Cetacean Offshore Distribution and Abundance in the European Atlantic (CODA)

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2 Lists of keywords and abbreviations

2.1 Keywords

Common dolphin, Striped dolphin, Bottlenose dolphin, Pilot whale, Fin whale, Sperm whale, Beaked whale, Abundance, Distribution, Habitat Use, Line Transect Surveys, Distance Sampling, Acoustics, Conservation, Management, Bycatch

2.2 Abbreviations

ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
CDS	Conventional Distance Sampling
CLA	Catch Limit Algorithm
DSM	Density Surface Modelling
ICES	International Council for the Exploration of the Sea
IFAW	International Fund for Animal Welfare
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee, UK
MRDS	Mark-Recapture Distance Sampling
OSPAR	Commission for the Protection of the Marine Environment of the North-East Atlantic
PAM	Passive Acoustic Monitoring
PBR	Potential Biological Removal
SCANS	Small Cetacean Abundance in the North Sea and adjacent waters (1994)
SCANS-II	Small Cetaceans in the European Atlantic and North Sea (2005)

3 Executive Summary

The aims of project CODA were to estimate the abundance and investigate the habitat use of cetacean species in European Atlantic waters beyond the continental shelf and to develop further a management framework (procedure) for determining safe bycatch limits and to provide indicative calculations for the common dolphin in European Atlantic waters. The results were intended to inform assessments of conservation status of all cetacean species, inform assessments of the impact of bycatch of common dolphin, and inform assessments of the impact of anthropogenic sound on deep-diving whales.

State-of-the-art visual survey methods were used on five survey ships to collect data for abundance estimation along 9,651 km of transects in a 968,000 km^2 survey area off the continental shelves of Britain, Ireland, France and Spain in July 2007. Design-based and/or model-based estimation methods, appropriate to the data, were used to estimate abundance. Best estimates of abundance were: 116,709 (coefficient of variation = 0.34) common dolphins; 67,414 (0.38) striped dolphins; 19,295 (0.25) bottlenose dolphins; 25,101 (0.33) long-finned pilot whales; 2,077 (0.20) sperm whales; 6,765 (0.99) minke whales; 9,019 (0.11) fin whales; and 6,992 (0.25) beaked whales.

Passive acoustic data collected on all ships will be used in further research to distinguish vocalisations among odontocete species; this will aid in monitoring of some species. Sperm whale abundance was estimated from acoustic data for part of the survey area.

Habitat modelling revealed features of the environment that most influenced the distribution of the different species; sea surface temperature and depth were common predictors. Areas of higher density were predicted in the south of the survey area for common dolphins, striped dolphins and fin whales, in the north for pilot whales, and localised areas in the north and south for sperm and beaked whales.

To assess the status of common dolphins in the European Atlantic, an integrated population dynamics model was developed and fitted to data on abundance, life history and bycatch. The assessment was conducted for common dolphins assumed to be a single population in the SCANS-II and CODA survey areas 1990-2007. However, the assessment was unable to provide useful information about population growth rate; ways of improving it are discussed.

Bycatch management procedures first developed under project SCANS-II were further developed, tested for robustness, and used to calculate safe bycatch limits for common dolphins in the SCANS-II and CODA survey areas for three interpretations of the ASCOBANS interim conservation objective: to allow populations to recover to and/or maintain 80% of carrying capacity in the long term. These bycatch limits are indicative and cannot immediately be used for management purposes; a series of steps that must first be taken, initiated by agreeing conservation objective(s) at the policy level, is listed.

There is clear conservation benefit in having these new results on abundance, habitat use and capability to calculate safe bycatch limits to inform assessments of conservation status and the impact of bycatch and other human activities on cetacean species. They will contribute to national reporting under the EU Habitats Directive and to the work of international organisations (OSPAR, ICES, ASCOBANS, IWC) with a responsibility for and/or interest in the conservation of cetaceans.

Policy implications include anticipating the need for another SCANS/CODA-type survey to take place in 2015, and consideration of the steps necessary before the safe bycatch limits for common dolphin can be used for management purposes.

4 Introduction

4.1 Project background

The bycatch of small cetaceans in fisheries is a major concern for the conservation of cetaceans on a global scale. In European waters, much of the research on bycatch has focused on the harbour porpoise, *Phocoena phocoena*. This species was the target of two major international projects supported by the EU LIFE Nature programme (SCANS and SCANS-II) aimed at assessing the abundance of this species and other small cetaceans in European continental shelf waters. The other species of concern with respect to bycatch in European waters is the short-beaked common dolphin, *Delphinus delphis*, which is taken in bottom set gill and tangle nets, drift nets and in pelagic pair trawls. Information on abundance is essential for an assessment to be made of the impact of fisheries on affected populations.

The SCANS projects generated an abundance estimate for the common dolphin in the Celtic Sea in 1994 (Hammond *et al.*, 2002), although this estimate is now believed to be significantly overestimated, and for the entire European Atlantic continental shelf in 2005 (SCANS-II, 2008). However, this species is wide-ranging and also occurs in deeper offshore waters. Previous estimates of abundance in offshore waters are fragmentary and most are biased due to limitations in the methodologies used.

