

# **ESTIMATION OF COSTS ASSOCIATED WITH IMPLEMENTING A DEDICATED CETACEAN SURVEILLANCE SCHEME IN UK**

**Peter G.H. Evans<sup>1,2</sup> and Len Thomas<sup>3</sup>**

<sup>1</sup> Sea Watch Foundation, Ewyn y Don, Bull Bay, Amlwch, Isle of Anglesey LL68 9SD, Wales, UK

<sup>2</sup> School of Ocean Sciences, University of Bangor, Menai Bridge, Isle of Anglesey LL59 5AB, Wales, UK

<sup>3</sup> Centre for Research into Ecological and Environmental Monitoring, School of Mathematics & Statistics, University of St Andrews, Fife KY16 9LZ, Scotland, UK

## **1. BACKGROUND**

There is an obligation under Article 11 of the EU Habitats Directive to undertake surveillance on the conservation status of all cetacean species occurring in UK waters, and to report on this every six years. Under the Habitats Directive, species and habitats should achieve and maintain a Favourable Conservation Status (FCS). The FCS, as defined by the Habitats Directive, is measured mainly by assessing changes in the following parameters: 1) natural range, 2) population size, and 3) habitat. It should also take consideration of threats/pressures as well as future prospects for species. Monitoring must therefore lead to a clear picture of the actual conservation status of a species and its trends on various levels, and should be coordinated in order to better detect changes in the distribution or abundance of these species that could reflect a failure to achieve FCS.

## **2. AIMS & OBJECTIVES**

The purpose of this project to estimate the costs associated with a dedicated cetacean surveillance scheme for UK waters. These costs will contribute to the further development of a UK Cetacean Surveillance Strategy.

As part of the development of the UK Cetacean Surveillance Strategy, the development of a cost effective approach is necessary. A dedicated sightings and acoustic survey approach for annual monitoring has already been outlined in order to meet the UK cetacean surveillance requirements. This project will provide the cost implications for instigating such a project. This will include:

- design and costings for a survey protocol with suggested track-lines and sampling frequencies for coverage of all UK waters, involving vessels and/or planes. This requires identifying suitable harbours and/or airstrips (with appropriate vessels/planes) around the UK, costing out likely daily distances covered, charter, and personnel costs including analysis.
- design of a possible C-POD arrangement for monitoring long-term usage in SACs and particular coastal sites (costed on a unit basis so that the numbers of PODs could be increased or reduced as required); costs to be split up into capital outlay, unit maintenance, deployment costs, and analytical costs.

- proposed costs for dedicated photo-ID of the major coastal bottlenose dolphin populations, including capital outlay, boat charter and any other running costs, catalogue maintenance, matching & analyses.

Wherever possible, emphasis will be placed on finding the most cost-effective ways to achieve a statistically robust surveillance system, which are clearly related to the power to detect trends.

### 3. METHODS & COSTINGS

#### 3.1 Line-transect vessel surveys

**Methodology** A basic requirement for a line-transect survey design is that the lines are laid out using a random allocation scheme that provides representative coverage of the area for which a density or abundance estimate is desired (Buckland *et al.*, 2001; Strindberg *et al.*, 2004). This enables one to extrapolate from a sample area by simply multiplying sample density by survey area. A survey design that gives representative coverage is one where each point in the area has an equal probability of being sampled. This is necessary because animals are not distributed randomly in space. For some methods of analysis, coverage is not required to be equal, but the probability that each point in the survey area will be sampled, nevertheless, must be known (Strindberg *et al.*, 2004). To generate this kind of design requires a computer program such as that which forms part of the Distance 6 software (Thomas *et al.*, 2010). Such designs are especially useful for surveying irregularly shaped areas, for which ensuring equal coverage probability is problematic.

The two survey designs most commonly used are sets of equally spaced parallel lines or a regular zigzag pattern. Both are examples of systematic random designs, which produce more precise estimates than purely random designs (Strindberg *et al.*, 2004). If the objective is to derive estimates of average abundance/density, then new lines should be chosen each time (Thomas *et al.*, 2004). However, where the focus is upon measuring trends, then the same lines should be repeated each time (Thomas *et al.*, 2004).

Transects should as far as possible run perpendicular to any density gradient (Buckland *et al.*, 2001, Chapter 7). Coastal surveys, for example, typically have transects that run more or less perpendicular to the shore line or zigzag away from it. On the other hand, lines running on an east-west axis may have to cope more with glare than those on a north-south axis. This could be a particular issue for aerial surveys, and some compromise may be necessary.

Large vessels tend to be used for systematic line-transect surveys because they offer a stable and high platform, and sufficient space to house a large team, a particular advantage if the vessel is required to remain at sea for extended periods. They also offer a greater opportunity to operate double platforms for determining  $g(0)$  (probability of detection along the track-line, or at least the component of this due to perception bias).

Nevertheless, constraints of habitat (e.g. shallow depth, complex coastlines) and resources (e.g. charter costs) often favour the use of smaller vessels for surveys (see, for example, Evans *et al.*, 2007b; Dawson *et al.*, 2008).

There is an argument that small vessels have limited range and therefore may only be suitable for coastal areas. On the other hand, they often can attain higher speeds (15-30 knots, or 28-37 km/hr) than the large vessels traditionally used for line-transect surveys, whose maximum speeds may not exceed 15 knots. This gives them greater flexibility to travel quickly to or from the start/end points of transects, or to escape bad weather. A line-transect survey of common dolphins using a small (<15m) vessel in an offshore area of 3,134 km<sup>2</sup> in the Celtic Deep between Ireland and Wales, typically traversed between 220 and 300 km in a day, with a cruising speed on transect of 10-12 knots (18.5-22 km/hr) (Evans *et al.*, 2007a). It also had provision for six persons to sleep aboard, although this rarely proved necessary.

A more significant constraint for a small vessel applies if one is seeking to operate a double platform, the higher one preferably being at least 5m above sea level (the greater the height, the easier it is to spot surfacing cetaceans above waves and at greater distances thus coping better with responsive movement; greater height also increases the resolution with which observers can measure the downward angle to sightings). However, for those vessels without a flying bridge, one can construct a viewing platform on top of the wheelhouse, using the foredeck or placement within the wheelhouse itself as the other platform. These should ideally operate independently of one another so that a sighting by one observer (pair) does not affect the other (i.e. two-way independence). The higher platform can be used to detect animals at a distance and thus determine whether responsive movement has occurred (which tends to be positive in the case of common, bottlenose and white-beaked dolphins, and negative in porpoises, depending on type and size of vessel). A small vessel is unlikely to be sufficiently stable to mount big-eye binoculars to scan greater distances, and it will be more practical to use hand-held ones (e.g. 7x50, 8x40, or 10x50). Dawson *et al.* (2008) provide a number of illustrations for how this can operate in practice.

If a small vessel is used, a catamaran has advantages over displacement mono hulls. Catamarans are capable of higher cruising speeds with less horsepower, and they can be more stable. On the other hand, the narrowness of the hulls may make some more sensitive to pitching, although this can be minimised by travelling down-swell along survey lines (Dawson *et al.*, 2008). We have also used catamarans of 10-15 m length for line-transect surveys, and found them to be speedy yet economical, stable platforms with a large cruising range, and capable of easily taking on board a team of eight to ten.

The main advantage of small vessels is their much lower cost. This enables more surveys to be conducted for an equivalent price of a large vessel, resulting in larger numbers of encounters, and potentially more robust abundance estimates. They also have more ports and harbours available to them from which to operate. Of course, this may be counteracted by logistical constraints in certain areas (e.g. they are unlikely to be

appropriate for surveying to the margins of the EEZ west of Rockall), and if the number of vessels used is high it may introduce extra heterogeneity.

Cetaceans tend to have clumped distributions around particular bathymetric or oceanographic features. Some species, for example bottlenose dolphin and harbour porpoise, often occur at higher densities near-shore in the vicinity of headlands, bays or channels between islands. Line transects running perpendicular to the coast or zigzagging from them, do not sample these locations very well. To cater for this, it is proposed that the Nearshore zone is monitored by a transect that runs parallel to the coast at a distance that enables one to have as high a probability as possible of detecting all cetaceans within that strip. With favourable survey conditions (sea state 2 or less and good visibility), this is estimated to be 250m either side of the track-line, thus surveying a 500m wide coastal strip.

Three main survey strata are thus proposed: 1) for the nearshore strip, vessel transects of 500m width (250m half width) running parallel to the coast (with a double observer protocol so that the usual assumption of uniform distribution of animals with respect to distance is not required), and sub-sampling a proportion; 2) zigzag (vessel) transects covering the area out to 12 nm (c. 22 km) (or alternatively, to double the line spacing and then have a “crossed” zigzag design where one covers one set of zigzags on the way out and the other set on the way back); and 3) for the area from 12 nm to the edge of the EEZ, parallel (aerial) transects but at wider spacings since overall encounter rates will generally be lower (see Appendix 2).

**Costings** The costings presented here are based upon a charter rate of £70/hour using a 10-15m vessel, although rates will vary between operators and will also be contingent upon how fuel costs change. Some vessels may require an elevated platform (using stainless steel scaffolding) to be added on in order to provide a platform height of 5m above sea level. The cost of this will also vary depending upon how much extra height is required above the wheelhouse, but a platform of this nature built recently cost £2,500 including labour.

Basic survey equipment required includes binoculars for each observer, an angle board, a GPS preferably linked to a laptop or PDA, and if data are being recorded electronically, an external hard drive as back-up. For double platform surveys, there should be three to four observers (two as primary observers and one to two as secondary observers), and a recorder operating at any one time; for single platform surveys, the number of observers is reduced to two, along with a recorder. In order to avoid fatigue, a dedicated team of at least six persons is recommended so that they can be rotated hourly and each allowed periods of rest. Field costs are summarised in Table 1.

Capital costs per survey team are therefore c. £2,000, with costs for boat charter (on the basis of use of a 10-15m vessel, a survey team of six persons, and low cost reticle binoculars) at around £2,250 per 200km travel – c. £11.25/km. However, with current inflation and increases in VAT, etc, it may be prudent to increase these estimates by 10% or so. We assume that some vessels will have suitable flying bridges enabling a double

platform to be used, but that it will be necessary to add a platform in the case of some vessels (arbitrarily set at forty for the time being), yielding an additional capital cost of c. £100,000.

**Table 1.** Field costs for vessel-based line transect surveys

|                     | <b>Description</b>  | <b>Cost</b>    |
|---------------------|---|----------------|
| <i>Boat charter</i> | 10-hr survey (200 km coverage) @ £75/hr                           | £ 750          |
| <i>Personnel</i>    | 6 x 10 hrs staff time @ £25/hr                                    | £ 1,500        |
| <b>Sub-total</b>    | For one day of survey (10 hrs duration, 200km distance travelled) | <b>£ 2,250</b> |
| <i>Equipment</i>    | 6 x 7x50 Fujinon BIF reticle binoculars                           | £ 1,320        |
|                     | 2 x Garmin eTrex H handheld GPS                                   | £ 125          |
|                     | 16 rechargeable batteries & charger                               | £ 38           |
|                     | 2 angle boards  | £ 15           |
|                     | Dell Inspiron IM501R Athlon P320 4 GB 320 GB laptop computer      | £ 303          |
|                     | Western Digital MyBook Studio Edition II 2TB external hard drive  | £ 167          |
| <b>Sub-total</b>    | Capital costs per survey team                                     | <b>£ 1,968</b> |

Costs (obtained 31 Jan 2011) of GPS, batteries & charger, external HD from [www.amazon.co.uk](http://www.amazon.co.uk); reticle binoculars from [www.bhphotovideo.com](http://www.bhphotovideo.com); Dell laptop computer from [www.dell.co.uk](http://www.dell.co.uk)

Costs are calculated here on the basis that the nearshore and inner strata will be surveyed by vessel. Appendix 2 gives details of recommended survey design and track lengths. One feature of small vessels vs. large ones is that almost all ports and harbours around the UK can cater for small vessels. This makes travel time/distance to start points a relatively easy process. The period off-effort can be further reduced if during returns to port, the nearshore stratum is surveyed in a one-pass mode (see Appendix 2 for further discussion of survey design for that stratum). The other option (as stated earlier) is that the line spacing is doubled on the inshore stratum and one adopts a “crossed” zigzag design where one covers one set of zigzags on the way out and the other set on the way back. For the time being, we will assume 10% of total survey lengths to be required off-effort (where returns are incorporated in nearshore stratum surveys), and 20% otherwise. Note that the inshore stratum for the Northwest, under the present scenario, is surveyed by plane.

