inferred (Hedley *et al.*, 2004).

[13] This is a technical distinction: survey design that incorporates some sort of randomisation result in equal coverage probability (i.e. any point within the survey area has an equal probability of being sampled), and resulting analyses are *design-based*. If survey design is constrained – e.g. because of the presence of wind turbines – then coverage probability is not equal. In this case, the correct analytical approach would be to model surface density.

Pre-consenting

In order to produce an EIA (EPS) or provide information for an Appropriate Assessment (SAC), Developers will need to characterise their site with respect to species presence, density and habitat use. For some areas, adequate data may already exist, and a thorough assessment of existing data and whether there will be a significant added value of collecting more data should be the first stage of any pre-consenting environmental monitoring plan. Where more data collection is necessary, then surveys should be undertaken. Temporal and spatial data on marine mammals within the development area could, but only in very limited cases, be used to plan mitigation of potential impacts; for example, avoiding the use or restricting timing of noisy construction methods if there are areas or periods with regularly high densities of animals, or in the case of wave and tidal, positioning devices in a way or area that would minimise barrier effects. Baseline data are crucial as a standard against which future measurements can be compared, allowing impacts to be assessed.

There is the potential for large-scale surveys of multiple sites during this phase to collect absolute abundance data. A coordinated approach to monitoring the licensed Round 3 wind farm zones, for example, would provide more meaningful data in a population context and could be more cost effective (see section 5.5).

Post-consenting

Post-consenting monitoring in general should focus on testing the predictions made during the impact assessment. In the case of wind farms, this will be numbers of animals displaced or injured. For wave and tidal installations, this will expand to include numbers of animals displaced or injured, but also animals killed, and barrier effects.

Construction and operation

Changes in animal distribution, density and behaviour are most likely during the construction phase as a result of increased human activity in an area (such as noise, boat traffic). Continuing monitoring throughout the operation phase might allow an assessment to be made of the longevity of any effects and whether distribution, density/abundance and other biological metrics return to baseline. Behavioural data and other metrics such as body condition or reproductive success might be particularly useful in the context of understanding potential impacts of wave and tidal devices on animal's habitat use and reaction to devices.

The methods to be used during this phase will depend on the characteristics of the devices and construction plans. For example, visual and acoustic ship surveys may be impractical during post-consent surveys, though this will depend on exclusion zones around turbines, and whether exemptions could be granted to survey vessels. In this case, surveys would be feasible, though note that resulting abundance estimates would be model-based, and not design-based.

Further operational issues will include whether aircraft can fly at a suitable survey height over operational wind farms. Through-out this section of the report, it should be assumed that 'aerial surveys' refer to traditional, observer-based techniques, and not high-definition (HD) photographic surveys. For example, in some cases aerial surveys are not recommended due to likely height restrictions around operational wind-farms. HD surveys are able to maintain higher altitudes while 'on effort' and would therefore be suitable for operational wind-farms. However, and as discussed in Section 5, such surveys are not yet sufficiently developed to warrant full recommendation here.

It may be possible to collect useful data from platforms of opportunity (PoOPs) travelling to/through the development site to supplement /compliment dedicated effort. PoOPs are viable for most scales, technologies and phases of development but properly designed surveys will always provide stronger inference and should be given preference. An additional consideration is that sites for offshore wind developments are likely be away from main shipping and ferry routes, so there may be limited capacity to gather data opportunistically.

Pre-consent survey design should be maintained as closely as possible throughout the post-consent monitoring work.

Decommissioning

The life-span of renewable farms is on the scale of decades. It is unlikely that such long-term monitoring would be required or that the resources to plan for this level of monitoring would be available for the project's duration. At the time of decommissioning, surveys may be reinstated using techniques akin to those used during construction if the effects of decommissioning are of interest. In this study we have focussed the recommendations on methodologies for baseline data collection in order to facilitate consenting, and the construction and operational phase of development, rather than decommissioning.

5.3.2 Scale-dependent monitoring

The scale of the generic scenarios has been split by demonstrator, commercial and zone[14]. It is assumed that any development with a total potential power output of equal to or less than 10MW (tidal and wave; from either an individual unit or an array); or equal to or less than 100MW (wind; from either an individual unit or an array) is a demonstrator. Developments of greater than 20MW (tidal and wave) or 100MW (wind) are considered commercial. This means that the footprint (i.e. the physical space it occupies) of demonstrator projects will generally be smaller. It is assumed that for both demonstrator and commercial, the same legislative requirements for EPS and SACs will apply.

The size of licensed zones will determine the type of monitoring that can be achieved. For example, chartering a large ship to survey a small zone will not be practical. Similarly, buying hundreds of PODs for monitoring a large zone might be unfeasible. Zones (e.g. as identified for Round 3 wind) are the largest scale, and will be surveyed in order to identify the best site within them for development in terms of optimising output from the development but minimising environmental disruption; the development site is therefore smaller than a zone. Sites for wave technology are less well defined but the entire west coast of Scotland has potential. In Scotland and on the coast of Wales, key tidal sites are within the channels of the offshore islands or are generally more geographically constrained and are comparatively small compared to wave and wind footprints.

[14] A distinction is being made here between the scale of development that may be represented by a commercial enterprise and the scale of whole licensing zone for renewable energy development. While they could be the same, a commercial-scale of development is likely to only occupy a fraction of a zone that has been allocated for potential development.

Fixed point observations for commercial scale wind and wave sites will likely be too large and too far offshore to be adequately covered by even multiple fixed point observers.

We have not recommended absolute abundance surveys for demonstrator projects. The exception for this is with aerial surveys. Absolute abundance surveys (DP methods) using aerial methods are only marginally more expensive than relative abundance surveys (SP methods); therefore in situations where aerial surveys are feasible, DP methods are preferred. These methods still provide the most defensible results over larger temporal and geographical scales; hence the inclusion of these in commercial scale scenarios.

5.3.3 Cumulative effects

Offshore renewable energy developments are not the only activities taking place within the marine environment and the Strategic Environmental Assessment process for offshore renewables has identified a need to take in to account cumulative impacts. It is very difficult to predict cumulative impacts from first principles. Just because impacts are not seen from commercial demonstrators does not mean that impacts will not be evident when devices are scaled up both in size and number (see below for discussion of barrier effects and displacement). Cumulative impacts may occur as a result of the accumulation of the effects of renewable energy developments but they may also occur because of other anthropogenic stresses (perhaps from shipping, fishing, or other similar activities). Strategic Environmental Assessment and Environmental Impact Assessments need to consider these in detail but the power to predict them will probably always be low. In reality, the Biological Significance of an impact from renewable energy development will probably never be able to be view in isolation from the effects of other stressors and only through an effective approach to marine spatial planning will it be possible to make decisions about which stressors to manage in order to minimise overall impacts.

The following is an example of a mechanism, using anthropogenic noise, which could help to manage cumulative impacts:

This mechanism would operate under the principle that Regulators could allocate shares in the anthropogenic noise budget to different marine users. Under the Marine Strategy Framework Directive (MSFD) there are descriptors for 'noise' and strategic monitoring of noise through the licensing process will contribute to the definition of Good Environmental Status. Some renewable energy developments, especially during the construction phase of wind farms that use pile driving, have the potential to add significantly to the noise budget. It is clearly within the remit of the Regulator to specify whether Developers need to provide evidence of their noise budgets but, in these circumstances, some fairly simple methods could be used by Developers to measure the contributions made by them to the ocean noise budget and, since these will be cumulative with other sources of noise, these budgets could be used as an indicator of cumulative impact across all sources. By setting upper limits to noise production Regulators could develop a simple system for constraining the cumulative impacts of those effects that relate to noise production. The onus is most probably on the Regulators to develop background monitoring of noise budgets, based upon advice from their Scientific Advisers, and to allocate shares of those budgets to different parts of the marine user community.

5.3.4 Technology

The three technology categories broadly divide the methods for marine mammal monitoring, into those appropriate for offshore (wind and wave) and coastal (wave and tidal). Even before considering issues of scale and phase of development, each technology type has a different suite of potential effects or stressors on marine mammals that will be related to the physical characteristics of the device and the site characteristics of the development. These differences will, to an extent, drive decisions regarding how to monitor and for what objective.

Wind

For wind farms, the main impact is considered to occur during installation, for which pile-driving seems to currently be the most cost-effective method (though this is dependent on the substrate). Pile driving creates acoustic disturbance which displaces harbour porpoise from the immediate area and perhaps to a distance from the noise source of 20km (Tougaard *et al.*, 2009). However, once the development is operational, distribution seems to return to pre-disturbance levels. While it is not yet known if such temporary displacement has longer-term consequences, it does seem in general that the operational phase of a wind farm carries less potential risk to marine mammals than installation.

The height of the turbines, radius of exclusion zone around each device, water depth and the construction plans (how many devices, how far apart) will influence the choice of methods for the operational phases. Ship-based methods might be unworkable during the construction and operation phase (line transect and towed arrays) if the operation devices are too close together; and aircraft might not be able to fly at a suitable survey height. Alternatively, ship-based methods may be used to provide model-based estimates of abundance, provided it is possible to survey between turbines, or work around construction operations.

Tide and wave

In the case of tidal and wave developments, our understanding of the effects on marine mammals is currently poor. In theory however, it is likely that risks from such devices will occur during operational phases, and could be long-term. For example, turbines that are underwater and have moving parts (e.g. an open blade tidal turbine) have the potential to result in injury or mortality through strike and collision. Tidal devices that are placed in narrow channels between land masses could form a barrier to movements/migration. Large expanses of ocean holding wave devices could have the same effect. Commercial scale wave and tidal developments could result in long-term displacement of animals. So for tidal and wave sites, the focus for research and monitoring needs to be initially on near-field behaviour and movements at demonstrator sites; and on longer-term monitoring of movements, habitat use and mortality at commercial sites.

The potential for barrier effects and habitat displacement, like cumulative impacts (see above) need to be considered in more detail. These are likely to vary between species and they are difficult to predict from small-scale commercial demonstrators.

Tidal development sites are likely to pose some logistical challenges due to the high water flow through the area. Particularly in the larger, commercial scale operations, visual operations from both from boats and planes may be difficult. The combination of tide, wind, and any prevailing swell can result in sighting conditions that are simply not conducive to visual marine mammal observations. Boat-based surveys may be difficult in some areas due to the sea conditions (rough, with high tidal flow); while in some sites aerial surveys may not be feasible due to local geographical features such as high cliffs. However, it is also important to realise that along complex coastlines, aerial surveys are generally more preferable to boat surveys due to navigational challenges faced by boats.

The technology types and likely site locations will also affect monitoring decisions. For example, the choice of methods for wind sites (which tend to be offshore) is more restricted than sites closer to shore (e.g. tidal); in general, photo-ID, telemetry and fixed-point surveys from land are not appropriate. Aerial surveys could be used for offshore sites depending on their range and proximity to landing strips and fuel. For some offshore sites, there may be a significant transit time to arrive at the site. Thus the transit time required for each survey flight will need to be carefully considered. For large sites, and especially if sites can be combined, it may be more cost effective to use ship-based survey methods from vessels that can remain at sea. However, aircraft are also favoured at sites that include complex coastlines which makes ship navigation difficult. Ships using towed arrays are generally not workable when depths are shallower than 10m. Additionally, line-transect surveys from boats are likely to face certain restrictions at least at operational wind farm sites, because the turbines would interfere with survey design. Operational surveys for all technology types will depend on exclusion zones placed around turbines and (in the case of aerial surveys at offshore wind sites) the height of the turbines. Aerial surveys at operational wind farms would only be feasible if planes can fly between turbines (and in that case, resulting abundance estimates would be model-based) – this will depend on the spacing of turbines and flight restrictions.

5.3.5 Species-dependent monitoring

Not all monitoring methods are appropriate for all marine mammal species. Visual surveys are a wide spectrum method and data can be gathered for all species. However, acoustic methods target species that have distinctive, frequent vocalisations that can be easily detected. Data on most cetacean species can be collected using towed hydrophones. However, the software designed to extract vocalizations is limited to a handful of species (harbour porpoise, sperm whales, pilot whales and some beaked whales); most dolphins cannot be identified to species from acoustic data. As minke whales do not echolocate, and other vocalisations are periodic, they are not suited to detection acoustically.