There was thus a need for a large-scale survey of offshore waters beyond the continental shelf to allow a more comprehensive assessment of the impact of bycatch on the common dolphin in European Atlantic waters. Such a survey would also generate new information on the distribution and abundance of other cetacean species, which, together with the results from project SCANS-II, would better enable EU Member States to report on conservation status, as required under the Habitats Directive. This applied particularly to the bottlenose dolphin, *Tursiops truncatus*, listed under Annex II, but also to other species known to occur in the area, including the common dolphin, striped dolphin, *Stenella coeruleoalba*, fin whale, *Balaenoptera physalus*, sperm whale, *Physeter macrocephalus*, and a number of species of beaked whale.

Deep diving species of whale are vulnerable to sound generated by human activities, particularly in oil and gas exploration and military sonar. Notwithstanding the need to improve our understanding of the effects of sound on these species, improvement of knowledge of their distribution and abundance will help mitigation strategies by minimising the spatial and temporal overlap between the animals and the human activities.

The Cetacean Offshore Distribution and Abundance (CODA) project aimed to generate unbiased estimates of abundance in offshore waters beyond the continental shelf to inform assessments of conservation status of all cetacean species, inform assessments of the impact of bycatch of common dolphin, and inform assessments of the impact of anthropogenic sound on deep-diving whales.

The SCANS-II project also developed a generic management framework (procedure) for setting safe bycatch limits for small cetacean populations; safe limits were generated for the harbour porpoise for each of the SCANS-II survey blocks for three possible conservation objectives. The procedure could be implemented for harbour porpoise at the national or international level once policy decisions on the conservation objectives have been made (SCANS-II, 2008). There is a need to adapt the framework so it can also be applied to small cetacean species subject to bycatch other than the harbour porpoise, particularly the common dolphin. Project CODA aimed to undertake this further development and to calculate safe bycatch limits for the common dolphin in European Atlantic waters.

4.2 Aims and objectives

The principal aim was to estimate abundance of common dolphin and other cetacean species in offshore European Atlantic waters and to provide information for a management framework to assess the impact of bycatch and recommend safe bycatch limits for common dolphin. Other objectives were to investigate distribution and habitat use for common dolphin and other species and to obtain information on sperm whales and other deep diving species to contribute to our understanding of the impact of industrial and military seismic and sonar activities.

Specifically, the objectives were:

1. To map summer distribution of common dolphin, bottlenose dolphin, fin whale, deep diving whales and other cetaceans in offshore waters of the European Atlantic;
2. To estimate abundance of common dolphin, bottlenose dolphin, fin whale, sperm whale and other species, as data allow, in offshore waters of the European Atlantic;
3. To develop further the bycatch management framework developed under project SCANS-II to assess the impact of bycatch on and calculate safe bycatch limits for common dolphins.
4. To investigate habitat use and preferences of common dolphin and other species, as data allowed, in offshore waters of the European Atlantic.

5 Adopted approach

5.1 Survey Methods

The shipboard surveys for data collection were planned for July 2007 to coincide seasonally with SCANS-II. Visual and acoustic methods were used onboard four[1] ships. The survey area was divided into four survey blocks and transects designed to ensure equal coverage probability using program DISTANCE (Thomas *et al.* 2006; Figure 1).