For this inshore stratum, at field costs of £11.25 per km, a realized on-effort line length of 4,882km, and off-effort lengths of 10% (488km) or 20% (976km), the overall costs per survey are given in Table 2.

**Table 2.** Overall field costs for vessel-based line-transects throughout the inshore stratum (per survey)

| <b>Line length</b> | <b>Description</b> | <b>Cost</b> |
|--------------------|--------------------|-------------|
| 4,882km            | 1) On-effort       | £ 54,923    |
| 488km              | 2a) 10% off-effort | £ 5,490     |
| 976km              | 2b) 20% on-effort  | £ 10,980    |

|                     |  |                 |
|---------------------|--|-----------------|
| <b>TOTAL (1+2a)</b> |  | <b>£ 60,413</b> |
| <b>TOTAL (1+2b)</b> |  | <b>£ 65,903</b> |

For the nearshore stratum (which includes all of the British Isles), at field costs of £11.25 per km, and on-effort line length (for all but the northwest stratum) of 5,484km if surveyed in one pass, or 10,968km in two passes, the overall costs per survey are shown in Table 3.

**Table 3.** Overall field costs for vessel-based line-transects throughout the nearshore stratum (per survey)

| <b>Line length</b> | <b>Description</b>                         | <b>Cost</b> |
|--------------------|--|-------------|
| 5,484km            | One-pass survey - Southeast                | £ 61,650    |
| 10,968km           | Two-pass survey - Southeast                | £123,300    |
| 24,800km           | Two-pass survey – Northwest (20% coverage) | £ 55,800    |

Thus, if inshore and nearshore strata are surveyed together using a one-pass survey in the Southeast nearshore stratum, the overall field cost would be £60,413 + £61,650 = £122,063. If such surveys were conducted at a frequency of six per year, the total annual cost would be around £732,400. The Northwest nearshore stratum contains a very indented coastline with many islands, some very small. Covering all of these is probably excessive (it should be noted that the coastline length estimate is exaggerated by rivers and skerries that are included). We therefore propose sub-sampling that stratum (using a two-pass survey) with 20% coverage of the 24,800km total estimate (concentrating upon west & north Scottish mainland coasts and islands above a certain size), resulting in a cost of £55,800. If these were conducted at a frequency of six per year, the overall cost for the Northwest nearshore stratum would amount to £334,800. Since local vessels would be used on an opportunistic basis (when weather conditions are favourable), it is anticipated that there should be no extra downtime expense.

Depending upon how much time is required for processing and checking of data collected, one (possibly two) full-term personnel is likely to be needed for analyses of vessel and aerial surveys combined.

### **3.2 Line-transect aerial surveys**

**Methodology** The major advantage of aerial surveys over vessel-based ones is that they can cover large areas in a short space of time, enabling surveys to make use of narrow windows of good weather that commonly are experienced in the British Isles given its maritime climate. Sea state in particular can have a major effect upon an observer's ability to detect a cetacean, and planes potentially provide the opportunity to survey large areas in optimal weather conditions. Aerial surveys are also more easily conducted in those near-shore areas that have dissected coastlines or around island archipelagos such as Northern and Western Scotland. And there is evidence that for certain species (e.g. harbour porpoise), the problem of responsive movement is less for planes than vessels, presumably because a plane moves rapidly out of range with limited impact. On the other hand, the high speed of a plane means that observers have only a very short time to spot a surfacing animal compared with a slower moving vessel; it may also be easier to count

groups from a slower moving vessel. Besides perception bias, the rapid travel across an area by a plane can introduce greater availability bias, particularly for those species that have long dives, spending extended periods of time underwater. In areas of low density, aerial surveys may therefore not be very effective because they yield too small sample sizes. On the other hand, the availability process from a plane is quite simple: either the animal is at (or very near) the surface when the plane goes over or it is not. This “instantaneous” availability process is much easier to account for (assuming some knowledge of animal surfacing rates) than the “intermittent” availability process that is more realistic in slower-moving surface vessels, where animals are intermittently either more-or-less continuously available at the surface for some periods of time and then below the surface for others. Hence, although availability bias is a greater problem for aerial surveys, it is easier to account for.

The availability of suitable planes and airstrips may also limit where aerial surveys can be conducted whilst the amount of fuel a plane can carry and amount of time a pilot can fly will place some limit on the survey area. Generally, for aerial surveys of marine mammals, a total continuous flying time of 5.5 hours is considered the maximum, both for the pilot and observers.

Choice of plane is very important. Partenavia PN68 aircraft are the preferred option, although larger twin otters, a two motor Cessna, or a Britten Norman BN 2 Islander have been used in some surveys. The plane should have twin engines for safety and be high-winged, preferably with a bubble window beside each rear seat for ease of viewing (from abeam to the track-line). A belly port has the additional advantage of providing downward visibility (and, if necessary, deployment of a video camera), although most planes do not have this facility. There are five Partenavia aircraft in the UK, two of which are equipped with bubble windows. These are owned and run by Ravenair, based at Liverpool airport, and they have been used frequently before for both offshore marine bird and mammal surveys (including SCANS).

Typically, aerial surveys of marine mammals are conducted at speeds of 90-110 knots (165-205 kmh<sup>-1</sup>) over ground (depending on wind conditions), flying at a height of 500-600 ft (150-180 m) (Scheidat *et al.*, 2005; Palka, 2005; Grünkorn *et al.*, 2005; Hammond, 2008). The height of 600 ft allows the observer more time to view the area and increases the strip width effectively surveyed, although identification of similar species does become more difficult.

Although zigzag track lines are often used in order to maximise coverage of an area with minimal time wasted transiting between tracks, on aerial surveys this gives observers little opportunity to rest, and so parallel tracks are recommended here. However, zigzags could be an option for the offshore stratum, where off-effort times are relatively long. In both cases, it is usual for tracks to run perpendicular to the coast.

If distance sampling is being used to derive estimates of absolute density, then it is necessary to measure the height of the plane throughout the survey using a radar altimeter. The angle of declination is collected using a handheld inclinometer to

determine perpendicular distance. When using a computer to enter the data, one channel can be used to feed in the height of the plane. A voice-activated tape recorder in combination with a computer programme (such as the VOR programme developed by Lex Hiby & Phil Lovell) is useful. The time of recording is saved automatically, and the recording is saved as a \*.wav file on the computer. The information is then entered at the end of the day. Back-up systems should be included in case of computer failure. This should be a handheld GPS, watches with large displays, and tape recorders.

Two observers are used, one watching on either side of the plane. An additional person as recorder, situated in the co-pilot seat, is useful to ensure that all data are immediately stored and saved. The disadvantage of aerial surveys over vessel based ones using this arrangement is the absence of a double platform scheme. It may be that the person in the co-pilot seat could act as a separate observer or if there was space behind, another person could fill that role, providing one-way independence (see below).

The following data should be collected: aircraft position (every 2-4 seconds and whenever a sighting is made), general flight information (observer positions), environmental conditions for each track or when they change (sea state, glare, subjective judgment of conditions, turbidity, and percentage cloud cover) and sighting information (species, group size, presence of young animals, behaviour, swim direction, cue, reaction, and inclinometer angle, unless distance “bins” are used). Emphasis should be paid to increasing scanning effort close to the trackline to reduce the size of the left truncation strip in the distribution of detections, during analyses, and also to avoid the rounding of angle measurements, which will lead to clumping in the histogram of distances. A belly window would help minimize the first potential bias. Training of observers on protocols for data collection and use of computer should be conducted first on land, whilst first flights are best made as extras using the side windows to scan. Correct species identification is more likely if the observers already have a lot of field experience. Emergency training should include establishing clear protocols for plane evacuation, and the plane should have all the appropriate safety equipment necessary for an emergency landing on water.

In order to avoid observer fatigue on longer surveys, positions can be rotated (including that of the recorder) after each transect. One person can go off-effort either transiting from one trackline to the next or circle for some minutes to give observers a rest. Observers may also keep alert by recording the presence of vessels, etc, within a particular arc (e.g. 20°).

The assumption of line-transect surveys is that all targets present on the track-line will be detected with certainty. Just as with vessel-based surveys, this is clearly violated. In order to determine the probability of detection along the trackline ( $g(0)$ ), two methods have been developed – the tandem method (Hammond *et al.*, 1995) where two planes fly in tandem of one another, and the circle back method (Hiby & Lovell, 1998; Hiby, 1999) where the plane circles back and re-surveys a portion of the track-line after a sighting has been made. Both methods can have practical difficulties (Hammond, 2008). An alternative if space allows is to carry two observer teams (i.e. four observers) each



working independently so that mark-recapture-distance sampling can be used. In that case, care is needed to ensure the two observer teams do not influence one another, and that they closely follow an established protocol. Failing that, another possible option is to have a third observer on a rear seat recording sightings on the side with the best sighting conditions, thus providing one double counted strip on each transect (Grünkorn *et al.*, 2005; Diederichs *et al.*, 2008). This latter approach is suggested here.

In recent years, high-definition (HD) photography has been used effectively to survey marine birds in the vicinity of wind farm sites (Mellor *et al.*, 2007; Mellor & Maher, 2008; Hexter, 2009a, b; Thaxter & Burton, 2009). Besides the fact that it reduces labour costs and observer variability, it has the potential to provide more accurate counts of groups of animals. Although birds were the target group, marine mammals such as seals and porpoises have been recorded in this way.

The main problem issues are 1) species identification, particularly between dolphin species (and this would probably also apply to rorqual whales), 2) the fact that the probability of detection along the track-line ( $g(0)$ ) remains unknown, and 3) that detectability will vary with the turbidity of the surface layers. Although intuitively one might expect that only availability bias (presence of animals but not at the surface) would affect  $g(0)$ , perception bias (presence at the surface but undetected) could also apply when lighting conditions are not good (e.g. if there is glare or it is heavily overcast). At present there is no way to account for these. It would, however, be useful to test HD photography alongside conventional visual aerial surveys for a direct comparison. For the time being, this approach is not costed here.

**Costings** The costings presented here have been assembled in collaboration with Ravenair, the only company in UK offering Partenavias, the most suitable survey aircraft, and with WWT Consulting who have the most practical experience of aerial surveys (targeting marine birds but also recording marine mammals, basking sharks, turtles and ocean sunfish – WWT, 2009) in the UK. Plane charter rates may increase with inflation, and travel times are going to vary according to the location of the nearest airstrip, and the schedule adopted for covering various regions around the British Isles.

A recommended schedule is for aerial surveys to be undertaken in the offshore sector of UK waters and in the Northwest (due to its dissected coastline) every two months. Another option would be to survey every month.