Telemetry has been used more extensively to study seals than small cetaceans common to UK waters due to the inherent problems with tag attachment to cetaceans. In other parts of the world tagging of cetaceans is more common, and the methods have evolved significantly over the past decade or so. Opportunistic tagging of harbour porpoise occurs at least in Denmark (Eskesen *et al*., 2009) and the Bay of Fundy (Johnston *et al*., 2005). Photo-ID is limited to species and populations which are sufficiently marked and has been used in the UK to study bottlenose dolphins, and harbour and grey seals. Telemetry has been suggested in some instances, and when combined with GAM they are the basis of “usage models” (Matthiopoulos *et al.*, 2004), developed to generate maps of grey seal at sea usage from telemetry and aerial survey data. Maps of potential usage can be overlaid with maps of offshore renewable areas, for example, which would be useful for consenting and mitigation. As discussed in section 4.1, we encourage a thorough review of available telemetry data as part of a scoping study. This should include finding out whether there are unanalysed data. Should further telemetry data be warranted, we would recommend collaboration amongst Developers of wind, wave or tidal power devices.

In the context of our monitoring scenarios, photo-ID has only limited use for both pinnipeds and cetaceans.

5.4 Generic scenario-based monitoring recommendations

Generic monitoring scenarios and recommendations are summarised in Table 10 for each of the project phases, according to the technology used and the project scale. The table should be considered as a guide to be read in conjunction with these notes. The table does not, by itself, constitute full and complete advice. Some methods may appear in the table as being feasible alternatives, but have not been described in the text as the recommended approach. However, the exact methods applied will be dependent on the specific questions being asked, the site characteristics and the particular species of interest.

The focus for all pre-consent surveys should be on characterisation; though the extent (if any) to which this is required would be determined during site-specific scoping studies. In the following generic recommendations, we assume that further survey work will be required.

Given that characterisation surveys could happen months or years prior to actual construction, post-consent monitoring should include a short pre-construction survey (possibly a period of weeks, rather than months or years) to re-establish a suitable baseline for impact monitoring.

These recommendations are, of course, only indicative of the procedures and all approaches will need to be agreed with the Statutory Nature Conservation Advisers

5.4.1 Recommendations

Demonstrator projects:

Wind:

Pre-consenting –

Objective: characterise site with respect to marine mammals present, and seasonality in distribution and density; use data for EIA, prediction of impacts etc.

AAM is recommended as a principle monitoring technique to characterise seasonal baseline acoustic activity in order to compare it to installation periods and possibly operational. Single platform boat or aerial surveys may still be warranted to establish baseline distribution and relative abundance, but this is likely to depend on the overall scale of the project and its location. Telemetry (pinnipeds) and photo-ID (cetaceans) may also be warranted depending on the location of the site, particularly with respect to pinniped SACs.

Post-consenting -

Objective: establish new baseline immediately prior to construction; monitor for subsequent changes in distribution and density; monitor for return to baseline levels; use data to check EIA predictions.

Surveys should occur immediately prior to construction to establish new baseline for impact monitoring. We recommend AAM; fixed point observations (if possible); and telemetry and/or photo-ID depending on the proximity of SACs. AAM is likely to be the most cost effective way of monitoring this at demonstrator sites. Boat-based surveys may not be feasible during construction although are likely to be less constrained that aerial surveys which may be of limited use during construction and operation phases of wind farms, depending on height of the turbines and resulting flight restrictions. The use of telemetry and aerial surveys can continue to be used to monitor pinniped populations.

There is some evidence from one study in Denmark that harbour porpoise density and distribution, which seems affected during installation of turbines, could return to baseline levels after installation. More evidence is required on the temporal scale of this effect, particularly if new installation methods and/or different turbines are being tested. Very limited evidence exists on the potential effects of pile driving on species other than harbour porpoise and pinnipeds.

Wave and tidal:

Pre-consenting –

Objective: characterise site with respect to marine mammals present, and seasonality in distribution and density; use data for EIA, prediction of impacts etc. Focus on use of area as migratory path, or for regular travel between areas (especially in the case of tidal).

AAM is recommended as a principle monitoring technique for cetaceans to establish baseline acoustic activity in order to compare it to installation periods and possibly operational. Single platform boat or aerial surveys may still be warranted to establish baseline distribution and relative abundance, but this is likely to depend on the overall scale of the project and its location. Telemetry (pinnipeds; maybe cetaceans) and photo-ID may also be an option depending on the location of the site, particularly with respect to pinniped SACs.

Post-consenting –

Objective: establish new baseline immediately prior to construction; monitor for subsequent changes in distribution and density; monitor for return to baseline levels; use data to check EIA predictions regarding impacts – focus on barrier/exclusion effects, and strike.

Surveys should occur immediately prior to construction to establish new baseline for impact monitoring. We recommend AAM; fixed point observations (if possible); and telemetry and/or photo-ID depending on the proximity of SACs. Boat-based surveys may not be feasible during construction. Aerial surveys would be a more practical alternative for dedicated sighting surveys. Emphasis during operational monitoring of demonstrator wave installations should be on the near-field behaviour and movements of marine mammals. AAM and periodic fixed point observations (where practical) should form the basis of monitoring programs. Telemetry could also be a very useful tool for obtaining fine-scale movement data in the area of the development. This would be especially useful for investigating possible barrier effects or long-term displacement.

Commercial projects:

Wind:

Pre-consenting –

Objective: characterise site with respect to marine mammals present, and seasonality in distribution and density; use data for EIA, prediction of impacts etc.

The emphasis here should be on establishing baseline distribution and abundance data in order to assess the likelihood of a disturbance or injury offence (EPS); or a significant disturbance of qualifying species and/or deterioration of habitat (SAC). If the proposed construction technique is pile-driving, it should be assumed that displacement, at least of harbour porpoise, will occur. Characterisation surveys may assist in planning mitigation, particularly seasonal restrictions (if they are to be considered). The methods we recommend are aerial or ship-based surveys combined with AAM and/or towed acoustic monitoring. Telemetry could also be a very useful tool for obtaining usage data in the area of the development.

Post-consenting –

Objective: establish new baseline immediately prior to construction; monitor for subsequent changes in distribution and density; monitor for return to baseline levels; use data to check EIA predictions.

Surveys should occur immediately prior to construction to establish new baseline for impact monitoring. Vessel or aerial surveys may be feasible, but this will depend on the height and spacing of the turbines (for aerial) and any exclusion zones around the turbines (for vessels). AAM will remain an excellent method for ongoing monitoring. Note that for some species, e.g. minke whales, which may be sensitive to acoustic disturbance from pile-driving operations, acoustic monitoring methods will not be adequate, and some form of visual monitoring will be necessary. The use of telemetry and aerial surveys can continue to be used to monitor pinniped populations.

Wave and tidal:

Pre-consenting –

Objective: characterise site with respect to marine mammals present, and seasonality in distribution and density; use data for EIA, prediction of impacts etc. Focus on use of area as migratory path, or for regular travel between areas (especially in the case of tidal).

Objectives of consenting and baseline monitoring may be determined in part by whether or not focussed impact studies have occurred at demonstrator sites. If impact risks are better understood then (as with wind) the focus would be on establishing baseline distribution and densities in order to assess the likelihood of a disturbance or injury offence (EPS); or a significant disturbance of qualifying species and/or deterioration of habitat (SAC). Telemetry (pinnipeds only for tidal; maybe cetaceans for wave) and fixed point observations may be an effective way of helping to establish movement patterns ahead of construction.

Post-consenting –

Objective: establish new baseline immediately prior to construction; monitor for subsequent changes in distribution and density; monitor for return to baseline levels; use data to check EIA predictions regarding impacts – focus on barrier/exclusion effects, and strike.

Surveys should occur immediately prior to construction to establish new baseline for impact monitoring. As noted previously, dedicated vessel surveys while construction is underway may not be feasible, so efforts should instead focus on aerial and AAM. The use of telemetry and aerial surveys can continue to be used to monitor pinniped populations.

The long-term nature of the potential effects of wave developments (e.g. barrier effects, long-term displacement) is such that the operational monitoring around these sites will differ from those at wind farm sites. Telemetry and fixed point observations may once again be used to investigate changes in movement patterns post-construction. Provided sites are not too far offshore, we would recommend using aerial methods for larger scale distribution and density surveys, as these methods tend to be more cost-effective than boat-based methods. Boat surveys may also be viable depending on whether exclusion zones are present around turbines within the development site.

Table 10: Generic approach to assessing marine mammal (C = cetacean; P = pinniped) monitoring methods for the marine renewable energy industry. Metrics are: AA = absolute abundance; RA =relative abundance; P= presence; D = distribution; H = habitat use; B=behaviour. Methods, DP = Double platform; SP = Single platform; LT = line transect; PoOP = platforms of opportunity and AAM = autonomous acoustic monitoring. '?' indicates some level of site specificity in the recommendation, and means that the method may be logistically feasible, but will not necessarily be suitable for all sites or developments.

	Renewables Development		Phase	Monitoring Type	Monitoring Method										
Scenario	**Scale**	**Technology**			**Fixed-point**	**Ship-based DP LT**	**Aerial DP LT**	**Ship SP LT**	**Aerial SP**	**PoOP Ship**	**PoOP Aerial**	**Towed Array**	**AAM**	**Photo-Id**	**Telemetry**
				Metric Needed		D,AA,H, B		D,RA,H					P,B	D,AA,H,B	D.H.B
1	Project Demonstrator	Wind	Pre - consenting	Baseline	CP		C	C	CP	C	C	C	C	C?	C?P
2			Post -consenting	Impact	CP		C?	C?	C?P	C	C	C?	C	C?	C?P
3		Wave	Pre - consenting	Baseline	CP		C	C	CP	C	C	C	C	C?P?	C?P
4			Post -consenting	Impact	CP		C	C?	CP	C	C		C	C?P?	C?P
5		Tidal	Pre - consenting	Baseline	CP		C?	C?	C?P	C	C		C	C?P?	C?P
6			Post -consenting	Impact	CP		C?	C?	C?P	C	C		C	C?P?	C?P
7	Project-Commercial	Wind	Pre - consenting	Baseline		C	C	C	CP	C	C	C	C		P
8			Post -consenting	Impact		C?	C?	C?	C?P	C	C	C?	C		P
9		Wave	Pre - consenting	Baseline		C	C	C	CP	C	C	C	C	C?	C?P
10			Post -consenting	Impact		C?	C	C?	CP	C	C		C	C?	C?P
11		Tidal	Pre - consenting	Baseline	C?P?		C?	C?	C?P	C	C	C?	C	C?P?	C?P
12			Post -consenting	Impact	C?P?		C?	C?	C?P	C	C		C	C?P?	C?P
13	Zone	Wind	Consenting	Baseline		C	C	C	CP	C	C	C	C		P
14		Wave				C	C	C	CP	C	C	C	C		P
15		Tidal				C	C	C	CP	C	C	C	C		P

5.5 Combining effort

Surveying as large an area as possible rather than carrying out several small area surveys is practical because:

- Demands on resources, particularly vessels and personnel, are less;
- Organisation is more straightforward; and
- Larger areas will likely capture more of the distributional range of marine mammals.

As marine mammals are wide ranging animals, it makes sense when collecting data on distribution and abundance to try and survey as much of their range as possible. In addition, combining survey effort may in fact be a necessity that cannot be avoided (see 6.6.1). Where sites or zones are in close proximity, transit time between sites may be less than returning to land and carrying out independent surveys. Wider scale surveys are also useful to understand any observed changes in numbers within the zones to see if animals just moved elsewhere. In other cases (e.g. telemetry studies) combining effort amongst Developers could also help to spread the cost of survey and monitoring work.

The idea of combining effort should not just be applied to field methods, but also analysis and data storage, to make these tasks also as cost effective as possible. Finally, combining effort may also enable a greater understanding of possible cumulative effects from different projects.