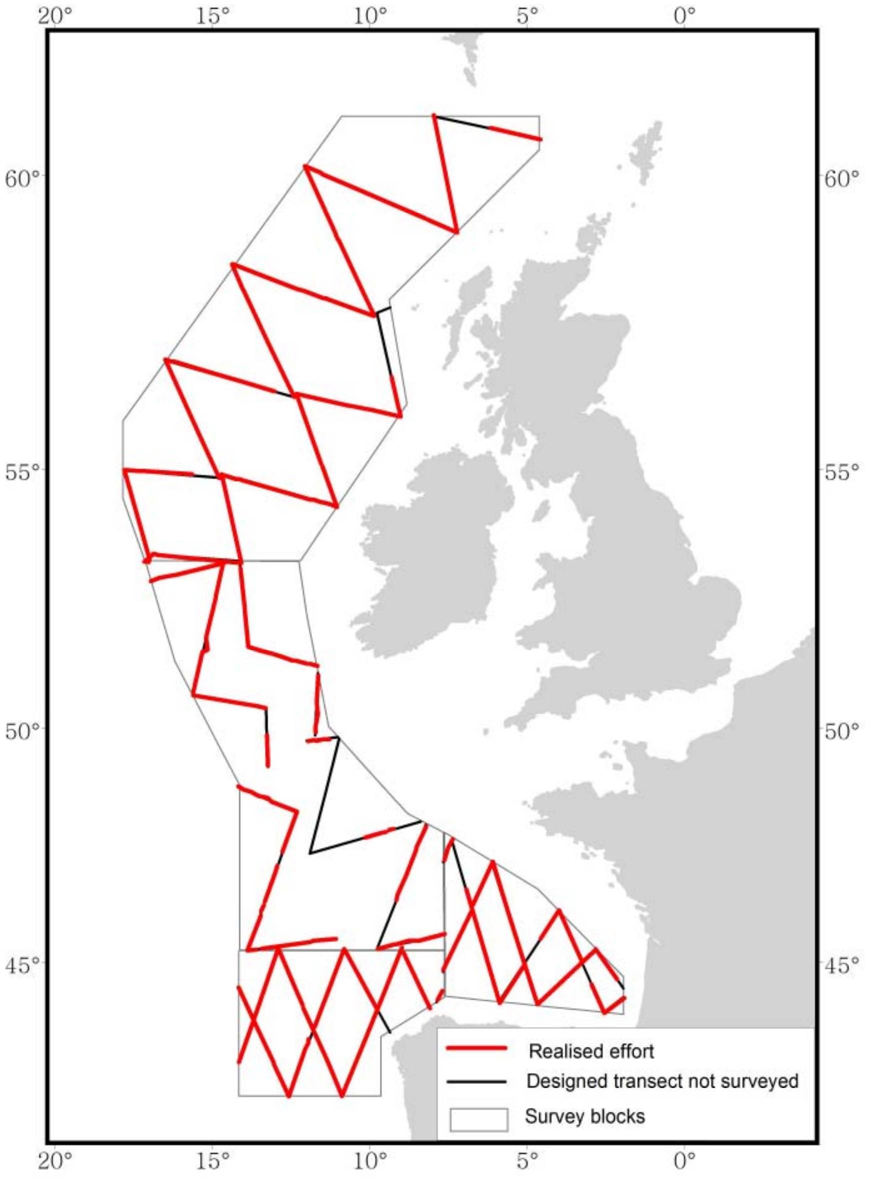


Figure 1: Survey blocks, designed cruise tracks and realised effort for the CODA surveys.

[1] The number of ships became five after *Rari* had to be replaced by *Germinal* two weeks into the surveys.

5.1.1 Visual survey

State-of-the-art methods for conducting visual surveys of cetaceans from ships had been developed and employed during the SCANS-II project (SCANS-II, 2008). These methods were used and further enhanced for the CODA surveys.

The approach adopted was a double platform survey with two teams of observers on each ship to allow generation of abundance estimates that are corrected for animals missed on the transect line and also for the effects of movement of animals in response to the approaching ship. One team, known as the "Primary", searched with naked eye close to the ship (out to 500m). The other team, known as "Tracker", searched far way from the ship from a higher platform using bigeye or 7x50 binoculars and tracked detected animals until two or three resightings after being seen by Primary or until they had passed abeam. Two observers on each team searched at any one time. The other two observers of each team acted as duplicate identifier (DI) or data recorder (DR), or rested. The DI identified "duplicates": sightings of single or groups of animals detected by the Tracker that were resighted by the Primary. Duplicates were classified as Definite (at least 90% likely), Probable (at least 50% likely), or Remote (less than 50% likely). The DR recorded all data (sightings, effort and environmental) into a laptop computer. Sightings were classified with identification certainty levels: High, Medium, and Low.

The SCANS-II project had invested a lot of resources in the development of automated data collection systems. Specifically, the IFAW Logger software had been adapted to allow double platform survey data to be accommodated and real-time data collection and storage in an Access database. This new version of Logger was implemented on the CODA surveys.

The key sightings data collected on a line transect survey are the distance and angle to each detected group of animals. A number of developments were made so that these could be recorded as accurately as possible. As much as possible of the data recording was automated through a system that required the simple depression of a sightings button at the time each detection was made. Angle was measured accurately using a camera attached to the binoculars that took photographs of lines on the deck. A video camera mounted on each pair of tracker binoculars was used to measure distance accurately. The video operated on a buffered system so that when the sightings button was pressed, frames from the previous 6 seconds of footage were stored. This ensured that the first surfacing of the animal was captured. The button press also triggered the audio system, so that the observers recorded their sightings information via microphone to be recorded on soundcards in the data-recording laptop computer. The project benefited from a development in computer hardware, the "Firestore", which captures and stores digital imagery from video cameras and thus simplifies the overall collection, processing and storage of images; this makes the technique more transferable to other surveys.

5.1.2 Acoustic survey

The acoustic data collection system aimed to detect as many odontocete species as possible, with particular emphasis on sperm whales, beaked whales, oceanic dolphins and harbour porpoise. To cover the wide frequency range used by these species, two recording/detection systems were used. The first was the high frequency automatic click detector (RainbowClick; Gillespie & Leaper 1996) used to detect harbour porpoises during the SCANS-II survey, which was set up to be most sensitive between 100 and 150 kHz. The second was a system which recorded continuously to computer hard drive at a sample rate of 192 kHz, giving an effective system bandwidth of 2kHz to 90kHz (the lower cut off frequency of the hydrophone to the upper frequency limit of the recording equipment). This second system was sensitive to all other odontocete species likely to be encountered in the survey region.