Some expenditure on capital equipment is required and this is detailed in Table 3. For logistical reasons, probably there will need to be separate survey teams for different regions, each with its own set of survey equipment. Binoculars are not routinely used on aerial surveys, but are useful for backup. An SLR stills camera or HD video camera are useful extras. Safety equipment is necessary, to carry on board the plane. In most circumstances this will be provided by the charter airline.

**Table 3.** Field costs for aerial line transect surveys

|  | Description | Cost |
|--|-------------|------|
|--|-------------|------|

|                                   |   |                    |
|-----------------------------------|---|--------------------|
| <i>Plane charter</i> <sup>1</sup> | 25 survey days with 28 overnight stays x 6 (offshore stratum)     | £ 725,200          |
| <i>Plane charter</i> <sup>2</sup> | 49 survey days with 10 overnights x 6 (Northwest inshore stratum) | £ 216,840          |
| <i>Personnel</i> <sup>1</sup>     | 3 persons @ £25/hr for 153 hrs + 28 overnights @ £150/person x 6  | £ 98,550           |
| <i>Personnel</i> <sup>2</sup>     | 3 persons @ £25/hr for 49 hrs + 10 overnights @ £150/person x 6   | £ 48,830           |
| <b>Sub-total</b>                  | Annual survey costs (assuming 6 surveys/year)                     | <b>£ 1,089,420</b> |
| <i>Equipment</i>                  | 2 x 7x50 Fujinon BIF reticle binoculars                           | £ 440              |
|                                   | 1 x Garmin eTrex H handheld GPS                                   | £ 62               |
|                                   | 16 rechargeable batteries & charger                               | £ 38               |
|                                   | Suunto PM-5/1520 PC clinometer                                    | £ 115              |
|                                   | Dell Inspiron IM501R Athlon P320 4 GB 320 GB laptop computer      | £ 303              |
|                                   | 2 Sony ICDBX800 digital voice recorders with microphones          | £ 50               |
|                                   | Western Digital MyBook Studio Edition II 2TB external hard drive  | £ 167              |
| <b>Sub-total</b>                  | Capital costs per survey team = £1,175 x 6 teams                  | <b>£ 7,050</b>     |

Costs (obtained 31 Jan 2011) of GPS, batteries & charger, clinometer, voice recorders, and external HD from [www.amazon.co.uk](http://www.amazon.co.uk); reticle binoculars from [www.bhphotovideo.com](http://www.bhphotovideo.com); Dell laptop computer from [www.dell.co.uk](http://www.dell.co.uk)

Ravenair calculates on the basis of aircraft hourly BLOCK HOUR rates of £590 (this and all prices below require VAT adding). World fuel price changes may escalate the rate, but this could be dealt with as a contractual issue. They currently charge their clients for actual block time and costs incurred on survey and positioning. Charges are also made for days away from base (Liverpool) for each area. The total block hour per day is approximately 5 hours. Night stops are calculated to include pilot hotel and subsistence costs, and an estimate of transport, and is estimated at £150. Airports that would be used include: Stornoway, Islay, Oban, Belfast (Northwest), Lerwick, Wick, Dundee (Northeast), Liverpool (NW England/North Wales), St Marys, Newquay, and Haverfordwest (SW England/South Wales), Shoreham (Southern England), Norwich, Humberside and Newcastle (Eastern and NE England). Airport fees are estimated at £250 per day. At times, it will be necessary to have hangarage and de-icing, which is charged back to the end user.

Finally, consideration must be given for the following: maintenance planning, availability of pilots, observers, aerodromes and most of all the weather. Some positioning may be required between survey blocks to get the best of the weather windows etc.

Ravenair's indicative costings for the offshore stratum are calculated on the basis of 25 days of survey (5 hrs/day), making a total of 125 hours + 153 hours (28 days @ 5 hrs per day) for travel between airport and survey. There would be 28 night stops at £150 per night, costing a total of £4,200. Airport fees at £250 per day for 25 days of survey amount to £6,250. Charter rates for a total of 153 hours at £590 amount to £90,270. Adding this to the night stop & airport charges of £10,450 gives a total of £100,720. When 20% VAT is added, this gives a grand total of £120,864. If the surveys are conducted six times a year, this gives an annual cost of £725,184 as Ravenair's costs. To this must be added the survey team's costs. With three observers working 153 hours on the task at £25/hour, this totals £3,825. However, given the fact that they will also require 28 overnight stays, if that is costed also at £150 per person per nightstop, there should be £12,600 added (28 x

£150 x 3 persons), making a total of £16,425. For six surveys, the overall survey team costs would be £98,550 per year (see Table 3).

For the northwest inshore stratum on the basis of 11 days of survey (total 48.5 hrs) and 10 nightstops, costs were estimated at £28,615 for the charters + £1,500 for the nightstops + £2,750 for airport fees, giving a total of £30,115. When 20% VAT is added, this gives a grand total of £36,138. If the surveys are conducted six times a year, this gives an annual cost of £216,828. The survey team's costs would be £25 x 48.5 hrs x 3 observers = £3,638. With 10 overnight stays at £150 per person per nightstop, there should be £4,500 added (10 x £150 x 3 persons), making a total of £8,138. For six surveys, the overall survey team costs would be £48,828 (see Table 3). To allow for downtime due to delays caused by unfavourable weather conditions, a 15% contingency is applied throughout (as advised by WWT on the basis of their field experience).

### **3.3 Static acoustic monitoring**

**Methodology** Acoustic monitoring of cetaceans from fixed points has the advantage that animals can potentially be detected in all weathers and at both day and night. Automated data collection reduces personnel costs whilst providing continuous monitoring in a standardized manner for extended periods. Because detection ranges are limited, at least for dolphins and porpoises that produce high frequency sounds (whistles in the case of the former, and clicks in both cases), monitoring is likely to be applicable to only a small area. Its value is therefore primarily as a cost effective means for establishing trends in how particular areas (e.g. within an SAC, or in conjunction with certain human activities) are being used by cetaceans - between years, seasonally and over shorter time periods (daily & tidal cycles). By its nature, acoustic monitoring requires animals to be vocal and detectable. In the context of the UK continental shelf, this means that static acoustics will be most usefully applied to a species like the harbour porpoise that echolocates more or less continuously. However, both dolphins and porpoises emit sounds in narrow beams so that if they are oriented away from the hydrophone, they will be less easily detected than if they are facing it.

Estimates of absolute abundance from acoustic detections remain difficult to obtain, particularly when animals occur in groups, although much progress has been made in recent years with the development of hydrophone arrays, algorithms for better classification and location of sounds, and statistical approaches for density estimation (Mellinger *et al.*, 2007; Moretti *et al.*, 2009; Thomas & Marques, 2009; Marques *et al.*, in press a, in press b), and this work is currently being extended to PODs using a 'time present' model (e.g. at Bangor University in collaboration with CREEM, University of St Andrews), and other approaches (e.g., Baltic Sea SAMBAH Project - L. Kyhn *et al.*, *pers. comm.*).

Static acoustic monitoring (SAM) systems can be fixed cable hydrophones, radio-linked hydrophone systems, or fixed autonomous devices (Mellinger *et al.*, 2007; Moretti *et al.*, 2009; Norris *et al.*, 2010). In Europe, PODs and Pop-Ups are the main SAM units that have been deployed to monitor cetaceans. In deeper waters (up to 4,000 m), Pop-Ups

have generally been used (see, for example, Swift *et al.*, 2002; Clark *et al.*, 2007), mainly to detect baleen whales and sperm whales. They can be deployed using a relatively small anchor, and retrieved by activation of a burnwire release mechanism. The hydrophone records sounds between 10 Hz and 2 kHz, and is surrounded by a perforated PVC tube that shields it from water motion. Sampling rate can vary from 2–64 kHz. However, hard drive space becomes a limiting factor in Pop-Ups at sample rates greater than 20 kHz, and to power this requires a lot of batteries, these making up a significant volume in the housing. Deployment is up to 90 days with a 120 GB hard drive, although in the next generation Pop-Ups, flash storage media will replace the energy-intensive, motorized disk drives currently used. Pop-Ups can be deployed singly or in an array, and are not restricted to deep water; they can also be deployed on or near the bottom in very shallow water.

For monitoring small cetaceans, particularly harbour porpoise and bottlenose dolphin, PODs have been widely used (see, for example, Leeney & Tregenza, 2006; Carstensen *et al.*, 2006; Verfuß *et al.*, 2007, 2008; Bailey *et al.*, 2010; Simon *et al.*, 2010), including for impact studies on harbour porpoises in conjunction with wind farm construction and operation (Koschinski *et al.*, 2003; Carstensen *et al.*, 2006; Tougaard & Henriksen, 2009; Tougaard *et al.*, 2009; Brandt *et al.*, 2010), effects of pingers (Leeney *et al.*, 2007), and habitat use (Senior, 2006; Philpott *et al.*, 2007; Verfuß *et al.*, 2008; Simon *et al.*, 2010).

The T-POD (Timed Porpoise Detector), manufactured by Chelonia Ltd (Long Rock, Plymouth, UK; [www.chelonia.co.uk](http://www.chelonia.co.uk)), is an acoustic self-contained data logger comprising a hydrophone, a filter and digital memory, which logs the time of detections and durations of sequences of echolocation clicks. Memory capacity is 128 MB and battery life is c. 6-10 weeks. To select echolocation clicks of cetaceans, the T-POD compares the sound energy picked up by a pair of bandpass filters with adjustable bandwidth, one of which (the target filter) is set to the click frequency of the species of interest. The energy picked up by the target filter has to be a certain amount higher than the energy picked up by the reference filter to cause a registration of the presented sound. When monitoring bottlenose dolphins and harbour porpoise in Cardigan Bay, we have used a target filter of 50 kHz and reference filter of 70 kHz to detect dolphin click trains, and a target filter 130 kHz and reference filter of 92 kHz, to detect porpoise click trains (Simon *et al.*, 2010). The target filter for harbour porpoises is set at the centre frequency of harbour porpoise clicks (Villadsgaard *et al.*, 2006). The detection of dolphins by T-PODs is generally less well described and understood than detection of porpoises, but bottlenose dolphin clicks appear to have peak energy at around 50 kHz (Simon *et al.*, 2010). In our study, we alternated channels between detection of the two species, with three channels dedicated to log dolphin click trains and three to log porpoise click trains.

Since T-POD units can vary individually in their sensitivities, it is necessary to conduct calibration tests in a tank and then validate the settings by placing units together in a cage in the sea for a period of time (Teilmann *et al.*, 2002; Verfuß *et al.*, 2007; Kyhn *et al.*, 2008; Simon *et al.*, 2010).

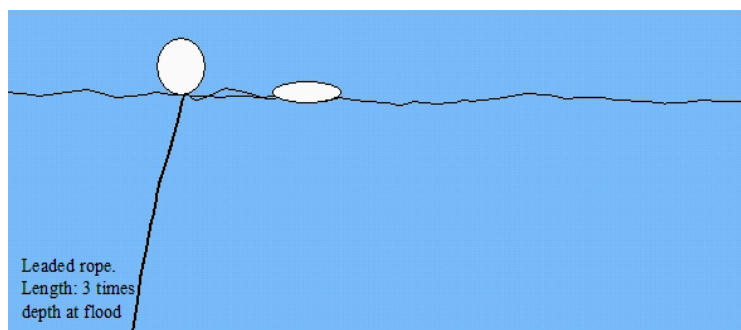
The T-POD has recently been superseded by the C-POD – a digital version that uses

waveform characterisation in order to select cetacean clicks, logging the time, centre frequency, sound pressure level, duration and bandwidth of each click. The false positive rate is low, and the wide frequency range, 20-160 kHz enables them to continuously log all small and medium-sized odontocetes. Because of their low power requirements, they can run for 4 months on 8 alkaline D-cells, and shortly battery power will be extended to six months. A removable Secure Digital (SD) memory card allows large volumes of data (16-32 GB) to be collected, enabling data downloading to be undertaken at sea without the need for a computer. Individual units also show less variability. Data are analysed using the C-POD PC software, and this has been refined recently to make it run more efficiently. The train filter developed as part of the software should also improve species identification as more data become available. However, at present, whereas porpoises and bottlenose dolphins can be confidently distinguished from one another, discrimination between different species of delphinids has not yet been achieved.