Ultimately, the success of combining effort will rest in part with the Developers, and whether each can obtain the information they need in a time frame that fits their schedule. It is beyond the scope of this report to consider the commercial and legal implications of this, and the suggestion is made simply because it makes considerable practical sense, particularly in light of the resource assessment.

5.6 Survey design

The identification of the most appropriate methods to use for a marine mammal survey is just one step (albeit a pivotal one) in the implementation of a monitoring programme. The next stage is actually designing the survey. The reality of survey design is that it is often a compromise between a perfect design and a more practical one driven by logistic/resource constraints.

The key considerations are:

- Definition of the survey area: the area to be sampled must be clearly defined. Spatial stratification may be considered depending on the biological and physical characteristics of the site.
- Design parameters: the required precision (CV) associated with levels of survey effort (km) and potential encounter rates for each species need to be estimated based on available data.
- Sampling design: several options exist for the layout of individual transects or points in a point transect survey (akin to positioning of PODs, for example).
- Sampling frequency: the monitoring objective will dictate whether seasonal surveys or a single annual estimate will be sufficient.

- Field protocols: defines data collection/sampling methods in the field which ensures high-quality data collection and assures statistical robustness of the results.

5.6.1 Designing surveys to investigate impact: the need for co-design

Before-after-control-impact designs (or BACI) are often favoured when designing studies to assess impacts. At least two sites (one for the impact area and one comparable control area) are monitored before, during, and after the activity with the supposed impact. If differences in a key metric (e.g. abundance of a species) are seen at the impact site compared to the control site, the inference is that the impact caused that change. In practice, selecting control sites is particularly difficult. Related to this issue is the fact that BACI designs are best suited for impacts with highly defined boundaries. In many instances an impact or disturbance will tend to attenuate with distance from the source. In this case, it would seem more sensible to design a sampling regime based on distance from the source of impact. This is referred to as gradient sampling design (Ellis and Schneider, 1997), and is gaining widespread acceptance in environmental impact monitoring (Ellis and Schneider, 2008).

In the context of offshore wind or other marine renewable energy projects, a likely source of impact may be the noise and resulting disturbance associated with pile-driving. A single pile-driving operation is clearly a point-source impact, so gradient sampling – especially using AAM (e.g. PODs) - might seem an obvious alternative. The idea would be to spread PODs out to sample from nearby the impact, to a distance at least as far as the known disturbance distance.

While this does seem like an appealing alternative, careful consideration of scale will also be needed. As the area over which construction activities are taking place increases, gradient sampling may become a less obvious alternative, in favour of some sort of BACI approach. This is because as the area of development increases, point source impacts will become harder to define. Moreover, as the complexity of neighbouring developments increases, gradient sampling also becomes more problematic because there may be insufficient distance between different developments for a gradient to investigate the full range from maximal impact to no impact, of for the BACI approach to be adopted because few suitable areas may remain unaffected by development activity.

This is perhaps the most compelling reason why Developers who are responsible for adjacent developments need to co-design the environmental surveys. Not only will this have the potential to reduce the overall costs of environmental survey but it may be a necessity if the design of the surveys and monitoring are to be useful or convincing. It may also be the only way in which Regulators can take proper account of cumulative effects of developments and provide appropriate conditions on licensing that, as much as possible, avoid cumulative impacts. Given the potential range over which effects may occur, and the distances between currently planned developments there may be no feasible alternative to having an agreed area-wide environmental monitoring methodology. Such co-design has further advantages in that this could occur at scales that have better congruence with the natural spatial distribution of marine mammal populations and also with current data resources, as well as the current methods that are available for determining distribution and abundance.

6 Conclusions and Future Work

6.1 Background

This study aimed to assess the methods available for monitoring marine mammals and their suitability for use at marine renewable energy sites. The Habitats Directive requires that marine mammal populations are maintained at a favourable conservations status and impacts need to be monitored to ensure they are not having a negative effect. European Protected Species also receive levels of protection from disturbance and as such, Developers of marine renewable energy will need to assess impacts in order to obtain the relevant licences at the consenting stage. Assessments need to be based on currently available data or new data collected from surveys using the methods recommended in this study.

6.2 Methodologies

Some generalisations with regard to monitoring can be made but the details of a monitoring strategy need to be considered on a site-by-site basis. The site-specific factors include species present, distance from shore, depth and characteristics of the devices to be used. It is also important to fully assess the extent of the existing data and how recent they are.

We recommend this three stage approach to method selection:

1. What is/are the survey objective(s), and what metric(s) should be used?
2. Of the available methods, which one(s) is/are practically feasible at your site?
3. Of these practically feasible methods, which is most cost effective at your site?

Monitoring should always be adaptive to make sure that the most appropriate techniques are applied at each stage of the development and in response to the questions being asked at each stage. The ability to adapt should also extend to the use of new technologies, as they become available. An obvious example here would be HD surveys for marine mammals, which (while not currently recommended) have the potential to become available in the next few years after appropriate validation.

6.3 Scenarios

Scenarios were developed to assess the applicability of different monitoring methods for each category (wind, wave and tide), phase (consenting, construction and operation) scale (demonstrator, commercial, zone) and location of development. We made several general conclusions for these scenarios:

1. Offshore wind sites: photo-ID and land based surveys are not suitable.
2. Commercial and zone offshore wind sites lend themselves to large-scale shipboard and/or aerial surveys.
3. The proximity to land of wave (demonstrator) and tidal sites favours the use of land-based methods.
4. Autonomous acoustic monitoring (e.g. PODs) is a useful tool throughout all phases, locations and scale of wind, wave coastal and offshore sites, and possibly tidal.
5. High definition photography may become a useful tool for the future especially for monitoring at the installation and operation phase of windfarms.

6. Passive acoustic methods are most sophisticated for the harbour porpoise; species identification for dolphins is currently being developed.

6.4 Cost effectiveness

There are general conclusions with regard the cost effectiveness of the monitoring methods:

1. For estimating absolute abundance of cetaceans, aerial surveys are more cost-effective than shipboard surveys
2. Double platform aerial surveys are a comparable cost to single platform surveys, and should be the preferred method because of the absolute abundance data generated
3. For relative abundance estimation (for porpoises only) towed array methods are preferred
4. PoOPs are the cheapest methods for estimating relative abundance, and can be used in the absence of resources (including finance, ships etc) but often have severe coverage limitations
5. Telemetry is costly but is the only option for obtaining data on pinnipeds at-sea usage
6. Developers would benefit by collaborating on monitoring work. This is more cost effective and logistically simpler, but it would also provide more meaningful data for wide-ranging marine mammals.

6.5 General remarks

This scoping study sought to address the issues around marine mammal environmental compliance and to provide options for the development of a consistent UK-wide strategic approach to environmental monitoring.

Designing appropriate monitoring for marine mammals is highly technically demanding. The number of parameters requiring to be taken in to consideration when designing compliance monitoring for offshore development is so large that providing templates or closely worked examples would have been impractical. Each offshore development will require to have its monitoring activities individually designed taking account of constraints associated with the level of background information available, the design and purpose of the offshore development, location relative to access and exposure, and the set of marine mammal species considered to be of greatest significance to the Regulator. The analyses of the cost-benefit trade-offs of different monitoring options were also very general in their intent and were designed only to provide a guide as to the costs involved. Clearly, individual Developers would need to undertake similar analyses should they wish to understand the cost-benefit tradeoffs of different specific options in each specific case.

High definition (HD) photography is both a promising and contentious issue. Some Developers have proceeded to use HD photography in the absence of complete validation. This is risky because, even if HD photography becomes a standard the chances that the designs currently being applied will be optimal for marine mammals is small. This need has emerged from an understandable wish from Developers to save costs by co-designing marine mammal and bird surveys. Traditionally these have been conducted separately because the methods differ quite significantly. In general, one would wish to design surveys around the variable being measured that the highest variance so as to constrain this variance as much as possible. Unfortunately, the current approaches appear generally to involve adding marine mammal surveys to those that have been optimised for seabirds. This approach to the problem suboptimal if the variance around seabird surveys is lower than the variance around marine mammal survey, which is almost certainly the case.

Overall, there is a need to think carefully before acting because the costs of not doing so are likely to be more serious in terms of tying up scarce expertise in these areas of work on needless activity than they are in terms of their financial cost. For example, a potential conclusion from this report is that carrying out marine mammal surveys to detect trends in absolute abundance around renewable energy development is a hopeless pursuit because these surveys are unlikely to provide the statistical power required to detect population change let alone sufficient information to provide an assurance that any change has been caused by the renewable energy development. Surveying marine mammals may only serve to satisfy the Regulators that as much as possible is being done to detect population changes even if they are very unlikely to detect those changes in the time scales required in order to be useful for making decisions.

Regulators probably need to begin thinking in terms of using simple indicators of compliance that represent variables that can be easily and cheaply measured, even if they may be rather poor indicators of the actual effects of renewable energy developments upon marine mammals. The Scientific Advisers need to support the development of these indicators. A disadvantage of such indicators will be, inevitably, that they will not always lead to the correct decisions being made by Regulators and, if this results in the assumptions made by the Regulators being very precautionary, this may mean that some Developers will incur high costs for no good reason. Nevertheless, the advantage of using these types of indicators is that the probability of the Regulators making the wrong decision can be modelled in advance and the possibility of incurring high financial costs (through delay, additional survey work or complete withdrawal of a licence) will be more transparent, thus making the financial risks easier to predict.

Perhaps, however, the most immediate need is for Developers to start to co-operate with each other to co-design monitoring that will satisfy Regulatory requirements. This will not only reduce the costs to individual developers but it will also produce a more satisfactory result for the Regulators. If this is to be implemented most effectively it will required a radical change in the current vision, on the part of both Regulators and Developers, for compliance monitoring of marine mammals around renewable energy developments with a move towards an increase in the spatial scales for monitoring to cover large sections of the UK regional seas (see Section 3.1) for further discussion and justification of this approach).

6.6 Future work

Some problems highlighted by this document could be resolved with targeted research to enable improved decision-making and more efficient data collection.

Possibly the single largest challenge associated with offshore renewable energy development is to square the circle between the need the Regulator has to define the limits of disturbance that are acceptable under current legislation and that of the Developer to demonstrate compliance. A fundamental question arising from this is *where, when and to what extent does disturbance occur*? There is a substantial capability gap between the current capacity of the scientific community to supply either of these needs. Both require fundamentally different types of new research.

Moreover, the scientific community has to learn that research needs to be very focussed upon solving practical problems; it is not the role of Developers to fund research that is of a general or fundamental nature, although if this is a spin-off from commercially-driven research then this needs to be exploited. Government, including the Research Councils, need to be ready to fund their share of the costs when research provides outputs that have general applications. For their part, commercial interests need to be ready to share data and experience so that the whole community can move forward and benefit from the experience of others. The use of commercial confidentiality with results of environmental monitoring data needs to be resisted strongly by Regulators because this will constrain progress, diminish the capacity for informed decision-making and reduce public confidence unless there is openness in the way that environmental data are used. A further problem is that the outputs of much of this research are required now and, in many cases, we cannot be certain that there are solutions to some of the fundamental problems being defined by Regulators. The research considered to be essential to assist the decision-making and licensing process is as follows:

1. Designing scale-based monitoring for the UK regional seas.
    a. Design and implement monitoring across the whole of the UK regional seas that will eliminate the need to design stand-alone monitoring at individual sites where developments are taking place.
2. Establishing whether there is disturbance.
    a. Conduct focussed studies of sensitive species in association with actual or simulated disturbance. The objective here would be to examine, for example, whether species have a capacity to avoid tidal turbines, or to avoid areas of high noise impact but then to return to normal because of habituation. This is probably the most effective use of tagging technology referred to within this report. There would be a need to conduct these studies on a number of sensitive species under different types of conditions.
3. Establishing the limits of disturbance.
    a. Development of a Management Procedure Model for establishing the limits to disturbance from offshore renewable energy development. Potential Biological Removal (PBR), or something similar to this, needs to be developed from its present formulation which has been designed to cater mainly for the

licensing of direct killing of marine mammals. Other forms of this method have been developed (e.g. the Revised Management Procedure of the International Whaling Commission, and the UK Special Committee on Seals) and it may be possible to borrow heavily from these systems of management.

   b. Improving the current characterisation of marine mammal populations. A problem with current baseline information is that it does not integrate across all available data. For example, SCANS data is probably the best data available but comes from one month in every 10 years, so is only a snap-shot of the populations. However, there are other data from JNCC and Seawatch, as well as strandings data, which could usefully be integrated to provide an improved pre-development base-line.

   c. Predicting population effects from other sources other than renewable energy development. Climate change, as well as other anthropogenic factors could contribute to changes in marine mammal populations in future. Consequently, even if changes are measured in association with offshore renewable energy development these need to be seen in the context of changes that might have happened anyway. Some changes are likely to be stochastic, but others may be more predictable, especially those associated with changes in water temperatures and food availability. There is a need to narrow down other sources of variation, including those from spatial variation in habitat type and quality, which could contribute to an observed change in abundance.