The hydrophones used during the SCANS-II survey consisted of 200m of cable with three hydrophone elements all close to the cable end (distances 200m, 200.25m and 203m from the cable dry end). The 25cm and 3m spacing were optimal for harbour porpoise and sperm whale localisation, respectively. For the CODA survey, the cables were extended by an additional 200m and two extra hydrophone elements, with 3m spacing mounted close to the join, resulting in a hydrophone with elements at 200, 203, 400, 400.25 and 403m. All hydrophones had a nominally flat frequency response from 2kHz to 200kHz. Depth sensors were mounted close to each group of hydrophone elements.

There were no dedicated acoustic operators on the vessels. The equipment was designed in such a way that it could be deployed by one of the visual observers each morning and data collection would then run automatically throughout the day until the dedicated observer recovered equipment and backed up data each evening.

No attempt was made to detect baleen whales, firstly because detection of low frequency baleen whale sounds in the noisy environment close to a vessel is extremely difficult and secondly because extending the bandwidth of the system to lower frequencies may have seriously compromised the system's high frequency performance needed for odontocetes.

High Frequency click detection

High frequency clicks were detected using the RainbowClick software, configured in the same way as for the SCANS II survey and monitoring the channels from the two hydrophone elements at 400 and 400.25m. Signals from the two hydrophones were digitised at a sample rate of 500kHz per channel using a National Instruments PCI-6250 data acquisition board. The software detected candidate clicks with energy in the 100-150kHz band in real time and only those candidate clicks were stored for analysis, the bulk of the data being discarded in real time.

Broad band recording

Continuous four channel broad band recordings were made using the IFAW Logger software. Signals from the two pairs of hydrophones with 3m spacing were digitised using an RME Fireface 800 sound card sampling at 192 kHz. Recorded data were written directly to large (2 Terabyte) external hard drives as four channel .wav files.

5.2 Survey Data analysis

5.2.1 Visual survey data

All data were validated before the analysis began. Validation was time consuming, mainly due to missing data, and was completed in December 2007. A workshop was held in January 2008 to allocate tasks to scientists from partner institutes and to begin analysis.

The methods used to generate abundance estimates were:

i) Conventional Distance Sampling , CDS (design-based approach - no correction for animals missed on the transect line or for responsive movement);

ii) Mark Recapture Distance Sampling, MRDS (design-based approach - correction for animals missed on the transect line and for responsive movement);

iii) Density Surface Modelling, DSM (model-based approach).

Analysis was allocated among partner institutes primarily on the basis of species, each applying one or a combination of methods to the data. Most used both MRDS and DSM; a CDS approach was used for species with insufficient data for these methods. All analyses were carried out in the software DISTANCE (Thomas *et al.* 2006) Release 6 and R (R Development Core Team 2007). The geostatistical approach was used as an exploratory tool for investigating the spatial scale at which a species is distributed.

Conventional and Mark Recapture Distance Sampling

CDS and MRDS are design-based methods because the abundance estimates from them rely on the survey design to provide a representative sample (equal coverage probability) within each block. Where data allowed, estimates of abundance were calculated for each survey block, corrected for animals missed on the transect line and for any responsive movement using MRDS methods. MRDS methods require an adequate sample size of duplicate sightings for fitting a detection function to these data. For some species, there were too few duplicate sightings so data from the Tracker and Primary platforms were combined, one of each duplicate pair removed, to create a dataset of unique sightings. These data were then analysed using CDS.

The method involved fitting one (CDS) or two (MRDS) detection functions to the sightings data to estimate the probability of detection as a function of perpendicular distance and other explanatory covariates. For MRDS, there is a choice between a full independence or a point independence model, based on whether or not there is evidence of responsive movement (see Laake & Borchers, 2004). This probability was then used in a Horwitz-Thompson-like estimator (Borchers, Buckland & Zucchini, 2002) incorporating group size data to estimate abundance.

Sightings of all identification certainty levels were used; only Definite and Probable duplicates were included in the MRDS analyses. The effect of different choices for these categories is explored below. Group sizes for Primary detections were corrected by using group size determined by Tracker (for duplicates) or via a group size correction factor (for non-duplicates) estimated from data for duplicates, for each species.

Statistical details are given in Appendix I and references cited therein.

Density Surface Modelling

CDS and MRDS provide estimates of abundance for predetermined survey blocks with equal coverage probability but provide no information on density at a finer spatial resolution. In the DSM approach, animal density is modelled in a Generalised Additive Model (GAM) framework using geographical, physical and environmental covariates to generate abundance estimates. The estimation process was carried out in five steps following Cañadas & Hammond (2006): (1) a detection function was fitted to the line transect data and any covariates that could affect detection probability (obtained from the MRDS analysis); (2) the number of groups in each segment was estimated through a Horvitz-Thompson-like estimator; (3) abundance of groups was modelled using a GAM as a function of available covariates; (4) group size was modelled using a GAM as a function of available covariates (for some species only); and (5) abundance of animals was estimated in each grid cell as the product of model predictions from steps 3 and 4, or step 3 and a mean group size.