The mooring system used in deployment will depend upon the local conditions – water depth, current strength, and vessel activity. Light anchoring systems can be used in protected areas, where little or no fishing takes place and only low tidal influences occur. Heavy anchoring gear may need to be used in areas of high fishing effort and heavy traffic or strong currents. In some cases these might require several anchors (weighing up to four tons), a cardinal buoy and one or more smaller buoys. Whatever mode of deployment is used, it is important that local users of the area are aware of the precise locations of the deployments, and there are no conflicts of interest. C-PODs are buoyant and, consequently, self-orientating, which helps their recovery so long as they do not become entangled in the moorings.

The units of measurement commonly used for PODs are the percent of porpoise or dolphin positive minutes, hours or days (Verfuß *et al.*, 2007, 2008; Diederichs *et al.*, 2008; Simon *et al.*, 2010; Brandt *et al.*, 2010), defined as the fraction of the observed time intervals with porpoise/dolphin registrations. The appropriate time interval(s) to use will depend on the densities of the target species and the nature of the study.

As noted earlier, it is difficult to relate click detections to actual numbers of animals, but a number of studies have successfully correlated detection rates with independent estimates of abundance/density (see, for example, Siebert & Rye, 2008; Kyhn *et al.*, 2008a, submitted; Rayment *et al.*, 2009). The detection functions obtained have been found to be comparable to those obtained from conventional visual line transect sampling (see, for example, Tougaard *et al.*, 2006; Tougaard, 2008). T-POD detections for the harbour porpoise decline sharply beyond 250m range, providing an effective detection radius of 107m (Tougaard, 2008), whereas for bottlenose dolphin, maximum ranges were much greater (1.25 km – Philpott *et al.*, 2007). A recent study on bottlenose dolphins yielded a very similar maximum detection range (1.27 km) for C-PODs, with >90% detections within 700m (Meier, 2010).



**Figure 1.** Example of a POD mooring set-up

**Costings** At any monitoring location, it is advisable to deploy a minimum of two C-PODs at a suitable spacing (0.5-1.5 km apart so that they can provide detection data that are more or less independent of one another), depending upon the specific objective). Within an SAC, typically between four and ten C-PODs would be deployed, depending upon the size of the area being sampled and the range of habitats within the site. Unit costs vary depending upon numbers purchased. For bulk orders, a unit currently costs £1,800 (otherwise £2,300) (N. Tregenza, *pers. comm.*). Since losses will inevitably occur from storms, entanglement, etc, this should be built into the estimates of the overall numbers required. This will be greater in areas with strong tides or high vessel activity, but typically has ranged from 10-25% (N. Tregenza, *pers. comm.*).

Mooring costs (including one light anchor with chain, two weights, leaded and unleaded ropes, and two buoys for buoyancy and to mark the site, per C-POD) will likely vary but are in the region of £150 per unit deployment (see Table 5). Eight alkaline D-cell batteries are needed for each C-POD and they last about four months. Thus in one year, each unit requires 24 batteries. A box of fifty Duracell Procell D/LR20 batteries currently costs c. £45 ([http://www.battery-force.co.uk/show\\_D\\_Batteries.html](http://www.battery-force.co.uk/show_D_Batteries.html)), so the annual cost per unit is c. £22.50. Some replacement of mooring ropes, carabiners, cable ties, jubilee clips, chains and buoys will be necessary over a 12-month period. This is estimated at c. £50 per unit. Allowing for a 10% margin of error, annual maintenance is estimated at £80 per unit.

**Table 5.** Cost of purchase and maintenance of equipment for deployment of ten C-PODs

|                | <b>Item</b>                                | <b>Cost</b> |
|----------------|--|-------------|
| <i>Capital</i> | 10 C-PODs @ £1800 each                     | £ 18000     |
|                | 10 5kg claw anchors @ £30 each             | £ 300       |
|                | 10 5m 6mm anchor chains @ £4/m)            | £ 200       |
|                | 10 buoys @ £7 each                         | £ 70        |
|                | Leaded rope (16mm 220m)                    | £ 80        |
|                | 20 rail-chair weights @ £3 each            | £ 60        |
|                | 16m of water pipe (for protection of rope) | £ 40        |

|                    |  |                |
|--------------------|--|----------------|
| <i>Maintenance</i> | 30 carabiners (10 changed 3x a year)             | £ 150          |
|                    | 200 cable ties                                   | £ 20           |
|                    | 60 D-shackles (3 per mooring replaced 2x a year) | £ 90           |
|                    | 10 swivels                                       | £ 25           |
|                    | 10 large jubilee clips @ £1.50 each              | £ 15           |
|                    | 20 small jubilee clips @ £1.25 each              | £ 25           |
|                    | 250 Duracell Procell D batteries (5 boxes of 50) | £ 225          |
|                    | Rope for mooring/towing (3 strand rope 16mm)     | £ 100          |
|                    | Miscellaneous - contingency                      | £ 100          |
| <b>TOTAL</b>       |  | <b>£ 19500</b> |

Costs (obtained 31 Jan 2011) for all items except C-PODs from [www.amazon.co.uk](http://www.amazon.co.uk)

Other costings include boat charter and personnel costs. In Cardigan Bay, deployment with servicing every four months of five sets of two PODs along the length of the SAC would involve six trips of six hours each. At a boat charter rate of £60/hour, this amounts to an annual cost of c. £2,200 (i.e. £220/unit). Servicing of only one to two C-PODs at a time clearly will increase the unit cost. On the other hand, depending upon the security of the moorings and risk of unit failure, servicing can be reduced to once every six months (and possibly soon only once a year), which would in turn reduce overall maintenance costs. One person working full-time potentially could manage 100 C-PODs at a time, assuming they were deployed in the same general region.

Overall costs (for purchase, deployment, maintenance including boat charter, and analysis) of 500 C-PODs, split more or less equally between five different regions (West Scotland; Hebrides; Northern Isles & NE Scotland; Eastern & Southern England; Wales, NW England & Northern Ireland) around the UK, are estimated to be:

|  |                   |
|--|-------------------|
| Capital equipment: 500 units @ £1,800/unit | £900,000          |
| Additional 75 units allowing 15% loss rate | £135,000          |
| Moorings, etc: 500 deployments @ £150 each | £ 75,000          |
| Annual Maintenance: 500 units @ £300/unit  | £150,000          |
| Five staff @ £25,000/annum                 | £125,000          |
| <b>Total</b>                               | <b>£1,385,000</b> |

At least one person (depending upon how many units are deployed) working full-time would be required to analyse the data collected. There is a new version of the C-POD software now on the website [www.chelonia.co.uk/cpod\\_downloads.htm](http://www.chelonia.co.uk/cpod_downloads.htm). It includes a new and radical development of the cetacean detection algorithm that gives substantially higher sensitivity and a much lower false positive rate than version 1. It also greatly simplifies the processing of datasets to derive acoustic detection rates.

As an alternative to deployment of c. 500 C-PODs around the British Isles, a sample of habitat types (e.g. headlands, sounds between islands, bays/estuaries, sandy vs muddy vs rocky substrates), monitored around the UK could be used to detect distributional trends. At the most economical extreme, ten sites (two in each of five regions) could be monitored with four C-PODs in each, placed in different habitat types, so as to provide fine-scale temporal resolution of trends at particular representative locations. The number

and arrangement of units will obviously depend upon the target questions being addressed.

### 3.4 Photo-ID

**Methodology** Since the 1980s, the technique of photo-identification (known as Photo-ID) and mark-recapture has been applied widely to a variety of cetacean species (Hammond, 1986, 2002; Hammond *et al.*, 1990; Würsig & Jefferson, 1990). Not only can Photo-ID provide population size estimates, and thus over a period of time, population trends, it can also reveal useful information on movements, home range size and use, habitat use, life history parameters, and social structure. The method when applied to cetaceans usually relies upon the reliable identification of individuals from natural markings such as nicks in the dorsal fin or pigmentation patterns on the body or tail of an animal. However, a number of species are not particularly amenable to the technique either because they are difficult to see clearly and photograph, or they are poorly marked, or identifiable markings are not long lasting.

For the application of mark-recapture to abundance estimation (and measures of life history parameters), it is important that a reasonable proportion of the population is well marked. The bottlenose dolphin is one of the few species that occurs regularly in shelf waters of the UK where this is the case. In and around Cardigan Bay (Wales), for example, around 60% of individuals within the bottlenose dolphin population have distinct markings (Pesante & Evans, 2008).

**Table 6.** Photo-ID potential for cetacean species in UK waters

| Species                     | % well-marked | Mark durability | Overall population size |           |
|-----------------------------|---------------|-----------------|-------------------------|-----------|
|                             |               |                 | shelf                   | off shelf |
| Bottlenose dolphin          | High          | High            | Small                   | Large     |
| Humpback whale              | High          | High            | V. Small                | V. Small  |
| Sperm whale                 | High          | High            | -                       | Medium    |
| Killer whale                | Medium        | High            | Small                   | Medium    |
| Fin whale                   | Low           | High            | V. Small                | Medium    |
| Minke whale                 | Low           | High            | Large                   | Medium    |
| Long-finned pilot whale     | Low           | High            | Small                   | Large     |
| Risso's dolphin             | High          | Medium-Low      | Small                   | Small     |
| Short-beaked common dolphin | Low           | High            | Large                   | Large     |
| White-beaked dolphin        | Low           | High            | Large                   | Small     |

In northern Europe, Photo-ID has also been used on humpback whale, sperm whale, killer whale, fin whale, minke whale, Risso's dolphin, short-beaked common dolphin, white-beaked dolphin and long-finned pilot whale. Table 6 summarises the potential (and limitations) for using Photo-ID on the above species for abundance estimation, bearing in mind that it is important to establish what proportion of the population is resident in the study area. On the basis that regular Photo-ID surveys will only be feasible in shelf seas around UK, the potential is greatest for near-shore populations of bottlenose dolphin, and to a lesser extent, killer whale, humpback whale, fin whale and Risso's dolphin. On the



other hand, humpbacks and fin whales do not occur in particular shelf areas of the UK with sufficient regularity for a photo-ID programme to be established. Furthermore, although humpbacks are readily identifiable by the markings on the undersides of their tail flukes, in British shelf seas they rarely fluke-up and most ID photos have been of the back and dorsal fin of animals. However, since Photo-ID can provide additional useful information (e.g. individual ranges & movements), it is recommended that the method be used opportunistically on all species with identifiable marks.