4. Improving methods for measuring distribution and abundance

   a. Acoustic monitoring: although acoustic monitoring is now developing in to an operational tool for measuring the distribution and abundance of cetaceans much more needs to be done to improve the hardware and software to allow deployment in high energy environments and offshore, providing real-time data links and to provide the capability of measuring overall noise budgets. This could be achieved through the use of both static (buoys) and active devices (gliders) simulating the movement of the animals themselves through sound fields. Appropriate calibration of devices is also needed.

   b. Aerial survey using high-definition (HD) photography: There are considerable doubts about whether HD photography is yet at a stage to provide cost-efficient and reliable survey data for cetaceans. A full assessment of its effectiveness, measured against the traditional survey methods needs to be undertaken.

It is hoped that this project will form the start of an ongoing dialogue between The Crown Estate, Developers, Regulatory bodies and Scientific Advisers to make sure that best practice is observed in the design, implementation, and enforcement of marine mammal monitoring methods in the UK for all marine renewable developments.

SMRU Ltd recommends holding a further workshop with the Regulatory bodies and the Developers at the Round 3 windfarm sites, as the first stage of the implementation of this best practice approach.

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8 Appendix I – Resource Assessment

Summary

- The availability of suitable platforms (ship and aircraft) to conduct marine mammal surveys will be limited. Few have the required specification and some (aircraft) are already in use for other survey work (e.g. seabirds).
- It should not be assumed that planes can necessarily conduct bird and marine mammal surveys at the same time (this may be possible with careful planning, and depending on the platform).
- Planning will therefore need to start well in advance of anticipated survey periods. It is vitally important to have quality control checks at each and every stage of survey design, planning, execution and analysis to ensure the quality of the results.
- Another limiting factor is likely to be trained and experienced personnel. At some levels training can be reasonably easily provided. However, in the areas of survey design and analysis, and acoustic surveys, considerable skill and expertise is required.
- Equipment costs for most survey types are relatively modest when the cost is spread over the lifetime of the project.
- The overall efficiency of surveys for some R3 sites will almost certainly be improved through collaboration between Developers. Many sites will require similar surveys, with similar requirements and planning. Combining resources should cost less than carrying out a number of separate, but essentially identical, surveys.

Introduction

The resources needed for monitoring depend on the methods to be used. However, some general recommendations can be made as regards infrastructure, equipment and staff requirements. Selecting one method over another (e.g. vessel versus aerial surveys) will be based on a number of factors including availability of infrastructure and staff, cost and logistics. This section discusses planning and designing a survey, equipment needed, infrastructure (including ports, airstrips, planes and vessels), and expertise.

Planning and design

All surveys need to be carefully planned to ensure that objectives will be met and data collected are robust. Thorough planning and survey design will ensure efficient processing and analysis of the field data to obtain the required metrics. To ensure consistency and data quality, we recommend drafting observer manuals for each type of survey (e.g. aerial visual, boat visual, acoustic, dedicated seal surveys). Survey protocols should be designed in a standardized format to be shared amongst Developers, enabling inter-site comparisons.

There are several tools available to help plan survey design, data collection and analysis. For example, the DISTANCE (Thomas *et al*., 2010) can be used to design line-transect surveys as well as analyse the data. In the field, software such as LOGGER[15] is useful for automating data collection on visual surveys and minimising human error in data input.

Equipment

The minimum equipment needed to conduct any type of survey that will allow adequate data collection for analysis has been assessed (Table 11).

Ship-based and aerial surveys

All costs for the line transect surveys (methods 1-4, Table 11) are based on those from the SCANS-II survey (SCANS-II, 2008) carried out in 2005; these costs have been adjusted for inflation. Detailed costs were also available from SCANS-II for the towed acoustic array (method 5) and the PoOP visual and acoustic surveys (methods 6 and 7). Although SCANS-II was a large scale survey of the European Atlantic continental shelf, both the visual and acoustic equipment used is transferable to smaller scale projects.

The equipment used in SCANS II was very high spec and systems were largely automated for real-time data collection and validation. There are significant advantages for using such systems, as they reduce the likelihood of mis-recorded information in the field, and transcription mistakes later on; hence we have favoured these systems in the costs presented here. However, equipment costs could be significantly reduced if using largely manual systems. For example, non-automated equipment for a double-team aerial survey (Panasonic Toughbook for data recording; external hard drive; four inclinometers, Dictaphones and digital timepieces; one handheld GPS to record effort and facilitate navigation) would cost approximately £2,000 (compared with £6,500 in Table 11).

For most survey types it is also worth purchasing either a handheld GPS unit (e.g. Garmin Map60Cx or similar) or a GPS data logger. While most vessels and planes now have onboard GPS systems, data retrieval may not be straightforward. A logger or handheld GPS would remove the need for NMEA output to obtain data from onboard systems (see Table 12).

Double platform ship-board methods are more expensive than single platform because twice the amount of equipment is required. The return for this extra expense is robust estimates of absolute abundance. However, use of non-automated systems could reduce this cost.

[15] http://www.ifaw.org/ifaw_international/join_campaigns/whales/solutions/groundbreaking_research_on_our_flagship/download_cetacean_research_software/index.php

Table 11: Costs of purchasing (capital) equipment needed to carry out surveys using the various monitoring methods. All costs are current minimum estimates. These costs are not guaranteed in any way by SMRU Ltd.

	Monitoring Method	Costs (£)
1	Ship-based DP LT Data recording laptop & automated buttons Big eye binoculars Reticle binoculars Angleboards External hard-drive backup	13,943
2	Aerial DP LT Data recording laptop Inclinometers Tape recorders External hard-drive backup	6,503
3	Ship SP LT Data recording laptop & automated buttons Reticle binoculars Angleboards External hard-drive backup	4,393
4	Aerial SP LT Data recording laptop Inclinometers Tape recorders External hard-drive backup	6,503
5	Towed acoustic array Hydrophone Towing cable Computer Electrics: sound cards, buffer box, gps.	7,250
6	PoOP visual survey Data recording laptop & automated buttons Reticle binoculars Angleboards External hard-drive backup	4,393
7	PoOP towed array Hydrophone Towing cable Computer Electrics: sound cards, buffer box, gps.	7,250
8	Photo-ID SLR camera and lens Case External hard-drive backup	1,750
9	Autonomous acoustic data loggers 4* PODs External hard-drive back-up	11, 970
10	Telemetry 12 GPS Phone tags (costs for satellite tags will vary dependant on manufacturer, and hardware requirements) (Nets)	40,000 (10,000)
11	Land-based observations Theodolite Binoculars Data recording laptop External hard-drive for data backup	7,700
12	Dedicated pinniped surveys Binoculars Digital SLR External Hard Drive	2,000

Other surveys

Photo-ID

The basic requirements costs for equipment to carry out photo-identification projects (method 8, Table 11) are a suitable camera; reasonable frame per second (fps) rate (minimum of 3 fps, is recommended for small cetaceans, with 5 or more being ideal) and lens (minimum of 200mm for small cetaceans, but consider 300 or 400mm for large whales). It is assumed that a boat could be chartered although purchase of a rigid-hulled inflatable boat for long-term projects might be more cost-effective.

Autonomous acoustic monitoring (AAM)

The number of PODs (method 9, Table 11), required will vary depending on the size of the area to be monitored and the objectives of the study. Many studies have used a single POD (e.g. Carlstrom, 2005) but these tend to focus on acoustic behaviour and would unable to give information on cetacean occurrence over an area greater than the detection range of one POD (~300m). Monitoring studies of Danish offshore wind farms have employed between 2 and 8 PODs (Teilmann *et al.*, 2002) dependent on area (the farms in this case consisted of between 11 and 80 turbines). For this exercise, costs are based on the purchase of four PODs. Larger areas would probably require more PODs to get adequate coverage.

When costing POD studies it is sensible to build in some redundancy to account for loss and failure of equipment in the field. Some researchers suggest that ideally you should place up to double the number of PODs in the field. In part, decisions on how much field redundancy is required may depend on maintenance schedules. The new generation of PODs (C-PODs) can potentially be left for up to 5-6 months before needing fresh batteries and a fresh memory card. There is more potential over such a long time-frame for gear to be lost or to fail, and therefore significant redundancy should be incorporated. If maintenance can happen more frequently (e.g. monthly) then this might reduce the need for extra PODs. Also, maintenance trips will be much quicker if a complete second set of PODs exists to replace those already deployed. It should be noted that increased frequency of maintenance trips will contribute to the increased costs associated with the application of this method.

Telemetry

Satellite or GPS phone telemetry studies (method 10, Table 11) have relatively high costs associated with the tags themselves. A minimum sample of 12 individuals per species-specific tag deployment is recommended. Therefore, costs are given for the purchase of 12 SMRU GPS mobile phone tags[16] (developed for pinnipeds).

Although the initial outlay for the costs of the tags is relatively high, this approach does return a large volume of high quality individual based data. However, the equipment has a finite shelf-life; how long this is depends on the frequency of sampling and the environment in which it is used. Deployment of tags on pinnipeds or cetaceans also generally required the use of small boats and other infrastructure equipment – such as nets, which may need to be specially purchased for deployments.

Land based observations

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[16]http://www.smru.st-andrews.ac.uk/Instrumentation/pageset.aspx?psr=274

The costs for equipment to carry out land based observations (method 11, Table 11) are straightforward and relatively low. The basic requirements are a suitable theodolite (which provides accurate positional information of sighted animals) and binoculars (which are helpful to assist animal positioning). Using a digital theodolite, linked to a laptop running custom software, researchers can plot and track animals in real time.

Dedicated pinniped surveys

The key equipment required for dedicated seal surveys (method 12, Table 11) is dependent on the approach adopted. Good quality binoculars are required regardless, and for oblique photographs a good quality SLR, similar to one used for cetacean photo ID surveys, would be required. For thermal imaging surveys core equipment (such as the imager and pan and tilt head and mount) is generally rented (rather than purchased). It should be noted that there is limited availability of such equipment, and it may be nearing the end of its life-span. External hard drives are required for backup of digital images and video.

Infrastructure

This section considers the requirements for ports, harbours and vessels (for boat-based surveys – both visual and acoustic) as well as aircraft and airstrips suitable for aerial surveys.

Ports and Harbours

The minimum size for vessels conducting offshore cetacean surveys in UK waters is ~25m, with the capacity to hold at least four observers. This will limit which ports are suitable. For work requiring day-boats only (i.e. Rigid Hulled Inflatable Boat - RhIBs), requirements are more relaxed needing just a suitable slipway and refuelling facilities.

Locations for all commercial ports in UK waters were taken from the internet site Ports and Harbour of the UK[17] and plotted using ArcGIS (Figure 13). Each of the R3 zones has at least one port within 100 nautical miles (~ 10 hr steam) which could be used for vessel-based surveys (Figure 13). A complete list of these ports is given in section 11, Appendix IV.

[17] http://ports.org.uk/, accessed 14 October, 2009.