Statistical details of the DSM approach are given in Appendix II and references cited therein.

Constructing a model in which variability in animal density is explained by covariates describing the environment provides information on distribution that is more useful than scatterplots of sightings or sightings per unit of effort. The resulting models and maps improve our understanding of which features of the environment influence density and where high use areas are. Care must be taken in interpreting these results because the method is predictive rather than explanatory. Nevertheless DSM is a useful technique to obtain additional information on distribution and abundance if suitable covariate data are available. Density surface modelling can generate estimates of abundance that have greater precision than design-based methods. It also allows abundance to be estimated for areas that are different to the survey blocks originally defined for the survey.

5.2.2 Geostatistical Spatial Modelling

The aim of this approach was to investigate the influence of environmental factors on fin whale distribution. Correlograms were used to test for spatial autocorrelation in the fin whale dataset. Variogram models were fitted to look at the scales at which the data were spatially structured. After the relevant spatial scales had been identified, spatial filters were extracted with filtering kriging.

Spatial models were built using the extracted spatial filters and a number of environmental variables using Generalised Additive Models. For each spatial model, covariates with a spatial structure similar to the scale of the modelled spatial filter were tested, and the covariates used in each final spatial model were chosen according to a forward selection procedure. The final spatial models were then used to predict fin whale distribution at their respective scales, and these scale-dependent predictions were combined together and to the expected basal fin whale density in order to highlight the areas most suitable for fin whales.

The details of the methods developed are given in Appendix III.

5.2.3 Acoustic survey data

High Frequency Click Data

High frequency data were analysed in the same way as the SCANS-II data and by the same analyst. Porpoise clicks were first identified in the data using a statistical classification algorithm which compared the energy in the click at two different frequencies, the peak frequency and other parameters extracted from individual clicks frequency spectra.

A total of 602 hours of data were analysed. Only a single high frequency harbour porpoise click train was detected on the continental shelf to the SW of Britain and Ireland.

Broad band click trains from dolphins were identified in all areas.

Broad band recordings

Data from Block 1 (the UK sector) have not been analysed due to high levels of vessel noise. We continue to investigate whether useful information may be extracted from these data. Only data from the rear hydrophone pairs (at 400 and 403m) of the vessels operating in Blocks 2, 3 and 4 are presented here.

Recordings from each vessel were processed with the PAMGUARD click detector (Gillespie *et al.* 2008) to detect clicks from sperm whales and small odontocetes. Click files were then analysed by a single analyst (Swift) to search for click trains. Distances to sperm whale click trains were estimated using target motion analysis and the resulting perpendicular distances analysed using conventional distance sampling (CDS) methods to estimate acoustic strip width and hence abundance.

Details are given in Appendix IV.

5.3 Bycatch assessment and safe limits

As part of the EU SCANS-II project, bycatch assessment methods and management procedures were developed for harbour porpoise in the European Atlantic and North Sea (SCANS-II, 2008; Winship 2009). As part of the CODA project, these methods and procedures were developed further and applied to common dolphins in the Northeast Atlantic.

5.3.1 Assessment of the impact of bycatch on common dolphin

An understanding of the state and dynamics of a population is a prerequisite for assessing the impact of bycatch on its conservation status. Four quantities of particular interest are: 1) the bycatch removed from the population, 2) the size of the population, 3) the rate at which the population can grow in the absence of bycatch, and 4) the population size that could be achieved in the absence of bycatch. While knowledge of these quantities is essential for conservation and management, estimates of these quantities are often lacking or highly uncertain, as is the case for common dolphins in the Northeast Atlantic.

An integrated population dynamics model was developed for assessing the state and dynamics of a small cetacean population subject to bycatch. The population model is an age-structured model of the female component of a small cetacean population. The model can be fitted to a range of data on the population (e.g., abundance), life history (e.g., pregnancy rate, sexual maturity at age, age structure of natural mortality) and bycatch (e.g., age structure of bycatch mortality). The numbers of bycaught animals can be treated as known input to the model or bycatch can be estimated by fitting the model to data on bycatch rate per unit fishing effort with total fishing effort as input. The model is flexible and allows for a range of scenarios with respect to population dynamics (e.g., density-independent or density-dependent dynamics) and population structure (e.g., multiple subpopulations with dispersal among them). The model is fitted in a Bayesian statistical framework using a Markov chain Monte Carlo method. Full specifications of the model are described in Appendix V.

The integrated population dynamics model was fitted to several datasets on common dolphins in the Northeast Atlantic. The SCANS-II and CODA surveys provided absolute abundance estimates for common dolphins in Northeast Atlantic shelf waters in July 2005 and offshore waters in July 2007, respectively. Life history data were available for stranded and bycaught females from the UK and Ireland including sexual maturity status of known-aged animals, pregnancy status of mature animals, and age-at-death of animals dying as a result of natural causes and bycatch. Estimates of previous bycatch of common dolphins in several fisheries in the Northeast Atlantic were available from the literature.