The technique of mark-recapture as applied to Photo-ID relies upon photographing a sample of marked individuals in a population ( $n_1$ ). On a subsequent occasion, a second sample of marked individuals is photographed ( $n_2$ ) of which a number are already marked ( $m_2$ ). The proportion of individuals that are marked in the second sample can be equated with the proportion in the population at large ( $N$ ), the relationship being expressed as follows:

$$\frac{m_2}{n_2} = \frac{n_1}{N} \quad \text{(Equation 1)}$$

It is also necessary to obtain an estimate of the proportion of animals in each sample that is marked. Because the numbers of marked animals captured and marked each time is known, this allows population size to be estimated, re-arranging the equation thus:

$$\hat{N} = \frac{n_1 n_2}{m_2} \quad \text{(Equation 2)}$$

This simple two-sample estimator is known as the Petersen estimator or Lincoln index. The same approach applies when sampling on multiple occasions.

A number of assumptions are made about the data used in mark-recapture models. Those most relevant to cetaceans are that: 1) a marked animal will always be recognised if it is seen again; 2) samples of individuals must be representative of the population being estimated (in other words there should be full mixing between sampling occasions); and 3) within any one sampling occasion, every animal in the population should have the same probability of being captured.

The most common violations of these assumptions in cetacean photo-ID studies are that: 1) there is insufficient information in the mark to guarantee no duplicates, marks change or fade, or are erroneously recorded; 2) individuals have different capture probabilities (termed heterogeneity of capture probabilities) because they do not mix randomly due to differences in preference for particular areas, some may be more difficult to photograph, or are more distinctively marked (and therefore more easily recognised) than others. As a result, some individuals will be seen more often than expected and others less often; and 3) for closed population models, the population is actually not closed, with births and deaths occurring, and either permanent or non-random temporary immigration or emigration.

The program CAPTURE has models that can take account of heterogeneity of capture probabilities (Rexstadt & Burnham, 1991), whilst if animals are believed to emigrate

temporarily from the study area, there are also methods for taking this into account in the analysis (Whitehead, 1990; Kendall *et al.*, 1997).

If sampling occurs on two occasions close together in time, between which one can assume that births, deaths, immigration and emigration will be negligible, a closed population model can be applied. If the study has multiple sampling occasions, a time series of estimates can be obtained and there is more flexibility in analysis, and one can use open or closed population models (Hammond 1986). Pollock's robust design model (Kendall *et al.*, 1995) for an open population assumes that no mortality, immigration or emigration takes place *within* sampling sessions. The probability of an animal being captured at least once in any year can be estimated solely from the data collected during that year, using closed population models, whereas the longer intervals between years allow estimation of survival, temporary emigration from the area sampled, and immigration of marked animals back to that area.

To minimise some of the problems of violation of model assumptions, where possible efforts should be made to sample photographically as many individuals as possible, obtain good photographs (in good light, left & right sides for fin notches, and at right angles), grade images according to quality and use only the best. This requires choosing sampling sessions carefully and using good photographers with the appropriate equipment.

In shelf seas around the British Isles there are four regions where bottlenose dolphins occur regularly. These are (in descending order of estimated population size): a) Irish Sea; b) Eastern Scotland; c) South-west England; and d) Hebrides. Bottlenose dolphins in the former two regions probably account for c. 80% of the coastal UK population, although it should be noted that, further south, the Channel Isles have a significant population of this species, which appears to be linked to those in adjacent Normandy in northern France (Evans *et al.*, 2003; Evans & Teilmann, 2008).

In the Moray Firth, 15-20 surveys conducted annually resulted in population estimates with a CV of 0.15 (Thompson *et al.*, 2004). Increasing the number of surveys did not make an appreciable difference to the precision of the estimate. In Cardigan Bay, where lower encounter rates occurred per survey day (the population being spread over a wider area), 30 surveys were required for a comparable CV (Pesante *et al.*, 2008a). The number of surveys required will vary according to the dispersion of the animals and resultant encounter rates. In recent years, bottlenose dolphins are regularly observed all along the coast of Eastern Scotland from the Dornoch Firth south to the Scottish Border, on occasions extending north to Wick and south to North Yorkshire (Evans *et al.*, 2003; Thompson *et al.*, 2009). For adequately monitoring the population inhabiting eastern Scotland, it is recommended that Photo-ID surveys be undertaken in all four of the following main areas: 1) Inner Moray Firth; 2) North Grampian region; 3) East Grampian region; and 4) St Andrews Bay.

In the Irish Sea, although during summer (May-October) the bottlenose dolphin population occurs particularly within Cardigan Bay, for the rest of the year the species

ranges over wider areas, often in large groups, from southern Cardigan Bay north to Cumbria and the Isle of Man (Pesante *et al.*, 2008b; Baines & Evans, 2009). Survey effort in the northern Irish Sea remains low, and it may be the case that the population occurs regularly over a wider area still, with a portion of the Irish Sea population remaining outside Cardigan Bay through the summer. However, regular line-transect surveys over the entire region should identify that. For the time being, it is recommended that Photo-ID surveys be undertaken in three main areas: 1) Southern Cardigan Bay; 2) Northern Cardigan Bay; and 3) North-east Wales.

**Costings** Essential equipment for photo-ID includes a suitable camera and lens, a computer and external hard drive for storage of images, matching and mark-recapture analyses. A digital semi-pro SLR camera is recommended (e.g. Canon or Nikon) along with two lenses – a wide angle zoom and telephoto zoom (e.g. 18-80mm or 18-200mm, 75-300mm). Additionally, a lens hood, UV filter, spare batteries, and some memory (compact flash) cards are essential. Each Photo-ID survey region should ideally have two sets of camera equipment available. Estimated costs for equipment are given in Table 7. Most of this involves a capital outlay, which may need replacing every five years.

**Table 7.** Capital equipment and annual running costs for Photo-ID surveys per area

|                    | <b>Item</b>  | <b>Cost</b>    |
|--------------------|--|----------------|
| <i>Capital</i>     | 2 digital SLR camera bodies (e.g. Canon EOS 60D)                 | £ 1576         |
|                    | 2 15-85mm EF-S f3.5-5.6 IS USM wide angle zoom lenses            | £ 1218         |
|                    | 2 70-300mm EF f4-5.6 L IS USM telephoto zoom lenses              | £ 2548         |
|                    | 6 SanDisk Ultra CompactFlash 4GB memory cards (3 per camera)     | £ 56           |
|                    | 4 spare batteries (2 per camera)                                 | £ 72           |
|                    | 2 EW-78E lens hoods (for each 15-85mm lens)                      | £ 20           |
|                    | 2 ET-65B lens hoods for each 70-300mm lens                       | £ 22           |
|                    | 2 Hoya UV filters for each 77mm diameter 15-85mm lens            | £ 72           |
|                    | 2 Hoya UV filters for each 58mm diameter 70-300mm lens           | £ 46           |
|                    | Dell Precision T1500 Tower 1TB workstation desktop computer      | £ 900          |
|                    | Dell Professional P2411H 24" Widescreen monitor with LED         | £ 238          |
|                    | Western Digital MyBook Studio Edition II 2TB external hard drive | £ 167          |
| <i>Consumables</i> | 5 boxes of 100 Verbatim 43551 DVD+R for backing up images        | £ 80           |
| <b>TOTAL</b>       |  | <b>£ 7,005</b> |

Costs (obtained 31 Jan 2011) for cameras & lenses from [www.warehouseexpress.com](http://www.warehouseexpress.com);  
memory cards, batteries, lens hoods, UV filters, hard drive & DVDs from [www.amazon.co.uk](http://www.amazon.co.uk);  
desktop computer & monitor from [www.dell.co.uk](http://www.dell.co.uk)

Other costs include a fully equipped vessel as a platform for Photo-ID surveys, and associated personnel costs. Vessels used for this purpose vary from 5-7m rigid hull inflatables to larger (7-15m) inboard motorboats. Each has advantages and disadvantages. Rigid hull inflatables can be moved overland and launched quickly from different locations; they usually require lower maintenance, can operate at speed; and are generally more manoeuvrable. Their disadvantage is a relatively high capital outlay cost (c. £20-30k), MCA certification may require modifications or extra equipment), and running costs can be high (dependent upon engine horsepower and whether it is 2- or 4-stroke).

Inboard motorboats (such as those used frequently for inshore fishing) tend to be cheaper to purchase than RIBs, length for length, they usually offer a higher platform, and are usually cheaper to run. However, they generally offer less flexibility. The other option, which we have tended to adopt, is to charter a vessel (that already has MCA certification and the necessary safety equipment), along with a suitably qualified skipper. This avoids maintenance costs but can reduce flexibility. Photo-ID survey field costs have been calculated on the basis of boat charter (including skipper) and three field staff (two observers at least one of which is an experienced photographer, and a recorder), and these are detailed in Table 8.

Downloading of images, cropping, archiving and matching is a time-consuming process, requiring 4-6 person-months of work. This assumes the person(s) involved has already had training. For data analysis, a minimum of 2 person-months should be added.

**Table 8.** Overall field costs for Photo-ID surveys per area

|                     | <b>Description</b>                   | <b>Cost</b>     |
|---------------------|--------------------------------------|-----------------|
| <i>Boat charter</i> | 30 x 8-hr surveys @ £75/hr           | £18,000         |
| <i>Personnel</i>    | 3 x 250 hrs staff time @ £25/hr      | £18,750         |
| <i>Equipment</i>    | Garmin eTrex H handheld GPS          | £ 62            |
|                     | 16 rechargeable batteries & charger  | £ 38            |
|                     | Miscellaneous – recording forms, etc | £ 250           |
| <b>TOTAL</b>        |                                      | <b>£ 37,100</b> |

Costs (obtained 31 Jan 2011) of GPS & batteries from [www.amazon.co.uk](http://www.amazon.co.uk)

In order to derive an overall cost for monitoring bottlenose dolphins in the UK, the following assumptions are made:

- Eastern Scotland is split into four areas each with separate equipment and field costs, with 18 person-months spent on image processing, and 6 person-months for data analysis
- The Irish Sea is split into three areas each with separate equipment and field costs, with 18 person-months spent on image processing, and 6 person-months for data analysis
- Southwest England and the Hebrides are treated as single areas each with its own set of equipment and field costs, and 4 person-months spent on image processing and 2 person-months for data analysis
- For each area, thirty 8-hour survey equivalents are undertaken per year

On this basis, overall costs for bottlenose dolphin monitoring in the nine UK areas can be split into capital and running costs:

|                                |            |            |
|--------------------------------|------------|------------|
| Capital photographic equipment | £7,000 x 9 | = £ 63,000 |
| Capital survey equipment       | £100 x 9   | = £ 900    |
| Consumables                    | £330 x 9   | = £ 3,000  |

|  |             |                 |
|--|-------------|-----------------|
| Boat charter   | £18,000 x 9 | = £162,000      |
| Field personnel  | £18,750 x 9 | = £168,750      |
| Image/data processing & analysis<br>– 60 person-months @ £2k/month |             | = £120,000      |
| <b>Total</b>   |             | <b>£517,650</b> |

The above calculations are for monitoring bottlenose dolphins throughout coastal waters of the UK (excluding the Channel Islands). However, they can be adapted to apply to other species, the most obvious candidates being killer whale and Risso’s dolphin. Killer whales occur regularly in the Hebrides, and around Orkney and Shetland; Risso’s dolphins occur regularly in the St George’s Channel, North Wales & the Isle of Man, Hebrides, Orkney and Shetland (and, in recent years, Caithness).

Although bottlenose dolphin abundance estimates should derive from the proposed line transect surveys, the added value of photo-identification for this species is in providing information on individual movements, range sizes, habitat use, and various life history parameters such as mortality and birth rates.

#### 4. SUMMARY

We have provided a number of alternative scenarios each with different resource implications. As a general guide to overall costs for a comprehensive cetacean surveillance scheme in UK waters, Table 9 summarises the capital and running costs for each of the recommended methods. It should be emphasised that the different methods are not alternatives to one another; for the most part, they are serving different functions, as outlined earlier for each.