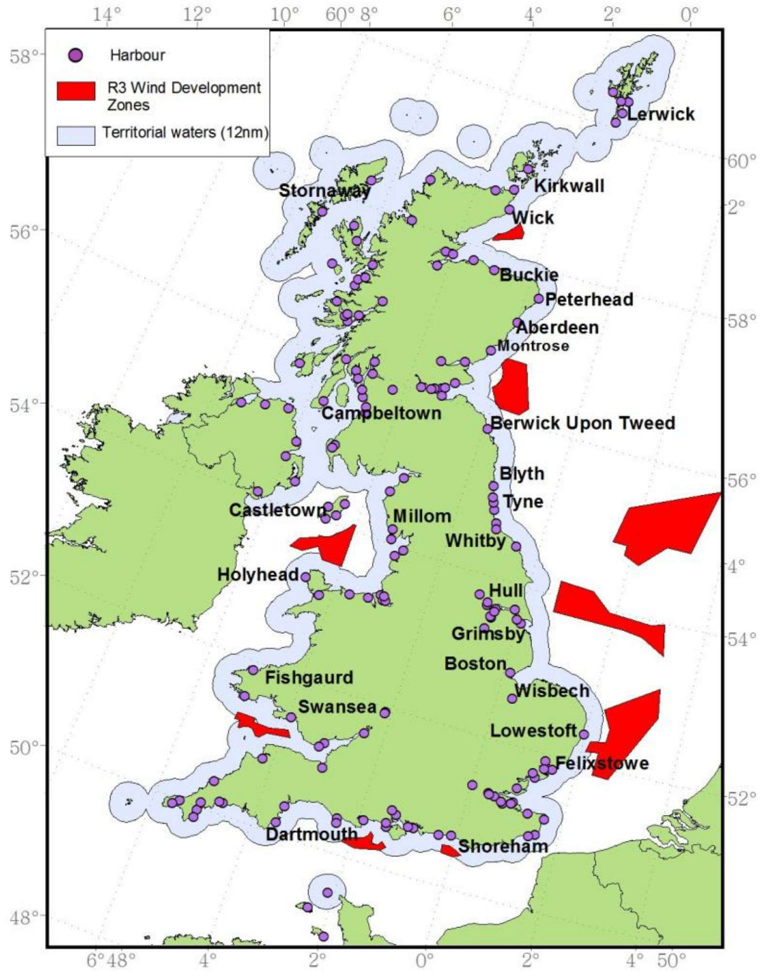

Figure 13: Locations of UK ports together with R3 licensing areas.

Airstrips

The main requirements of airstrips or airports are a) that the runway is long enough and b) refuelling facilities are available. A further consideration with aerial surveys is whether there are any restricted areas for flying at or near the survey region e.g., major airports, military ranges or nuclear facilities, or cliffs that are taller than the flying height. Such restrictions may further narrow the time window available for survey work, or preclude the use of aerial surveys requiring instead that surveys are vessel-based.

A list of all airstrips/airports (section 11, Appendix IV) was obtained from the internet site British Towns and Villages Network[18], and all locations were plotted using ArcGIS (Figure 14). During SCANS-II a number of UK airports were used for refuelling including Newcastle, Prestwick, Stornoway, Kirkwall, Sumburgh, Inverness, and Ronaldsway (Isle of Man). Smaller airports, with fewer commercial services, are often recommended for survey work as they can be more flexible to rapid re-fuelling requirements and issues relating to weather.

[18] http://www.british-towns.net/airports/uk_airports_list.asp, accessed 14 October, 2009.

The use of helicopters for thermal imaging surveys for harbour seals has less of a requirement for specific airstrips, and landing sites and not controlled for these aircraft. Fuel availability is a key consideration, and restrictions in location of airstrips or 'fuel' dumps can be reduced by having fuel specially transported by road to surveys locations. This option does significantly increase the efficiency of such surveys.

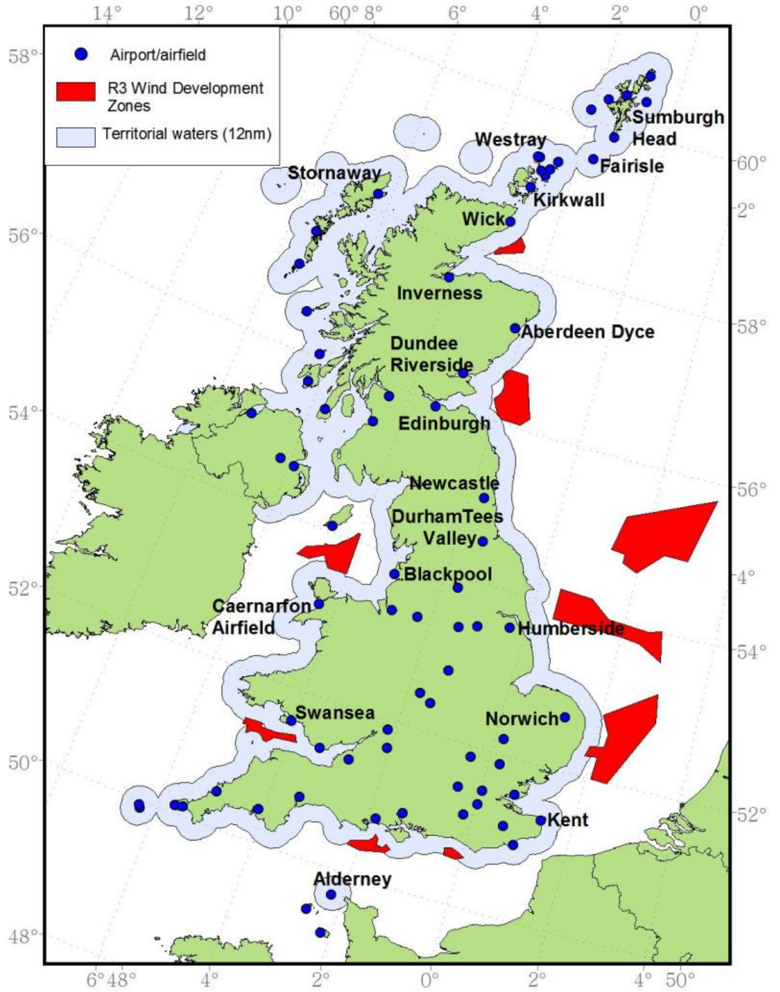

Figure 14: Locations of airstrips available for aerial surveys of R3 sites.

Vessels

The type of monitoring method being used will determine the type of observation platform/specification of boat required (Table 12). Appropriate certifications for both vessel and crew will be required.

The specification for a vessel suitable for double platform line transects surveys (DP LT) is the most extensive. Experience from the SCANS-II survey that required seven vessels for DP LT surveys during summer 2005 was that there are few vessels with two suitable observation platforms. On some ships a second platform was engineered and mounted on the ship. The requirements for single platform surveys are much simpler to fulfil; vessels with a single observation platform, which could be the wheel house or monkey island, are easier to source. The trade-off is that absolute abundance estimates require a double platform approach.

Noise is a key factor when chartering a vessel for towed acoustic surveys. The type of propeller, its revolutions per minute and age all influence how noisy the vessel will be when underway. The type of vessel suited to towed array surveys ranges from yachts to large fisheries research vessels.

The remaining monitoring methods (photo-ID, PODs and telemetry) require a "day boat", and a Rigid Hulled Inflatable Boat (RhIB) is most commonly used. A single RhIB with capacity for two scientists in addition to its crew would be sufficient for photo-ID and POD deployment. However, two RhIBs might be used on a seal telemetry exercise to carry plenty of "seal catchers". RhIBs have the advantage of speed, manoeuvrability and shallow draft for accessing coastal areas. Day-boats must be capable of, and legally able to, operate far enough offshore to be useful (e.g. 20 nautical miles from a safe haven). Many RhIBs, for example, may not be able to operate in offshore environments if they do not have sufficient shelter from weather for people onboard.

Aircraft

Line transect surveys

Aerial survey planes must be high-winged and twin-engine, and have valid and full certification to carry out commercial offshore charter work. In the UK, operators should hold Air Operators Certificates (AOC). Permission to land in other countries is a bonus, though this is unlikely to be a requirement for most R3 sites.

Either full or partial bubble windows are an advantage for aerial survey planes. There are analytical approaches for dealing with cases where one or both observer teams do not have full bubble windows, but it is certainly easier if such planes can be sourced (Table 13). The Partenavia P68 is a good example of a suitable plane that is often used for aerial cetacean surveys. Full bubble windows can be retro fitted for at least one observer pair. The supply of AOC-certified Partenavia craft is likely to be limited. Currently there are five such craft based in Liverpool[19] (one with bubble windows) that can be relocated for wildlife survey work. These craft are also being fitted out for high-definition photographic surveys. There are at least three other Partenavia with bubble windows in Denmark and France which were used for the SCANS-II surveys.

Dedicated seal surveys

Fixed wing surveys of seal haul out sites can be conducted from a high winged aircraft, or low winged if a window can be opened for oblique photography. Twin engine aircraft are required for working in more remote areas, but coastal flights can be conducted using single engine craft providing they have the appropriate certification. If vertical photography is being used, a specifically adapted craft is required (for example a Piper Aztec[20] currently used by SMRU for grey seal breeding season surveys).

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[19] Liverpool Aviation Services, http://www.liverpoolhandling.co.uk/index.html

[20] Giles Aviation, http://www.gilesaviation.co.uk/index.htm

The main constraint for thermal imaging surveys of harbour seals using helicopters is the availability of aircraft and equipment. SMRU has extensive experience of undertaking such surveys working closely with PDG Helicopters[21].

Table 12: Minimum specification for vessels used for different monitoring methods.

	Monitoring Method	Specification
1	DP LT	• Cruise speed 10 knots • Endurance ~14 days • Two observation platforms: at least 5m above sea level; one higher than the other; accommodate 3 observers; audibly and visually isolated; unobstructed forward view • Accommodation for 8 observers • Good stability
2	SP LT; PoOP	• Cruise speed of 10 knots • Single observation platform: at least 5m above sea level; accommodate 3 observers at a time; unobstructed forward view • Accommodation for 4 observers • Good stability
3	Towed hydrophone array	• Cruise speed max. 10 knots • Capable of deployment, towing and retrieval of hydrophone cable, usually of 2-400m in length • Aft desk space for cable storage • Fixed propeller preferable • Quiet engine • Accommodation for 1 acoustic technician
4	Photo-ID; AAM	• Day boat • Capacity for at least 2 scientists • Likely to require shelter from weather for offshore work, or likely to be limited in area of legal operation (e.g. within 20 nm of safe haven). • Vessels deploying/retrieving PODs would benefit from having a winch
5	Telemetry	• 2 day boats (manoeuvrable and robust) • Joint capacity for 8 trained personnel, nets and other equipment

[21] PDG Helicopters, http://www.pdg-helicopters.co.uk/

Table 13: Minimum specifications for aircraft used in line transect surveys.

	Monitoring Method	Specification
1	DP LT	• High winged • Bubble windows • Twin engine • Accommodate 4 observers (plus 1 navigator if required; SCANS-II – 2 observers + navigator) • NMEA outputs required (unless GPS handheld or data logger used)
2	SP LT; PoOP	• High winged • Bubble windows • Twin engine • Accommodate 2 observers (plus 1 navigator if required; SCANS-II – 2 observers + navigator) • NMEA outputs required (unless GPS handheld or data logger used)

Expertise

For all aspects of surveys and monitoring, there is potential for staff overlap. For example, the scientific coordinator may also be an observer, or take the lead in data analysis. What is important is that for each role, the key requirements are carefully considered and appropriate personnel employed. A well equipped and well designed survey can be rendered useless through poor execution. Similarly, the most experienced statistician still needs good quality data to perform robust analyses.

With all of these field techniques, health and safety guidelines need to be followed. All charter companies should hold the appropriate and up to date certification. All personnel working in the field should be fully trained and activities (e.g. seal catching) conducted under the appropriate licensing. Also, appropriate risk assessments should be conducted.