The assessment was conducted for the time period 1990-2007. The population was treated as a single, panmictic population inhabiting the Northeast Atlantic. The SCANS-II and CODA abundance estimates were combined into a single abundance estimate for this population, 180,075 (CV=0.272), and was assigned to the year between the two surveys, July 2006. Four model scenarios were considered which differed with respect to whether population dynamics were density-dependent or density independent, whether or not the population was assumed to be at carrying capacity at the beginning of the study period, parameterisation of age-specific natural survival rates.

5.3.2 Determining safe bycatch limits for common dolphin

Bycatch management procedures

Management procedures were developed for calculating bycatch limits for small cetacean populations. We considered two existing management procedures, the Potential Biological Removal procedure of the US Government (PBR, Wade 1998) and the Catch Limit Algorithm procedure of the International Whaling Commission (CLA, Cooke 1999), as candidates for this purpose. Both procedures take information about a small cetacean population as input and output a bycatch limit. The PBR procedure takes a single, current estimate of population size as input. The CLA procedure takes time-series of estimates of population size and estimates of previous bycatch as input. Both procedures explicitly incorporate uncertainty in the estimates of population size. Thus, the procedures also require estimates of the precision of the estimates of population size as input. Under the PBR procedure, the calculation of the bycatch limit uses a single, relatively simple equation. Under the CLA procedure, the calculation of the bycatch limit is slightly more demanding computationally, involving statistically fitting a simple population model to the input data series and then calculating the bycatch limit as a function of several quantities estimated through the model fitting. An important element of both procedures is the ability to update the bycatch limit as new data on the population become available. The procedures are applied at the spatial resolution of defined management areas. A given procedure is applied separately to each management area resulting in a separate bycatch limit for each area. Full specifications of the procedures are given in Appendix V.

Conservation objectives and tuning the management procedures

A key element of both management procedures is the ability to 'tune' the procedure, i.e. adjust the bycatch limits, to achieve specific conservation objectives, which must be established in quantitative terms. Only then can safe bycatch limits be calculated. For the purposes of this project, we used the interim conservation objective agreed by ASCOBANS: to allow populations to recover to and/or maintain 80% of carrying capacity in the long term. Carrying capacity is defined as the population size that would theoretically be reached by a population in the absence of bycatch. This objective is partially quantitative but two factors are not fully defined. Firstly, "long term" is not specified. We used a period of 200 years for the development of the management framework. Secondly, "recovering to and/or maintain 80% of carrying capacity" can be interpreted in different ways.

We developed three versions of the management procedures, achieved by different tunings of the parameters, to reflect this. The first was that this is an expected target that should be reached on average. Our first tuning therefore ensured that the procedures reached or exceeded 80% carrying capacity 50% of the time. This is the way the IWC's CLA was tuned. The second interpretation is that the population should recover to and/or be maintained at or above 80% of carrying capacity. To capture this, our second tuning ensured that 80% carrying capacity was achieved 95% of the time. This is a stricter target and produces a more conservative procedure. The third, an extreme alternative, extended the second tuning to meet the conservation objective in the face of a "worst case" scenario. This is a much more conservative approach and, by definition, has lower plausibility than the other two.

The management procedures developed are generic but the specific results are entirely dependent on the conservation objective adopted. If it is determined that alternative and/or additional conservation/management objectives are appropriate, the management procedures can easily be tuned to the new objective(s).

Operating model

We developed a computer-based simulation model, or operating model, for tuning the bycatch management procedures so that one would expect to meet specific conservation objectives in practice and for testing and comparing the performance of the two procedures. The operating model simulates a small cetacean population over time while periodically simulating surveys of the size of this population. Bycatch is removed from this population annually according to bycatch limits set by the management procedures. Critically, the management procedures do not have knowledge of the true size of the population; they only have the simulated survey data and bycatch limits as input. This is the key aspect of the simulation model that mimics how the management procedures would operate in reality and thus how one would expect populations to fare under the management procedures in practice. The model of the cetacean population incorporates age structure, density dependence (in birth rate), multiple subpopulations (with dispersal among them), and environmental variation (represented by systematic changes in carrying capacity, periodic catastrophic mortality events, and random fluctuations in birth rate). Survey estimates are generated with random error and potentially directional bias. Similarly, bycatch is modelled as a random (and potentially biased) realization of the set bycatch limit. The operating model allows for multiple management areas that do not necessarily correspond to the spatial ranges of subpopulations. Thus, the model allows for flexible spatial scenarios regarding management and subpopulation structure (e.g., seasonal mixing). Full specifications of the operating model are given in Appendix V.