The summary tables below assume continuous year-round deployment of 500 C-PODs (targeting particularly harbour porpoise and bottlenose dolphin); aerial and vessel surveys at a frequency of six per year, covering nearshore (using one-pass surveys in the Southeast & two-pass surveys in the Northwest), inshore, and offshore strata; and photo-ID focusing upon one species (bottlenose dolphin) in nine coastal areas of the UK.

**Table 9.** Overall (rounded) costs for UK cetacean surveillance strategy

a) Capital

| <b>Method</b>              | <b>Description</b>                        | <b>Cost</b>        |
|----------------------------|---|--------------------|
| <i>Vessel surveys - SE</i> | 20 sets of equipment, 40 add-on platforms | £ 140,000          |
| <i>Vessel surveys - NW</i> | 20 sets of equipment, 40 add-on platforms | £ 140,000          |
| <i>Aerial surveys</i>      | 5 sets of equipment                       | £ 6,050            |
| <i>Static Acoustics</i>    | 500 C-PODs + moorings                     | £ 1,110,000        |
| <i>Photo-ID</i>            | 9 sets of equipment                       | £ 64,000           |
| <b>TOTAL</b>               |   | <b>£ 1,460,050</b> |

b) Annual running costs

| <b>Method</b>              | <b>Description</b>                          | <b>Cost</b>        |
|----------------------------|---|--------------------|
| <i>Vessel surveys -SE</i>  | Boat charter + survey teams (6 surveys/yr)  | £ 732,400          |
| <i>Vessel surveys - NW</i> | Boat charter + survey teams (6 surveys/yr)  | £ 334,800          |
| <i>Aerial surveys</i>      | Plane charter + survey teams (6 surveys/yr) | £ 1,089,420        |
| <i>Aerial surveys</i>      | 15% contingency                             | £ 163,413          |
| <i>Static Acoustics</i>    | Deployments + maintenance                   | £ 275,000          |
| <i>Photo-ID</i>            | Boat charter + 9 survey teams               | £ 333,750          |
| <b>TOTAL</b>               |   | <b>£ 2,928,783</b> |

c) Annual analytical costs

| <b>Method</b>           | <b>Description</b>              | <b>Cost</b>      |
|-------------------------|---------------------------------|------------------|
| <i>Vessel surveys</i>   | 0.5 person @ £40,000/yr         | £ 20,000         |
| <i>Aerial surveys</i>   | 0.5 person @ £40,000/yr         | £ 20,000         |
| <i>Static Acoustics</i> | 1.0 persons @ £30,000/yr        | £ 30,000         |
| <i>Photo-ID</i>         | 60 person-months @ £2,000/month | £ 120,000        |
|                         | 10% employers contribution      | £ 19,000         |
| <b>TOTAL</b>            |                                 | <b>£ 209,000</b> |

Finally, to the above budget we would recommend that a total of 20 days (incorporating feedback from a peer review process) be assigned to producing a detailed survey design once the surveillance strategy has been established. At a rate of £450/day, this comes to £9,000. And to ensure the surveillance scheme is achieving its objectives and modifications are made where appropriate, a steering committee should be established with an annual peer review meeting. Around £8,000/year should be added as running costs to cover travel & subsistence with a small honorarium for each member (calculated as £500 honorarium + £500 T&S per person for a committee of eight).

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## **APPENDIX 1. Surveillance Approaches for Different Cetacean Species**

The methods recommended should vary according to species or groups of species, given differences in their relative abundance, dispersion and ecology.

### **1. Harbour porpoise**

Line-transect surveys: six per year (once every two months). Depending upon resources, these could be aerial and/or boat based surveys. For aerial surveys adopt parallel lines, otherwise use saw tooth design where possible if the transit times between parallel lines are considered too long (covering entire UK continental shelf in a systematic manner). Apply distance sampling methods to estimate absolute densities. For aerial surveys, ideally use a Partenavia high winged twin engined plane with bubble window, but, failing that, a Cessna or equivalent high winged plane). For vessel surveys, use a vessel capable of speeds to 20 knots (for ease of getting to and from transect points) and capable of a cruising speed of 10 knots. The vessel can be relatively small (10-20 metres), but ideally should have a flying bridge or other raised platform giving an observation height of c. 5 metres). Costs should be estimated for the coverage of the continental shelf waters and also include the number of person-days required, taking the use of trained volunteers into account where appropriate.

For particular coastal sites where information on long-term usage would be useful for management purposes, deploy C-PODs to monitor 24-hour, whole year activity where temporal resolution is an important consideration. It would be prudent to ensure there are no large gaps in coverage around the coasts of UK, and preferably with at least two units per site. The quantity deployed will depend on resources available but should probably be at least c. 200 and ideally up to c. 500. Approximately 50 are currently deployed in UK waters, but for specific purposes. Staff time required to maintain the PODs, download & process the data needs to be included.

### **2. Bottlenose dolphin**

Use of photo-ID for absolute abundance, densities, ranges & movements in four main areas where coastal populations of the species occur: a) Eastern Scotland; b) Hebrides; c) Irish Sea; and d) northern English Channel. This should be undertaken with sufficient power and effort to obtain statistically meaningful results for each of the four regions taking account of population size and encounter rate.

For other parts of the UK continental shelf, changes in abundance & distribution of this species will be obtained from line transect surveys. Additionally, for particular coastal sites, C-PODs deployed for harbour porpoise will also monitor bottlenose dolphin activity on a 24-hour year round basis.

### **3. Short-beaked common dolphin, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, killer whale and long-finned pilot whale**

Use surveys over the UK continental shelf as outlined in section 1. All species listed here, except for the white-beaked dolphin, have significant offshore populations. For most parts of UK waters, surveys can be treated exactly as in section 1. Only in the area west of the Hebrides, where UK waters go out beyond Rockall, may there be difficulties in using aerial surveys. This needs further investigation. If this area is to be covered systematically and on a regular basis, and a plane cannot be used, then a larger vessel will be required, in which case it may be possible to integrate such surveys with oceanographic/fisheries surveys in that region.

### **Beaked whales (northern bottlenose whale, Cuvier's beaked whale, *Mesoplodon* species), sperm whale, fin whale, sei whale, and humpback whale**

These species have predominantly pelagic distributions beyond the shelf edge. For shelf seas, their occurrence will be detected by adopting the approach described in section 1. Further offshore, the approach in section 3 will need to be adopted.

### **Other vagrant species**

Even with significant survey effort, it is unlikely that sufficient sightings will be obtained to enable abundance estimates to be made. Data on these species should be collected opportunistically during the survey work outlined above.

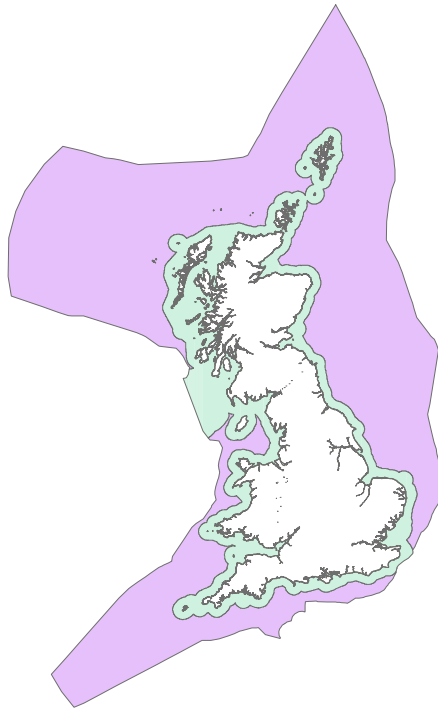
## APPENDIX 2. Preliminary design for survey of cetaceans in UK waters

This appendix presents a preliminary survey design, created for the purposes of enabling costing of the survey options, and garnering feedback from readers. The sub-stratification used here and transect lines should not be treated as final; effort needs to be devoted to refining the target coefficient of variation (CV), the GIS and expected encounter rate data, and tuning options such as the sub-stratum boundaries, survey types and effort weightings before a final design can be created.

### Stratification

Initially, we have divided the surveys into 3 strata:

- Nearshore – low water mark to 500m from shore. Area 8,712.36km<sup>2</sup>.
- Inshore – 500m to 12nm. Area 156,199km<sup>2</sup>.
- Offshore – 12nm to EEZ. Area 605,458km<sup>2</sup>.



Note that, in the above, we did not get a proper account of Northern Ireland waters, so the area around there is likely to be incorrect. Also, the seas around some isolated islands were put into the Offshore category. Lastly, the Nearshore stratum includes all islands, even if small, estuaries (and quite far up some rivers) and possibly even some freshwater lochs. We were unable to avoid these without considerable effort modifying the smoothed coastline. However, we have tried to make some allowances for this (see later). We used British National Grid as the projected coordinate system.

### Estimating survey effort per stratum

Encounter rates will vary with cetacean species, and in time and space, so that estimating the amount of survey effort required to achieve a particular level of precision inevitably is a compromise between the requirements of a surveillance scheme and what is realistic. Since the inshore transects are proposed to be done by small vessel, we first compared encounter rates from small vessel line transects surveys with those from SCANS II using large vessels. For the time being, the only direct comparison we could make was for block P. Both types of vessel survey traversed inshore and offshore areas within this block, although SCANS included in the block surveys to the south. There were also differences in the exact timing: SCANS was July 2005 whereas the small vessel surveys were through April–October 2004-06. The results indicate higher encounter rates for the small vessel. This might be a function of cetacean densities being higher in and around the Celtic Deep (which is quite possible), or intrinsic differences in the platforms (perhaps porpoises, for example, show a greater negative response before detection, to a large vessel), or a combination of the two.

**Table 1.** Encounter Rates from SCANS II from surveys using large vessels  
(with small vessel encounter rates in one block for comparison)  
(courtesy of P.S. Hammond; Sea Watch Foundation, *unpubl. data*)

a) No. of encounters (from primary observers) and effort (transect lengths) by survey block

| <i>Block</i>       | <b>P</b> | <b>P small</b> | <b>Q</b> | <b>S</b> | <b>T</b> | <b>U</b> | <b>V</b> | <b>W</b> |
|--------------------|----------|----------------|----------|----------|----------|----------|----------|----------|
| <i>Effort (km)</i> | 3548     | 3095           | 3113     | 1765     | 2685     | 2246     | 3022     | 3558     |
| <b>HP</b>          | 53       | 131            | 7        | 96       | 51       | 109      | 45       | 4        |
| <b>BND</b>         | 12       | 0              | 10       | 0        | 1        | 0        | 1        | 13       |
| <b>SBCD</b>        | 36       | 345            | 17       | 0        | 0        | 0        | 0        | 66       |
| <b>WBD</b>         | 0        | 0              | 45       | 0        | 24       | 2        | 50       | 0        |
| <b>MW</b>          | 7        | 33             | 10       | 0        | 9        | 13       | 21       | 0        |

b) Encounter rates (no. of encounters/km) by survey block

| <i>Block</i>       | <b>P</b> | <b>P<sub>small</sub></b> | <b>Q</b> | <b>S</b> | <b>T</b> | <b>U</b> | <b>V</b> | <b>W</b> |
|--------------------|----------|--------------------------|----------|----------|----------|----------|----------|----------|
| <i>Effort (km)</i> | 3548     | 3095                     | 3113     | 1765     | 2685     | 2246     | 3022     | 3558     |
| <b>HP</b>          | 0.015    | 0.043                    | 0.002    | 0.054    | 0.019    | 0.049    | 0.015    | 0.001    |
| <b>BND</b>         | 0.003    | 0                        | 0.003    | 0        | 0.0004   | 0        | 0.0003   | 0.004    |
| <b>SBCD</b>        | 0.010    | 0.111                    | 0.005    | 0        | 0        | 0        | 0        | 0.004    |
| <b>WBD</b>         | 0        | 0                        | 0.014    | 0        | 0.009    | 0.0009   | 0.017    | 0        |
| <b>MW</b>          | 0.002    | 0.011                    | 0.003    | 0        | 0.003    | 0.006    | 0.007    | 0        |