Logistics & administration

Each project will require a project manager to oversee all aspects of the project, from scientific to logistical planning. Administrative staff may be able to assist with purchasing or hiring of equipment, chartering vessels/planes, hiring observers, making travel bookings.

Scientific

All surveys will need a *scientific coordinator* who is familiar with appropriate design and analytical issues. Specialized programs are largely able to automate both the design and analysis of line-transect surveys but expert knowledge is still required to produce robust and defensible results. Similarly, acoustic surveys will need someone with appropriate expertise to take the lead in design and analysis.

Experienced *marine mammal observers* will be required for all surveys. These should be skilled at field identification of the range of species likely to be encountered, and the specific techniques being employed. In the case of line-transect surveys they will need to be willing to spend up to several weeks at a time at sea; or several hours at a time in a plane. A key requirement of the observers will be an ability to follow standardised instructions i.e. observer manuals developed for each survey type. It is hoped this would minimise variability between observers. Each observer should be familiar with field procedures before starting the surveys, and should re-read the manual periodically throughout all surveys. Ideally, a training period at the start of each survey should occur to allow observers to re-familiarise themselves with field procedures. The same principles apply to dedicated seal surveys.

The required *field staff* for acoustic surveys will depend in part on whether passive or towed methods are employed. For example, passive acoustics – where equipment is deployed and periodically retrieved for data downloading and maintenance – would not necessarily require experienced staff for deployment/retrieval but there is still an important design element in passive acoustic surveys, and the analysis would require appropriate expertise. In the case of towed acoustic surveys (where monitoring and data acquisition is real-time), it is recommended that only experienced personnel be used.

Photo-ID surveys require at least two experienced people. Cetaceans can be challenging to photograph well, and although having good equipment will facilitate this, robust analyses require data (i.e. photos) to be of a consistently high standard. The other key person for photo-ID work is the boat driver. The boat needs to be well positioned with respect to the cetaceans to allow the photographer to get high-quality images, while at the same time trying to minimise the influence of the boat on the behaviour of the animals. Having a skilled boat driver can be the difference between photo-ID surveys that are successful or otherwise.

Catching and tagging seals to deploy telemetry devices requires a team of trained and experienced personnel. Skills for handling animals as well as boats are required. Any catching activities need to be appropriately licensed under the Home Office Animals (Scientific Procedures) Act 1986.

Analyses of data collected using all techniques should be carried out by qualified and *experienced statisticians*. Seemingly simple programmes, such as the automated analysis software DISTANCE (Thomas *et al.*, 2010) or MARK, can be misused without the appropriate background knowledge.

References:

Carlström, J. 2005. Diel variation in echolocation behaviour of wild harbour porpoises. Marine Mammal Science **21**(1):1-12.

Teilmann, J., Henriksen, O.D., Cartensen, J. and Skov, H. 2002. Monitoring effects of offshore wind farms on harbour porpoises using PODs (porpoise detectors). Technical Report National Environmental Research Institute, Denmark, Roskilde. 95pp.

Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop & T.A. Marques 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology **47**:5-14.

9 Appendix II - Delivery Mechanisms

Summary

- Monitoring to date has varied substantially in its type and level, and the lack of a standard set of monitoring protocols has made it difficult to compare data sets from different wind farm sites.
- We recommend using standardised recording methods to ensure that data collected meet the objectives of the survey, errors and data manipulation are minimized, data are easily comparable between sites, and the development of a common database is facilitated.
- In addition, we recommend mammal observers and passive acoustic monitoring operators receive formal training on a Joint Nature Conservation Committee recognised training course. Data recording forms designed by the JNCC for use during seismic surveys could be amended for use by the renewable industry.
- We recommend development of a common database for integration of all survey data to assist with large scale analyses and comparison amongst sites. Such a database should be compatible with existing relevant databases such as the Joint Cetacean Database, have a GIS base to allow data to be searchable by geographic coordinates and be regularly updated and checked by a database manager in order to ensure data quality and availability to its users.
- Communicating results to the general public and facilitating access to information is also important. This could be achieved through a website, and each Developer should be encouraged to adhere to a standardised reporting format.

Introduction

Licence conditions associated with operational wind farms in the UK have to date focused on mitigation monitoring for marine mammals during the construction phase only. This monitoring has varied substantially in its type and level; the comparison across sites and sightings data has therefore not always been readily available. For example, there has not been a standard method of recording animal sightings, group size, behaviour, environmental conditions and passive acoustic monitoring (PAM) data. Also marine mammal data collection during preconstruction baseline surveys was often carried out during ornithological surveys. While combining bird and mammal surveys should be encouraged as a cost-saving measure, marine mammal observations require a dedicated team of observers following a marine mammal-specific protocol – when these guidelines are not followed the data may be of questionable value.

It is anticipated that there will be a large amount of data collected as part of the monitoring programmes at Round 3 offshore wind, wave and tidal sites. Standardised data recording methods are essential to ensure that the data collected will meet the objectives of the survey. Additional benefits are that errors due to data recording will be minimized, data will be easily comparable between sites, and data manipulation prior to analysis will be minimised. Further, it will facilitate the development of a common database allowing greater access to data, improved understanding of the issues and easier dissemination of results.

Analytical procedures and framework

During a monitoring survey, one or more observers scan an area following a pre-defined protocol, recording relevant data.

In order to ensure good quality data, several measures can be undertaken:

Observers

Marine mammal observers (MMOs) require a good understanding of the ecology of marine mammals (species identification, biology, behaviour & distribution) and familiarity with data recording rationale and procedures. Observers should also be aware of the scientific importance of accurate data recording. Training on acoustic detection techniques (i.e. PAM) is also beneficial.

In accordance with the seismic industry, marine mammal observers should receive formal training on a Joint Nature Conservation Committee (JNCC) recognised training course[22].PAM operators also should be required to undergo a standardised training course. During some previous UK wind farm construction projects, marine mammal observations during mitigation monitoring were carried out by crew members. It is imperative that the MMO is an unbiased observer, whose primary task is the collection of marine mammal data.

Data recording

It is essential to collect the appropriate data to enable adequate data analysis and realization of the desired output metrics (e.g., abundance estimates, distribution maps). A well- designed data recording form will ensure the relevant parameters are measured and furthermore facilitate the development of a common database.

The data recording forms designed by the JNCC for use during seismic surveys could be amended for use by the renewable industry. Data recorded should include general information (e.g. date, time, name of observer), environmental parameters (e.g. weather conditions, sea state), marine mammal sighting data (e.g. geographic coordinates, species, group size) and method used (e.g. type of platform, effort, specific parameters to the methodology).

As a general rule, units should be consistent. For example, if area is expressed as square kilometres (km^2) then all effort and sighting distances should also be expressed as kilometres. The use of consistent measuring units will minimize errors and reduce post-collection data manipulation. In some situations it may be possible to enter data directly into a field computer using either a spreadsheet, or (ideally) a purpose-built database. Look-up tables giving a pre-defined set of options in one specific field reduce mistakes and increase the consistency of the data, e.g., record visibility as p= poor (<1km), m= moderate (1-5km) or g= good (> 5km).

In situations where the use of software is required, preference should be given to widely used and robust programmes for automated data collection. One example is LOGGER 2000[23] - an open source automated data logging program which collects data from GPS and other ship's instruments and stores it in an Access database.

[22] http://www.jncc.gov.uk/page-4703

[23] http://www.ifaw.org/ifaw_international/join_campaigns/whales/solutions/groundbreaking_research_on_our_flagship/download_cetacean_research_software/index.php

As mentioned, all density and abundance calculations will likely be performed using the specialised software DISTANCE[24] (Thomas *et al.*, 2010). Large amounts of data can be imported into DISTANCE using delimited text files, so a system of data entry with the ability to generate appropriate text files is recommended.

PAM operators should use a standard suite of acoustic software e.g. PAMGUARD[25]. Other potentially useful software[26] includes RAINBOWCLICK - designed for the detection and analysis of sounds made by sperm whales) and PORPOISE - designed to run only with specialized electronic modules which convert the high frequency porpoise clicks into lower frequency click envelopes.

Parameters for visual surveys – an example using line-transect surveys for analysis in DISTANCE

Line-transect surveys have become the standard for visual methods to estimate density and abundance of marine mammals, with the freely available software DISTANCE (Thomas *et al.*, 2010) used for analysis. It is anticipated that Round 3 monitoring surveys for marine mammal density and abundance will largely utilise these methods, so a more detailed worked example of standardised procedures is given here.

Each survey will have several levels of data. Figure 15 shows a generalised hierarchy of data from a survey. This hierarchy matches that used by DISTANCE. It is anticipated that all density and abundance analyses will use this software.

The exact form of the data structure (Figure 16) will depend on the survey design but the basic outline is as follows: each survey area may or may not have defined strata[27]. For non-stratified surveys, the 'strata' level is effectively removed, and all other data are linked directly to the survey region. Each stratum (or the overall region) has a number of effort legs (or transects) associated with it. The number of transects will vary depending on the strata or survey region, and on the design. As a rule of thumb, however, each region needs a minimum of 15 transect lines for robust estimates of variance (Thomas *et al.*, 2007). Each effort leg will then have associated sightings. Figure 16 shows common data requirements for each level of the survey i.e. survey region, effort leg, and sighting.

[24] http://www.ruwpa.st-and.ac.uk/distance/

[25] http://www.pamguard.org/home.shtml

[26] http://www.ifaw.org/ifaw_international/join_campaigns/whales/solutions/groundbreaking_research_on_our_flagship/download_cetacean_research_software/index.php

[27] Here, strata are defined as discrete geographic units for which parameters (e.g. density) will be estimated individually. So a stratified survey is one in which the overall *region* is defined by several *strata* for which we have *a priori* knowledge about differences in some key parameters.

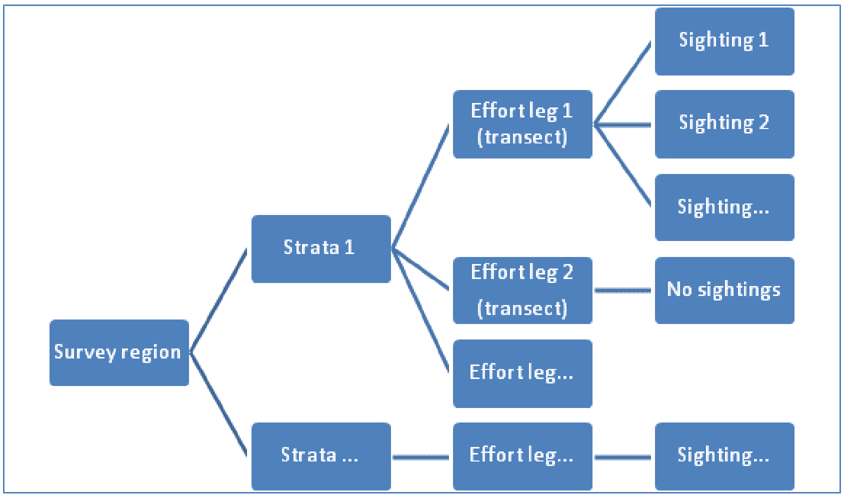

Figure 15: Generalised data hierarchy for line-transect surveys.

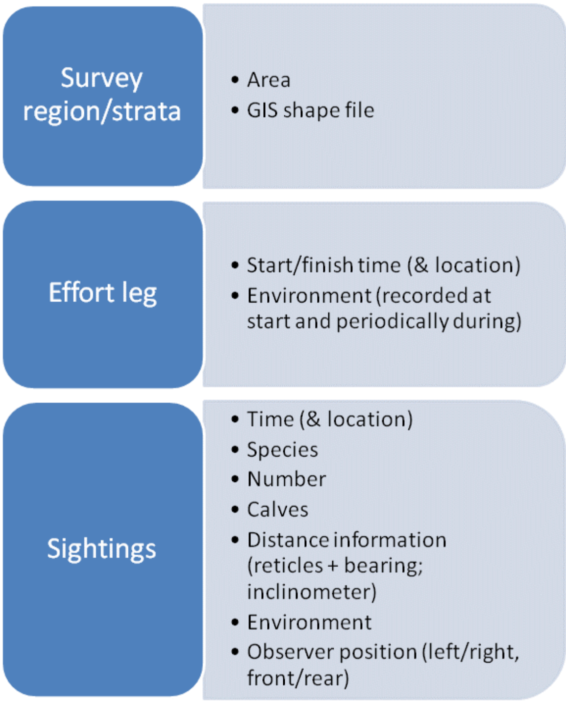

Figure 16: Data requirements for each data level within a survey.