Tuning the management procedures

The operating model was used to tune the management procedures so that one would expect to achieve the conservation objective in practice. All three tunings were based on a single subpopulation inhabiting a single management area. The operating model was used to simulate this subpopulation subject to bycatch as limited by the management procedures for a period of 200 years. Population status at the end of the 200-year simulation period was examined to determine whether or not the conservation objective was achieved. If the objective was not achieved then the values of the tuning parameters of the management procedures were adjusted and the simulation was run again. This process was iterated until the conservation objective was achieved.

The first version was developed in a manner similar to the tuning of the CLA by the IWC. All parameters of the operating model were set at their baseline values (Appendix V, Table 2). Initial population status (population size as a proportion of carrying capacity) was set to 0.99. We chose 4% per year as a conservative maximum population growth rate for common dolphins and a conservative maximum net productivity level of 50% of carrying capacity. The management procedures were then tuned under this scenario so that the median population status after 200 years was 80%. This tuning is therefore appropriate for a conservation objective of maintaining the population <u>at</u> 80% of carrying capacity in the long term.

The second version tuning was developed in exactly the same way except that the management procedures were tuned so that there was a 95% probability that population status was ≥80% after 200 years. This is appropriate for a conservation objective of maintaining the population <u>at or above</u> 80% of carrying capacity in the long term.

The third “worst-case” version used population parameter values identical to the first two versions and all parameters of the operating model were set at their baseline values except two. A 50% overestimate in absolute estimates of population size and a 50% underestimate in estimates of future bycatch were chosen as worst-case scenarios. Initial population statuses ranging from 0.05-1.00 were considered for this tuning. The management procedures were then tuned so that there was a 95% probability that population status was ≥0.80 after 200 years. This tuning is therefore appropriate for a conservation objective of maintaining the population at or above 80% of carrying capacity in the long term under a worst-case scenario.

Calculating safe bycatch limits for common dolphin

The operating model was used to calculate bycatch limits for common dolphins in the Northeast Atlantic.

Based on the available information about common dolphin population structure in the Northeast Atlantic reported in Murphy *et al.* (2008), the combined CODA and SCANS-II survey area was used as an appropriate management area. Bycatch limits for common dolphins were calculated for this area using the tuned PBR and CLA management procedures and the combined SCANS-II/CODA abundance estimate, 180,075 (CV=0.272), assigned to July 2006 assuming no knowledge of previous bycatch. The CLA management procedure can also use estimates of previous bycatch, so a second set of bycatch limits was calculated using the tuned CLA procedure, the abundance estimate and the time-series of bycatch estimates in Appendix V, Table 5.

6 Results

6.1 Distribution and Abundance

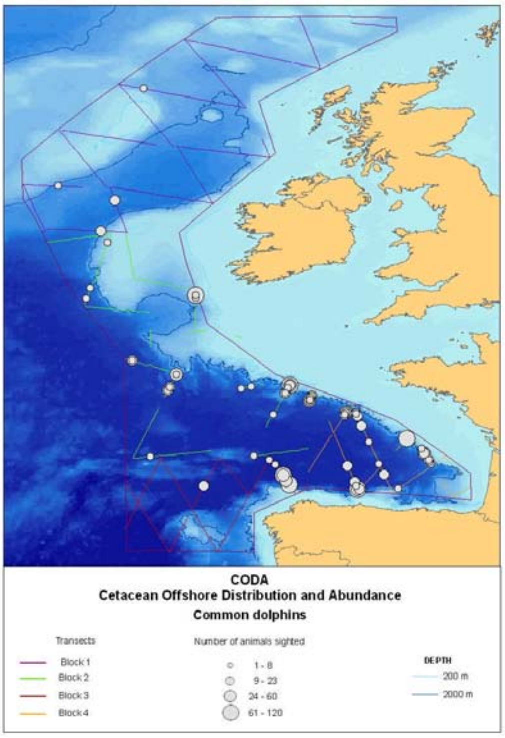
A minimum of 13 species was recorded during the survey, including bottlenose, white-sided, common and striped dolphin, pilot, killer, sperm and at least three species of beaked whale, and minke, fin and sei whale. Weather conditions during the summer of 2007 were relatively poor, especially in the northern sector, Blocks 1 and 2, reducing the time available for survey. In addition, problems with one survey ship reduced the time available for survey in Block 2. Nevertheless, almost 10,000km (Table 1) of survey effort was achieved, enabling abundance estimates to be calculated for common dolphin, striped dolphin, bottlenose dolphin, long-finned pilot whale, sperm whale, fin whale, sei whale and minke whale. Abundance was also estimated for groups of species: common and striped dolphin; long and short-finned pilot whales; beaked whales; large baleen whales (fin, sei, blue whales); and unidentified large whale (mostly baleen whales but possibly some sperm whale).