V = northern North Sea from Berwick-upon-Tweed to Wick eastwards (excl. Moray Firth) (mainly offshore)

W = coastal Biscay from France – Portugal (inshore, but in low HP density area)

Q = western Ireland north to west of Outer Hebrides and on to west of Shetland (offshore)

S = eastern Skagerrak + Kattegat (inshore, in high HP density area)

U = central North Sea from Berwick south to Cromer eastwards (mainly offshore, in high HP density area)

T = Norwegian Sea east of Northern Isles (offshore, in low HP density area)

P = South-West Approaches from Pembrokeshire south to SW England and S Ireland (mainly offshore)

P<sub>small</sub> = Celtic Deep from Pembs across to SE Ireland (using small vessels)

**Species:** HP = Harbour Porpoise; BND = Bottlenose Dolphin; SBCD = Short-beaked Common Dolphin; WBD = White-beaked Dolphin; MW = Minke Whale



**Table 2.** Encounter Rates from SCANS II from surveys using planes  
(courtesy of P.S. Hammond)

a) No. of encounters and effort (transect lengths) by survey block

| <i>Block</i>       | <b>B</b> | <b>H</b> | <b>J</b> | <b>L</b> | <b>M</b> | <b>N</b> | <b>O</b> | <b>R</b> | <b>Y</b> | <b>Z</b> |
|--------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| <i>Effort (km)</i> | 3674     | 649      | 1600     | 1543     | 1075     | 730      | 2264     | 2168     | 577      | 1522     |
| <b>HP</b>          | 122      | 25       | 54       | 103      | 44       | 37       | 73       | 79       | 9        | 0        |
| <b>MW</b>          | 2        | 0        | 2        | 0        | 0        | 0        | 4        | 7        | 0        | 0        |
| <b>WBD</b>         | 0        | 0        | 3        | 0        | 0        | 5        | 1        | 1        | 0        | 0        |
| <b>SBCD</b>        | 3        | 0        | 0        | 0        | 0        | 8        | 5        | 19       | 0        | 4        |
| <b>BND</b>         | 2        | 0        | 2        | 0        | 0        | 1        | 2        | 4        | 0        | 3        |

b) No. of encounters and effort (transect lengths) by survey block

| <i>Block</i>       | <b>B</b> | <b>H</b> | <b>J</b> | <b>L</b> | <b>M</b> | <b>N</b> | <b>O</b> | <b>R</b> | <b>Y</b> | <b>Z</b> |
|--------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| <i>Effort (km)</i> | 3674     | 649      | 1600     | 1543     | 1075     | 730      | 2264     | 2168     | 577      | 1522     |
| <b>HP</b>          | 0.033    | 0.039    | 0.034    | 0.067    | 0.041    | 0.051    | 0.032    | 0.036    | 0.016    | 0        |
| <b>MW</b>          | 0.001    | 0        | 0.001    | 0        | 0        | 0        | 0.002    | 0.003    | 0        | 0        |
| <b>WBD</b>         | 0        | 0        | 0.002    | 0        | 0        | 0.007    | 0.0004   | 0.0005   | 0        | 0        |
| <b>SBCD</b>        | 0.001    | 0        | 0        | 0        | 0        | 0.011    | 0.002    | 0.009    | 0        | 0.003    |
| <b>BND</b>         | 0.001    | 0        | 0.001    | 0        | 0        | 0.001    | 0.001    | 0.002    | 0        | 0.002    |

B = Channel

H = Near-shore Netherlands

J = Shetland & Orkney + Moray Firth

L = Nearshore NW Denmark

M = Nearshore W Norway

N = West Scotland

O = Irish Sea

R = Western & Southern Ireland

Y = Near-shore SW Denmark

Z = NE Biscay

**Species:** HP = Harbour Porpoise; BND = Bottlenose Dolphin; SBCD = Short-beaked Common Dolphin; WBD = White-beaked Dolphin; MW = Minke Whale

For this exercise, we rather arbitrarily use the upper end of the encounter rates for the two strata (0.05/km for the inshore, and 0.01/km for the offshore). We calculate required effort given target CVs of 0.1, 0.15 and 0.20, but produce example tracklines (which were used to calculate costings) assuming a target CV of 0.1, to offset the possibility that our estimates of encounter rates are over-estimates. The spacing of the tracklines and frequency of surveys can then be manipulated if necessary to adjust for different scenarios. We assume (simplistically) that the detection probability is the same in both strata, and is estimated independently in each stratum. Optimal allocation of effort in stratified surveys is discussed in Buckland *et al.* (2001, section 7.2.2). The proportion of effort to devote to each stratum depends on the relative density in the strata, and under

the situation outlined above (same detection probability in the two strata) is given by formula 7.37 of Buckland *et al.* (2001):

$$\frac{L_j}{L} = \pi_j = \frac{A_j D_j}{\sum A_v D_v} \quad (1)$$

where  $L$  is line length,  $A$  is area,  $D$  is density and the subscript denotes the stratum. If we use encounter rate instead of density in the above (which is OK as we assume the detection functions are OK) then we get  $\pi_1$  (i.e. offshore) =  $605458*0.01/(605458*0.01+156199*0.05) = 0.44$  and  $\pi_2$  (i.e. nearshore) =  $156199*0.05/(605458*0.01+156199*0.05) = 0.56$ . Under slightly different circumstances, one obtains formulae that allocate effort proportional to square root of density (formula 7.26), but we do not consider that here.

A more difficult problem is to determine total line length,  $L$ , for a given required CV on density. If there is just one stratum, then a useful approximation is given by formula 7.1 of Buckland *et al.* (2001):

$$L = \frac{b}{CV(D)^2 e} \quad (2)$$

where  $e$  is the average encounter rate,  $CV(D)$  is the target CV on density and  $b$  is constant related to the expected variance. In the absence of a better alternative for  $b$ , we follow the advice of Buckland *et al.* (2001) and use a value of 3. Then, (as a guideline for future calculations) for a range of required CVs and encounter rates, we get:

**Table3.** Required line lengths for a single stratum given encounter rate ( $e$ ) and target CV

|                 | <b>e = 0.05</b> | <b>e = 0.01</b> |
|-----------------|-----------------|-----------------|
| <b>CV= 0.1</b>  | 6000km          | 30000km         |
| <b>CV= 0.15</b> | 2667km          | 13333km         |
| <b>CV= 0.2</b>  | 1500km          | 7500km          |

However, we want to know the required line length when there are two strata, and effort allocation is as outlined above. Assuming the two strata are independent, we can obtain variance on overall density as an area weighted sum of the stratum variances:

$$var(D) = \frac{\sum A_j^2 var(D_j)}{A^2}$$

or, equivalently

$$CV(D) = \sqrt{\frac{\sum A_j^2 CV(D_j)^2 D_j^2}{D^2 A^2}}$$

Making use of eqns (1) and (2), and assuming that  $D=ec$  for some constant  $c$ , we obtain

$$L = \frac{b}{CV(D^2)} \frac{\sum A_j^2 e_j / \pi_j}{(\sum A_j e_j)^2} \quad (3)$$

This gives us the following effort allocations

**Table 4.** Required line lengths for two strata given encounter rates of 0.05 and 0.01 respectively, and effort allocation as in equation 3 (overall) and 1 (division between strata)

|                 | Total effort (km) | Inshore stratum effort (km) | Offshore stratum effort (km) |
|-----------------|-------------------|-----------------------------|------------------------------|
| <b>CV= 0.1</b>  | 16,481            | 9,283                       | 7,197                        |
| <b>CV= 0.15</b> | 7,325             | 4,126                       | 3,199                        |
| <b>CV= 0.2</b>  | 4,120             | 2,320                       | 1,799                        |

It is interesting to speculate on the sample sizes of observations that would go with these allocations, assuming encounter rates of 0.05 and 0.01 animals per km:

**Table 5.** Expected sample sizes in the above scenarios

|                 | Expected n observations | Inshore stratum n | Offshore stratum n |
|-----------------|-------------------------|-------------------|--------------------|
| <b>CV= 0.1</b>  | 536                     | 464               | 72                 |
| <b>CV= 0.15</b> | 238                     | 206               | 32                 |
| <b>CV= 0.2</b>  | 134                     | 116               | 18                 |

(Note that Buckland et al. (2001) recommend 60-80 per stratum for which a detection function is to be estimated). We can also estimate the CV that would be obtained from stratum-level estimates of density given the above levels of effort:

**Table 6.** Stratum-level CVs expected in the above scenarios

|                 | Inshore stratum expected CV | Offshore stratum expected CV |
|-----------------|-----------------------------|------------------------------|
| <b>CV= 0.1</b>  | 0.08                        | 0.20                         |
| <b>CV= 0.15</b> | 0.12                        | 0.31                         |
| <b>CV= 0.2</b>  | 0.16                        | 0.41                         |

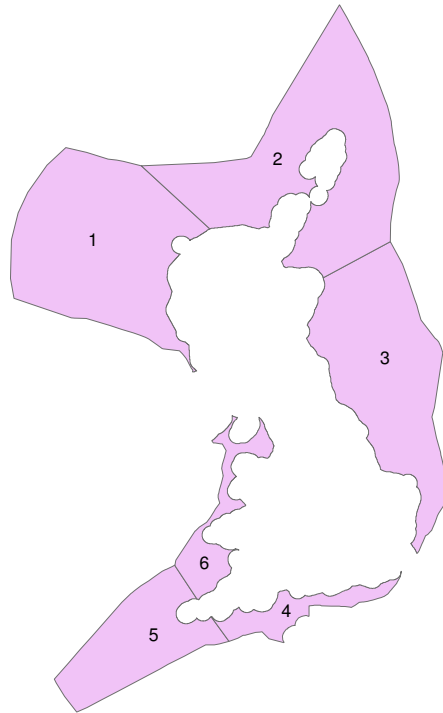
Note that all of the above calculations make some quite unrealistic assumptions (e.g., equal detection probabilities in both strata, but independent estimation), expected encounter rates are correct,  $b=3$ , and no additional uncertainty due to things like estimating  $g(0)$ . But they may be a useful guideline.

In what follows, we focus on the high-effort scenario. The other scenarios (and other alternatives as required) can be easily computed.

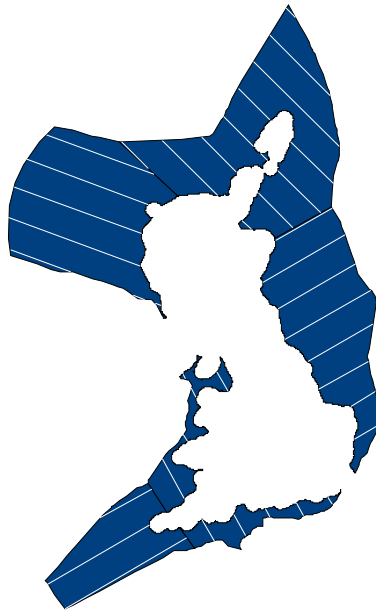
### **Offshore stratum tracklines**

The offshore stratum will be surveyed by plane, and hence parallel systematic lines seem appropriate. Using the design tool in Distance, entering a total survey effort of 7,197km yielded a suggested line spacing of 92.957km. However, some simulated realizations of a systematic parallel line transect survey all gave a lower total effort than 7,197km, so a slightly smaller spacing of 90km was used (this was also a nice round number!).