Survey region and strata are defined geographically and have associated areas. These should be defined within a Geographical Information System (GIS) environment such as ArcGIS[28]. It is likely that in most (if not all) cases, the surveys will be designed using the DISTANCE algorithms (Strindberg *et al.,* 2004; Thomas *et al.*, 2010).

[28] http://www.esri.com/products/index.html

Visual representation of data gathered during line-transect surveys will likely utilise ArcGIS or a similar GIS environment.

Data storage mechanisms

Large amounts of data are collected during monitoring surveys, and an efficient way to store, manage, organise and display such data is by creating a database.

Given that the spatial component is an important feature, the database would benefit from having a GIS base that allows data be searchable by geographic coordinates.

Envisaging the integration of data collected throughout monitoring surveys along the UK with other data, this database should be created in such a way as to be compatible with existing databases of relevance to marine mammals and marine conservation/ management. One such database is the Joint Cetacean Database where long term information on marine mammals is stored (Reid *et al*., 2003).

A database not only serves as a storage mechanism but also facilitates the interpretation of data at different levels and from different perspectives e.g., data can be pulled at a local/regional/ national scale or be interpreted along different time series. It also eases the comparison between data types, such as species or site.

Adding to the fact large datasets can provide an insight on species distribution and abundance; they can also be used as conservation/management tools. The Joint Cetacean Database has enabled the identification of potential Special Areas of Conservation for harbour porpoise (Reid *et al*., 2003).

Databases should be regularly updated and checked by a database manager in order to ensure data quality and availability to users.

Presentation and communication of data

Communicating results to the general public and facilitating access to information is important.

Each Developer should be encouraged to adhere to a standardised reporting format when presenting the results of all marine mammal monitoring undertaken at each phase of development. These reports should include as much detail as possible on how successful the monitoring methodology was and any issues that arose. This will enable comparisons to be made between various sites, and highlight any problems that may be addressed in the future.

Development of specific websites can, for instance, give easy access to project outputs and include an interactive mapping page, a catalogue of mapping studies, data templates and technical reports.

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Reid, J.B., Evans, P.G.H., and Northridge, S.P. 2003. Atlas of Cetacean distribution in north-west European waters. Reid, J.B., Evans, P.G.H. and Northridge, S.P. (Eds.). 76pp.

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10 Appendix III - Power calculation for distance sampling estimates based upon SCANS-II results

Background

Using information from the SCANS-II survey the shipboard detections of harbour porpoise and minke whales were made in Strata V (northeast Scotland), U (northeast England), and P (southwest England), along with effort in those areas were used to approximate uncertainty in abundance ($CV(\hat{D})$ equivalent of uncertainty in density) for various amounts of ship-based effort.

Aerial surveys were carried out in a number of strata relevant to offshore renewable energy development. Information on strata O (Irish Sea), N (Western Isles), J (Northern Isles), and B (English Channel) were subjected to the same power analyses as the shipboard data.

These data form the basis for computing power associated with various amounts of shipboard or aerial effort. These effort values can be converted to monetary values with information regarding platform hire and labour costs.

Target effort calculations based on SCAN-II data

Buckland et al. (2001) provides formulae associated with the computation of effort necessary to achieve desired levels of precision in density estimation. The relevant formula for our purposes is:

$$CV(\hat{D})^2 = \frac{1}{L} \cdot \frac{L_0}{n_0} \cdot \left[b + CV(\bar{s})^2\right]$$

where L is effort in km, L_0 is km of effort in this stratum during SCANSII, n_0 is detections during SCANSII, $CV(\bar{s})$ is coefficient of variation in cluster size from SCANSII and

$$b \approx n_o \cdot CV(\hat{D})^2$$

Computation of power

The formula is based on Gerrodette (1987:1366), and essentially his equation (15), but instead uses a non-centrality parameter (ncp) for the standard normal distribution:

$$ncp = \frac{\log(1+r)}{\sqrt{\dfrac{\log(CV(\hat{N})^2 + 1)}{t(t-1)(t+1)/12}}}$$

then

$$1-\beta = 1-\Phi(z_{1-\alpha/2} - ncp) + \Phi(z_{\alpha/2} - ncp)$$

This calculation is based upon an exponential decline at annual rate r with $CV(\hat{N})$ proportional to $\frac{1}{\sqrt{\hat{N}}}$ (appropriate for distance sampling estimators) with t being the number of annual surveys conducted, 2 in our situation.

References

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. (2001) Introduction to distance sampling: estimating abundance of biological populations. Oxford Univ. Press

Gerrodette, T. (1987) A power analysis for detecting trends. Ecology 68:1364-1372.

11 Appendix IV - List of ports, airports/strips suitable for marine mammal survey work

List of ports suitable for mobilising marine mammal monitoring surveys

No.	Name	Latitude			Longitude			Country	Description	Web details
1	Aberdeen	57	8	N	2	4	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=674
2	Ardrishaig	56	0	N	5	26	W	Scotland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=384
3	Ardrossan	55	38	N	4	48	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=358
4	Arisaig	56	54	N	5	50	W	Scotland	Leisure/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=413
5	Ayr	55	28	N	4	37	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=359
6	Ballycastle	55	11	N	6	13	W	N. Ireland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=320
7	Barrow-in-Furness	54	6	N	3	12	W	England	Commercial	http://www.ports.org.uk/port.asp?id=291
8	Barry	51	23	N	3	14	W	Wales	Commercial	http://www.ports.org.uk/port.asp?id=228
9	Belfast	54	37	N	5	54	W	N. Ireland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=308
10	Berwick-upon-Tweed	55	46	N	1	59	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=7
11	Bideford	51	1	N	4	12	W	England	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=209
12	Birkenhead	53	24	N	3	2	W	England	Commercial	http://www.ports.org.uk/port.asp?id=283
13	Blyth	55	7	N	1	29	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=12
14	Boston	52	58	N	0	1	W	England	Commercial	http://www.ports.org.uk/port.asp?id=49
15	Braye	49	43	N	2	11	W	Channel Islands	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=143
16	Bridgwater	51	9	N	3	2	W	England	Commercial	http://www.ports.org.uk/port.asp?id=215
17	Brightlingsea	51	48	N	1	2	E	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=79
18	Bromborough	53	21	N	2	58	W	England	Commercial	http://www.ports.org.uk/port.asp?id=284
19	Bruichladdich	55	45	N	6	21	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=754
20	Buckie	57	40	N	2	57	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=649
21	Burghead	57	42	N	3	29	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=650
22	Burntisland	56	4	N	3	13	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=706
23	Burton-upon-Stather	53	40	N	0	40	W	England	Commercial	http://www.ports.org.uk/port.asp?id=37
24	Caernarfon	53	9	N	4	14	W	Wales	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=262
25	Cairnryan	54	58	N	5	0	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=351
26	Campbeltown	55	25	N	5	34	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=374
27	Canna	57	3	N	6	30	W	Scotland	Leisure/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=447
28	Cardiff	51	27	N	3	9	W	Wales	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=221

29	Carron	56	5	N	3	9	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=725
30	Castletown	54	4	N	4	39	W	Isle of Man	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=295
31	Chatham	51	23	N	0	33	E	England	Commercial	http://www.ports.org.uk/port.asp?id=91
32	Coleraine	55	7	N	6	43	W	N. Ireland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=333
33	Corpach	56	50	N	5	7	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=415
34	Craignure	56	27	N	5	42	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=405
35	Dartford	51	27	N	0	15	E	England	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=95
36	Dartmouth	50	20	N	3	33	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=157
37	Douglas	54	9	N	4	28	W	Isle of Man	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=297
38	Dover	51	7	N	1	20	E	England	Leisure/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=100
39	Dundee	56	28	N	2	55	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=688
40	Eling	50	55	N	1	29	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=865
41	Falmouth	50	9	N	5	3	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=166
42	Felixstowe	51	57	N	1	20	E	England	Commercial	http://www.ports.org.uk/port.asp?id=63
43	Fingringhoe	51	51	N	0	58	E	England	Commercial	http://www.ports.org.uk/port.asp?id=940
44	Finnart	56	6	N	4	49	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=766
45	Fishguard	51	60	N	4	58	W	Wales	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=254
46	Fishnish	56	30	N	5	48	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=408
47	Fleetwood	53	55	N	3	1	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=286
48	Flixborough	53	38	N	0	41	W	England	Commercial	http://www.ports.org.uk/port.asp?id=46
49	Folkestone	51	5	N	1	13	E	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=102
50	Fowey	50	20	N	4	38	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=167
51	Gainsborough	53	24	N	0	47	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=38
52	Garston	53	21	N	2	54	W	England	Commercial	http://www.ports.org.uk/port.asp?id=287
53	Glasgow	55	51	N	4	14	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=361
54	Glenelg	57	13	N	5	38	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=433
55	Glensanda	56	34	N	5	31	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=418
56	Goole	53	41	N	0	52	W	England	Commercial	http://www.ports.org.uk/port.asp?id=32
57	Gorey	49	11	N	2	0	W	Channel Islands	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=135
58	Grangemouth	56	0	N	3	40	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=711
59	Greenock	55	57	N	4	46	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=363
60	Grimsby	53	35	N	0	5	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=39
61	Grutness	59	52	N	1	17	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=626
62	Gunness	53	33	N	0	43	W	England	Commercial	http://www.ports.org.uk/port.asp?id=40
63	Hartlepool	54	41	N	1	11	W	England	Commercial	http://www.ports.org.uk/port.asp?id=17

64	Hayle	50	11	N	5	25	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=186
65	Herm	49	28	N	2	27	W	Channel Islands	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=144
66	Heysham	54	1	N	2	53	W	England	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=292
67	Holyhead	53	18	N	4	37	W	Wales	Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=272
68	Howden	53	43	N	0	52	W	England	Commercial	http://www.ports.org.uk/port.asp?id=43
69	Hull	53	44	N	0	17	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=34
70	Hunterston	55	43	N	4	52	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=365
71	Immingham	53	37	N	0	11	W	England	Commercial	http://www.ports.org.uk/port.asp?id=41
72	Invergordon	57	41	N	4	9	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=596
73	Inverie	57	2	N	5	41	W	Scotland	Leisure/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=435
74	Inverkeithing	56	2	N	3	22	W	Scotland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=714
75	Inverness	57	29	N	4	14	W	Scotland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=653
76	Ipswich	52	2	N	1	9	E	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=85
77	Keadby	53	34	N	0	44	W	England	Commercial	http://www.ports.org.uk/port.asp?id=42
78	Kinlochbervie	58	27	N	5	4	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=521
79	Kirkwall	58	59	N	2	58	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=553
80	Langstone	50	47	N	0	59	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=120
81	Larne	54	50	N	5	48	W	N. Ireland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=328
82	Leith	55	59	N	3	10	W	Scotland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=716
83	Lerwick	60	9	N	1	8	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=632
84	Littlehampton	50	48	N	0	29	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=113
85	Liverpool	53	24	N	2	58	W	England	Commercial	http://www.ports.org.uk/port.asp?id=288
86	Llanddulas	53	17	N	3	39	W	Wales	Commercial	http://www.ports.org.uk/port.asp?id=276
87	Lochaline	56	32	N	5	46	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=423
88	Lochmaddy	57	36	N	7	9	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=482
89	London	51	30	N	0	7	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=97
90	Londonderry	55	2	N	7	13	W	N. Ireland	Commercial	http://www.ports.org.uk/port.asp?id=335
91	Lowestoft	52	28	N	1	46	E	England	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=64
92	Lymington	50	45	N	1	31	W	England	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=129
93	Mallaig	56	59	N	5	49	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=424
94	Methil	56	11	N	2	59	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=718
95	Millom	54	13	N	3	14	W	England	Commercial	http://www.ports.org.uk/port.asp?id=861
96	Mistley	51	56	N	1	10	E	England	Commercial	http://www.ports.org.uk/port.asp?id=88
97	Montrose	56	42	N	2	27	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=692
98	Mostyn	53	19	N	3	16	W	Wales	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=277