The stratum was divided into substrata so that the lines could be oriented in each stratum so as to be approximately perpendicular to the coast, or at least with a view to minimizing between-line variation in encounter rate if there is an animal density gradient that runs perpendicular to the shore. This yielded the following 6 substrata:



A single realization of this survey design was as follows:



| Substratum   | n lines   | effort, km (on effort only) |
|--------------|-----------|-----------------------------|
| 1            | 5         | 1808                        |
| 2            | 8         | 1975                        |
| 3            | 8         | 1610                        |
| 4            | 5         | 244                         |
| 5            | 3         | 952                         |
| 6            | 4         | 274                         |
| <b>Total</b> | <b>33</b> | <b>6864</b>                 |

There are a few issues here: the realized effort is still less than that called for by the optimal allocation formulae above; there are some short lines at the north east and north west corners of stratum 2. Both of these indicate that some further refinement would be useful (perhaps further decreasing the line spacing, and adjusting the stratum boundaries and line directions), but the above should be sufficient for the purposes of an initial costing.

#### **Inshore stratum – sub-stratification**

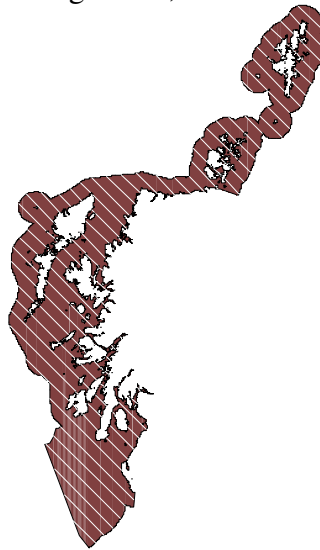
The intention is for this region to be surveyed mainly by small boat; however, the northwest part causes problems for small boat surveys due to the many islands and inlets. Hence it was decided to carve this off and cover with an aerial survey. The stratum was therefore divided into two: Northwest inshore and Southeast inshore, with areas, respectively, of 72,630km<sup>2</sup> and 83,499km<sup>2</sup> (note – this totals 156,129 rather than 156,199 as reported earlier for the inshore stratum, as some of this stratum included inshore lakes and other odd features, which have been deleted).



Given the above areas, and a total effort allocation of 9,283km for this stratum, this then yields the following allocations for the northwest and southeast substrata (assuming effort proportional to area): 4,318 and 4,965 km respectively.

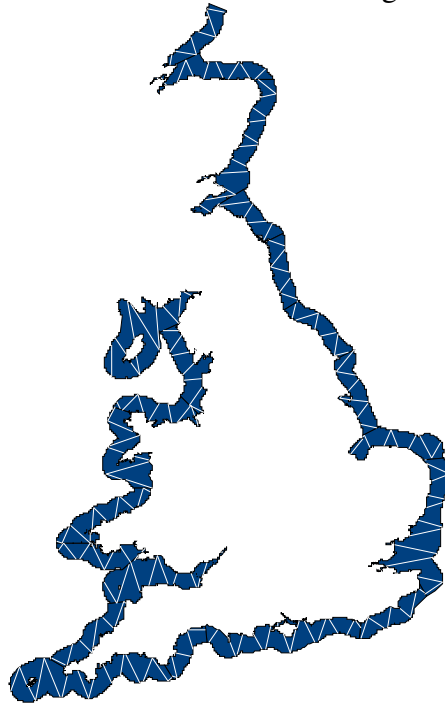
#### **Northwest inshore stratum tracklines**

These were given a parallel line design, with a spacing intended to give an expected line length of 4,318km. Using the suggested spacing of 17.7km gave a trackline length of 4,134km on one realization – a little low, so a spacing of 17km was used in what follows (again, this could be reviewed). Line orientation was NW-SE. A single realization of this design gave 46 samplers (transect lines, although some of these are split in two by islands, etc), and an on-effort line length of 4,327km.



### **Southeast inshore stratum tracklines**

This stratum is to be surveyed from small boats. Nominal survey effort here is 4,965km. It makes most sense for shipboard surveys to use a zigzag sampling design, and Strindberg *et al.* (2001) showed that an equal spacing zigzag design has good properties. Zigzag line placement takes place within a convex area, so it's important to sub-stratify highly non-convex polygons to make them as convex as possible (see Strindberg *et al.*, 2001 and Thomas *et al.*, 2007 for further details). To create this initial design, we split the area into 21 substrata, although this can be refined. We chose a design axis for each one that was, as far as possible, parallel to the coast, so as to make the lines as far as possible, perpendicular to the coast. We use a line spacing of 19km for comparability with the Northwest stratum. One realization of this design was as follows:



The realized on-effort line length here was 4,882km, and there were 166 lines.

### **Nearshore stratum**

This stratum was created by making a 500m buffer around the UK shoreline, in a GIS. The original size of this stratum on the GIS was 8,712km<sup>2</sup>. The survey design for this stratum would be a shipboard strip transect, where the vessel would proceed at 125m from the coast in one direction, surveying in a strip 125m either side of the vessel; it would then return at 375m from the coast in the opposite direction, surveying 125m either side of the vessel. These two passes make a strip transect of 500m width. An alternative design would be a line transect survey, but a standard “conventional distance sampling” style of line transect would not be feasible if the vessel moves along parallel to the coast as the assumption of uniform distribution of animal distances would not be met because of the known nonlinear change in density of animals with distance from the coast. However, a double-observer line transect is feasible, as this does not necessarily

assume a uniform (or even known) distribution of animal distances, and this may represent the best option. In this case, the survey vessels could make one single pass, perhaps at 250m from shore.

Given the original size of the stratum of  $8,712\text{km}^2$ , and given a width of 500m, the length of this stratum is  $17,424\text{km}^2$ . So, with two passes of a vessel, this implies a survey effort of 35,848km, if the whole stratum was surveyed. Note that this includes all the offshore islands in the UK, and all inlets and some rivers. One labour-saving alternative would be not to employ this type of survey in waters adjacent to the Northwest inshore stratum, where there are many inlets and islands (this could be sampled by the Northwest inshore aerial survey), and also to remove all rivers from the survey. Doing this (see figure below) reduces the size of the stratum to  $2,742\text{km}^2$ , so a survey effort of 5,484km if surveyed in one pass, or 10,968km if surveyed in two passes.

In the figure below, the area in red is the inshore stratum with rivers and some outlying islands removed, and also waters adjacent to the Northwest inshore stratum.

Another option would be to take a sample of the coastline – e.g., survey every 20km with a 20km gap.



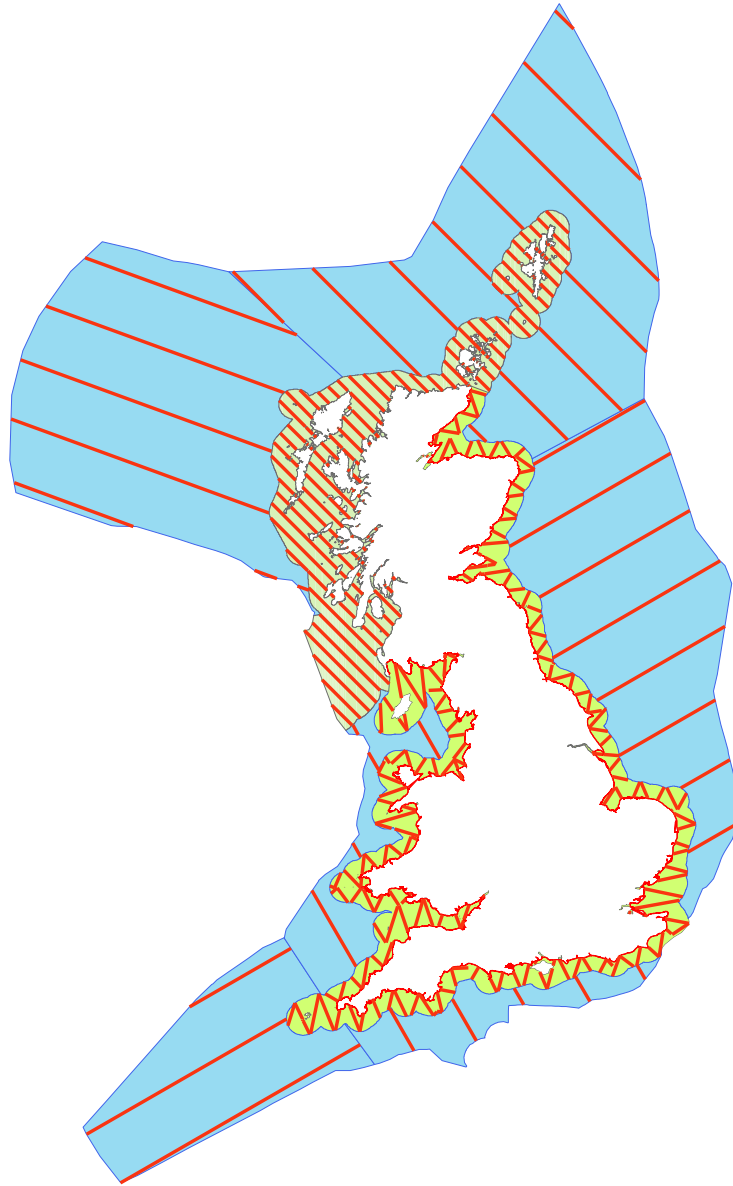
We do not deal with expected  $CV(D)$  for this stratum, as for the strip transect approach with complete coverage of the coast, one could argue that the variance should be zero.



Variance calculations could be performed for the other options, but it is unlikely that this stratum will contribute much to the overall variance, given its size.

### **Discussion**

Below is a figure showing all of the tracklines from the single realizations of the survey design from each stratum, just for illustration:



As mentioned above, creating the design entailed making a number of quite unrealistic assumptions. These led, among other things, to the result that effort allocation between strata should be in proportion to area times encounter rate, and given the five-fold difference in encounter rate expected between offshore and inshore strata, the survey coverage in the inshore stratum is far greater (line spacing approx. 19km in inshore stratum, but 90 in outer stratum). Under different (slightly less plausible) assumptions (Buckland *et al.*, 2001, section 7.2.2), an optimal allocation is in proportion to stratum

area times the square root of density. If it were felt that the offshore stratum had too little effort, using this allocation scheme would even up coverage between inshore and offshore stratum somewhat.

We note that, under the current scheme, the expected number of encounters in the offshore stratum is very low; likely not enough to fit a separate detection function to that stratum (although using covariates in an MCDS analysis is an alternative). This is problematic because the pooling robustness property of line transect surveys does not hold if coverage is not uniform between strata – this provides another motivation for slightly increasing the coverage in the offshore stratum, even relative to the maximum given here.

We note that survey effort for the nearshore stratum is very high, relative to the other strata and taking account of the nearshore stratum area. It is important to carefully consider whether devoting so much effort to a small stratum is worth the investment. Taking samples from this stratum (rather than a complete census) is a useful possible alternative, although it is worth noting that under the current scenario, vessels surveying the inshore stratum could undertake a single pass in the nearshore stratum on their return to the home port. In this case, using a double-observer line transect survey might be a useful option.

For all of these strata, we have not discussed how often these surveys would occur. The sample size calculations have assumed one estimate per survey. If within-year replication is required, then it may be possible to survey a subset of the lines on each survey period, hence saving effort. However, this would need to be discussed in the context of the goals of the survey.