99	Mousa	60	0	N	1	11	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=645
100	Nigg	57	41	N	3	59	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=599
101	Padstow	50	33	N	4	56	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=197
102	Par	50	20	N	4	42	W	England	Commercial	http://www.ports.org.uk/port.asp?id=171
103	Peel	54	13	N	4	41	W	Isle of Man	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=299
104	Pembroke	51	40	N	4	57	W	Wales	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=242
105	Penzance	50	7	N	5	32	W	England	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=198
106	Perth	56	23	N	3	26	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=693
107	Peterhead	57	30	N	1	46	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=667
108	Poole	50	42	N	1	57	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=131
109	Porthoustock	50	3	N	5	4	W	England	Commercial	http://www.ports.org.uk/port.asp?id=913
110	Portland	50	34	N	2	26	W	England	Commercial	http://www.ports.org.uk/port.asp?id=153
111	Portree	57	25	N	6	10	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=455
112	Portsmouth	50	47	N	1	5	W	England	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=123
113	Purfleet	51	28	N	0	14	E	England	Commercial	http://www.ports.org.uk/port.asp?id=93
114	Ramsey	54	19	N	4	22	W	Isle of Man	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=302
115	Ramsgate	51	20	N	1	26	E	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=99
116	Rhubodach	55	55	N	5	8	W	Scotland	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=380
117	Ripple	52	2	N	2	12	W	England	Commercial	http://www.ports.org.uk/port.asp?id=915
118	Rochester	51	24	N	0	31	E	England	Commercial	http://www.ports.org.uk/port.asp?id=908
119	Rochford	51	37	N	0	45	E	England	Commercial	http://www.ports.org.uk/port.asp?id=90
120	Rosyth	56	1	N	3	26	W	Scotland	Commercial	http://www.ports.org.uk/port.asp?id=722
121	Rothesay	55	50	N	5	2	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=381
122	Ryall	52	3	N	2	12	W	England	Commercial	http://www.ports.org.uk/port.asp?id=914
123	Scalloway	60	8	N	1	18	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=635
124	Scrabster	58	36	N	3	32	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=543
125	Seaham	54	50	N	1	19	W	England	Commercial	http://www.ports.org.uk/port.asp?id=19
126	Selby	53	47	N	1	5	W	England	Commercial	http://www.ports.org.uk/port.asp?id=36
127	Sharpness	51	43	N	2	28	W	England	Commercial	http://www.ports.org.uk/port.asp?id=226
128	Sheerness	51	26	N	0	45	E	England	Commercial	http://www.ports.org.uk/port.asp?id=92
129	Shoreham	50	50	N	0	14	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=115
130	Silloth	54	52	N	3	22	W	England	Commercial	http://www.ports.org.uk/port.asp?id=349
131	Southampton	50	53	N	1	23	W	England	Leisure/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=125
132	Stornoway	58	11	N	6	22	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=515
133	Strangford	54	22	N	5	32	W	N. Ireland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=318
134	Stranraer	54	55	N	5	2	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=357

135	Stroma	58	41	N	3	7	W	Scotland	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=544
136	Sunderland	54	55	N	1	22	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=22
137	Swansea	51	37	N	3	56	W	Wales	Commercial	http://www.ports.org.uk/port.asp?id=235
138	Teesport	54	37	N	1	9	W	England	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=23
139	Teignmouth	50	33	N	3	29	W	England	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=164
140	Thamesport	51	25	N	0	43	E	England	Commercial	http://www.ports.org.uk/port.asp?id=94
141	Tilbury	51	27	N	0	22	E	England	Commercial	http://www.ports.org.uk/port.asp?id=89
142	Tobermory	56	38	N	6	5	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=410
143	Troon	55	32	N	4	39	W	Scotland	Leisure/Commercial	http://www.ports.org.uk/port.asp?id=370
144	Truro	50	15	N	5	2	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=182
145	Tyne	54	59	N	1	25	W	England	Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=24
146	Uig	57	35	N	6	21	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=461
147	Ullapool	57	54	N	5	8	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=471
148	Walls	60	13	N	1	34	W	Scotland	Leisure/Fishing/Commercial/FerryTerminal	http://www.ports.org.uk/port.asp?id=643
149	Warrenpoint	54	5	N	6	11	W	N. Ireland	Commercial	http://www.ports.org.uk/port.asp?id=319
150	Weymouth	50	37	N	2	27	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=132
151	Whitby	54	29	N	0	38	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=30
152	Whitstable	51	21	N	1	5	E	England	Fishing/Commercial	http://www.ports.org.uk/port.asp?id=110
153	Wick	58	26	N	3	4	W	Scotland	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=583
154	Wisbech	52	40	N	0	10	E	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=57
155	Workington	54	39	N	3	33	W	England	Commercial	http://www.ports.org.uk/port.asp?id=343
156	Yarmouth	50	42	N	1	30	W	England	Leisure/Fishing/Commercial	http://www.ports.org.uk/port.asp?id=126

List of airports/strips suitable for marine mammal survey work

No.	Airfield/Strip Name	Latitude		Longitude		Web details
1	Alderney Airfield	49.70676	N	-2.21538	W	http://www.british-towns.net/os/level_4_display.asp?GetL3=17894
2	Baltasound Airfield - Unst	60.75	N	-0.85	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17858
3	Barra Airfield	57.017	N	-7.433	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17860
4	Caernarfon Airfield	53.10232	N	-4.3372	W	http://www.british-towns.net/cy/level_4_display.asp?GetL3=17895
5	Colonsay Landing Strip	56.05713	N	-6.24564	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=18730
6	Eday Airfield	59.1902	N	-2.77212	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17874
7	Fair Isle Airfield	59.535831	N	-1.628056	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17862
8	Foula Airfield	60.12176	N	-2.05118	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17863
9	Headcorn Aerodrome	51.15584	N	0.64545	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=18630

10	Kemble Airfield	51.66768	N	-2.05715	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=18377
11	Machrihanish Airfield - Cambeltown	55.42928	N	-5.68027	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17861
12	North Ronaldsay Airfield	59.36666667	N	-2.433333333	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17866
13	Outer Skerries Airfield	60.42532	N	-0.75102	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17867
14	Papa Stour Airfield	60.31666667	N	-1.7	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17868
15	Papa Westray Airfield	59.351662	N	-2.900278	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17859
16	Port Howard Airfield	-51.61208	S	-59.51606	W	http://www.british-towns.net/os/level_4_display.asp?GetL3=19075
17	Sanday Airfield	59.25027778	N	-2.576666667	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17869
18	Scatsta Airfield	60.43628	N	-1.29379	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17857
19	St Just Airfield	50.10257	N	-5.67165	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17882
20	St Marys Airfield	49.91333	N	-6.296666	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17855
21	Stronsay Airfield	59.15528	N	-2.64139	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17870
22	Tiree Airfield	56.499167	N	-6.869167	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17871
23	Tresco Airfield	49.94934	N	-6.32795	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17892
24	Westray Airfield	59.35	N	-2.95	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17872

	Airport Name	**Latitude**		**Longitude**		**Web details**
25	Aberdeen Dyce International Airport	57.20253	N	-2.19907	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17844
26	Belfast International Airport	54.65574	N	-6.21736	W	http://www.british-towns.net/ni/level_4_display.asp?GetL3=17854
27	Benbecula Airport	57.48103	N	-7.36204	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17020
28	Biggin Hill Airport	51.32761	N	0.03438	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=19019
29	Birmingham International Airport	52.45329	N	-1.74511	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17849
30	Blackpool International Airport	53.77314	N	-3.03137	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17879
31	Bournemouth International Airport	50.78358	N	-1.84021	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17840
32	Bristol International Airport	51.38357	N	-2.71448	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17852
33	Cambridge Airport	52.20369	N	0.17587	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=14625
34	Cardiff International Airport	51.39856	N	-3.34572	W	http://www.british-towns.net/cy/level_4_display.asp?GetL3=17851
35	City of Derry Airport	55.04305	N	-7.15944	W	http://www.british-towns.net/ni/level_4_display.asp?GetL3=17877
36	Coventry Airport	52.36984	N	-1.48127	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=15845
37	Dalcross Inverness Airport	57.5425	N	-4.0475	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17864
38	Dundee Riverside Airport	56.45274	N	-3.01459	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17878
39	Durham Tees Valley Airport	54.51261	N	-1.43277	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17632
40	East Midlands Airport	52.82891	N	-1.32874	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=15835
41	Edinburgh Airport	55.94906	N	-3.36117	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=16871
42	Exeter International Airport	50.73499	N	-3.41486	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17853
43	George Best Belfast City Airport	54.62251	N	-5.87305	W	http://www.british-towns.net/ni/level_4_display.asp?GetL3=17876

44	Glasgow Airport	55.86876	N	-4.43479	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17349
45	Glasgow Prestwick International Airport	55.50484	N	-4.58954	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17875
46	Glenegedale Airport - Islay	55.681944	N	-6.256667	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17865
47	Gloucester and Cheltenham Airport	51.89122	N	-2.15881	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17881
48	Guernsey Airport	49.43331	N	-2.59421	W	http://www.british-towns.net/os/level_4_display.asp?GetL3=17856
49	Humberside International Airport	53.57516	N	-0.35092	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17847
50	Isle of Man Ronaldsway Airport	54.08666	N	-4.63452	W	http://www.british-towns.net/os/level_4_display.asp?GetL3=17848
51	Jersey Airport	49.20607	N	-2.19355	W	http://www.british-towns.net/os/level_4_display.asp?GetL3=17893
52	Kent International Airport	51.34525	N	1.35055	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=17886
53	Kirkwall Airport - Orkney	58.95787	N	-2.90129	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17842
54	Leeds Bradford International Airport	53.86607	N	-1.65662	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17846
55	Liverpool John Lennon Airport	53.33482	N	-2.85245	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17845
56	London City Airport	51.50498	N	0.04721	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=17883
57	London Gatwick Airport	51.15289	N	-0.18226	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17332
58	London Heathrow Airport	51.47197	N	-0.45353	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17110
59	London Luton Airport	51.87697	N	-0.37036	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17850
60	London Stansted Airport	51.88693	N	0.24711	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=17345
61	Lydd Airport	50.95532	N	0.93826	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=17885
62	Manchester Airport	53.35619	N	-2.27983	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=14430
63	Newcastle International Airport	55.03872	N	-1.69151	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=14494
64	Newquay St Mawgan Airport	50.44677	N	-5.00386	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17887
65	Norwich International Airport	52.67576	N	1.28111	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=14505
66	Penzance Heliport	50.12804	N	-5.51841	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17888
67	Plymouth City Airport	50.42431	N	-4.10902	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17889
68	Robin Hood Doncaster Airport	53.47594	N	-1.00825	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17880
69	Sheffield City Airport	53.39413	N	-1.389	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=14545
70	Southampton Airport	50.9504	N	-1.35522	W	http://www.british-towns.net/en/level_4_display.asp?GetL3=17890
71	Southend Airport	51.57222	N	0.69883	E	http://www.british-towns.net/en/level_4_display.asp?GetL3=17884
72	Stornoway Airport	58.21488	N	-6.32885	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17843
73	Sumburgh Airport - Shetland	59.87942	N	-1.29124	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17841
74	Swansea Airport	51.60252	N	-4.06707	W	http://www.british-towns.net/cy/level_4_display.asp?GetL3=17891
75	Wick Airport	58.45797	N	-3.09188	W	http://www.british-towns.net/sc/level_4_display.asp?GetL3=17873