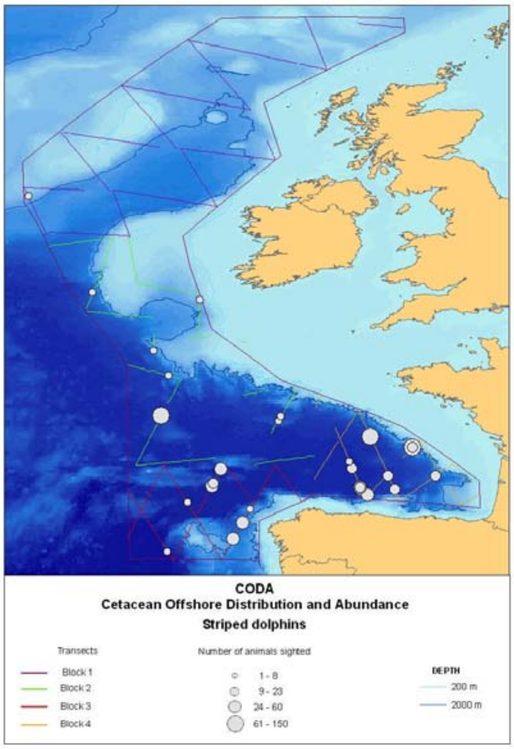
Table 1: Block sizes and survey effort (km) searched by the shipboard surveys. % Beaufort indicates the percentages of effort at or below the indicated sea states.

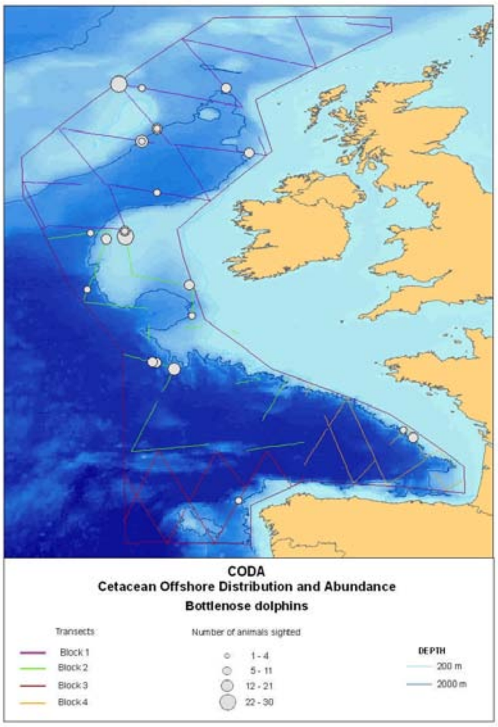
Block	**Surface area (km^2)**	**Total effort (km) Beaufort < 6**	**% Beaufort**				
			≤ 4	≤ 3	≤ 2	≤ 1	= 0
1	348,722	3,408.8	100	69.4	35.4	6.9	0.9
2	336,407	2,296.9	97.8	61.1	16.7	4.5	0
3	160,537	2,180.4	99.9	67.2	23.8	13.3	0.4
4	121,872	1,765.4	94.1	62.4	24.9	9.7	0

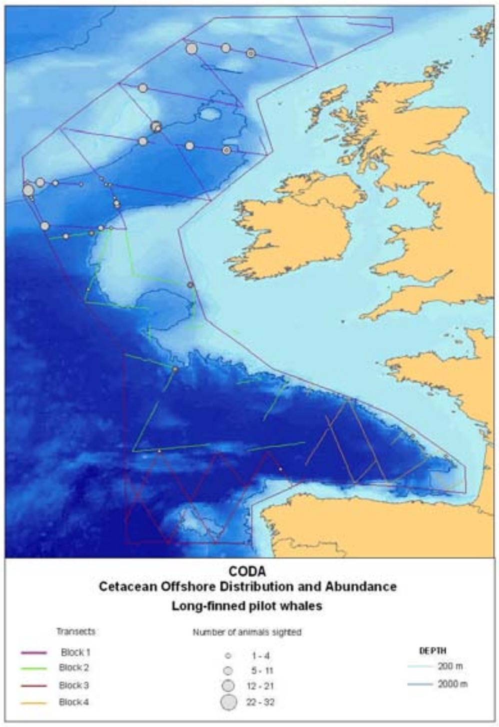
6.1.1 Distributions of sightings

Figure 2 shows the distribution of sightings of the main species encountered.


CODA
Cetacean Offshore Distribution and Abundance
Common dolphins
Transects
Block 1
Block 2
Block 3
Block 4
Number of animals sighted
1 - 8
9 - 23
24 - 60
61 - 120
DEPTH
200 m
2000 m


CODA
Cetacean Offshore Distribution and Abundance
Striped dolphins
Transects
Block 1
Block 2
Block 3
Block 4
Number of animals sighted
1 - 8
9 - 23
24 - 60
61 - 150
DEPTH
200 m
2000 m


CODA
Cetacean Offshore Distribution and Abundance
Bottlenose dolphins
Transects
Block 1
Block 2
Block 3
Block 4
Number of animals sighted
1 - 4
5 - 11
12 - 21
22 - 30
DEPTH
200 m
2000 m


CODA
Cetacean Offshore Distribution and Abundance
Long-finned pilot whales
Transects
Block 1
Block 2
Block 3
Block 4
Number of animals sighted
1 - 4
5 - 11
12 - 21
22 - 32
DEPTH
200 m
2000 m

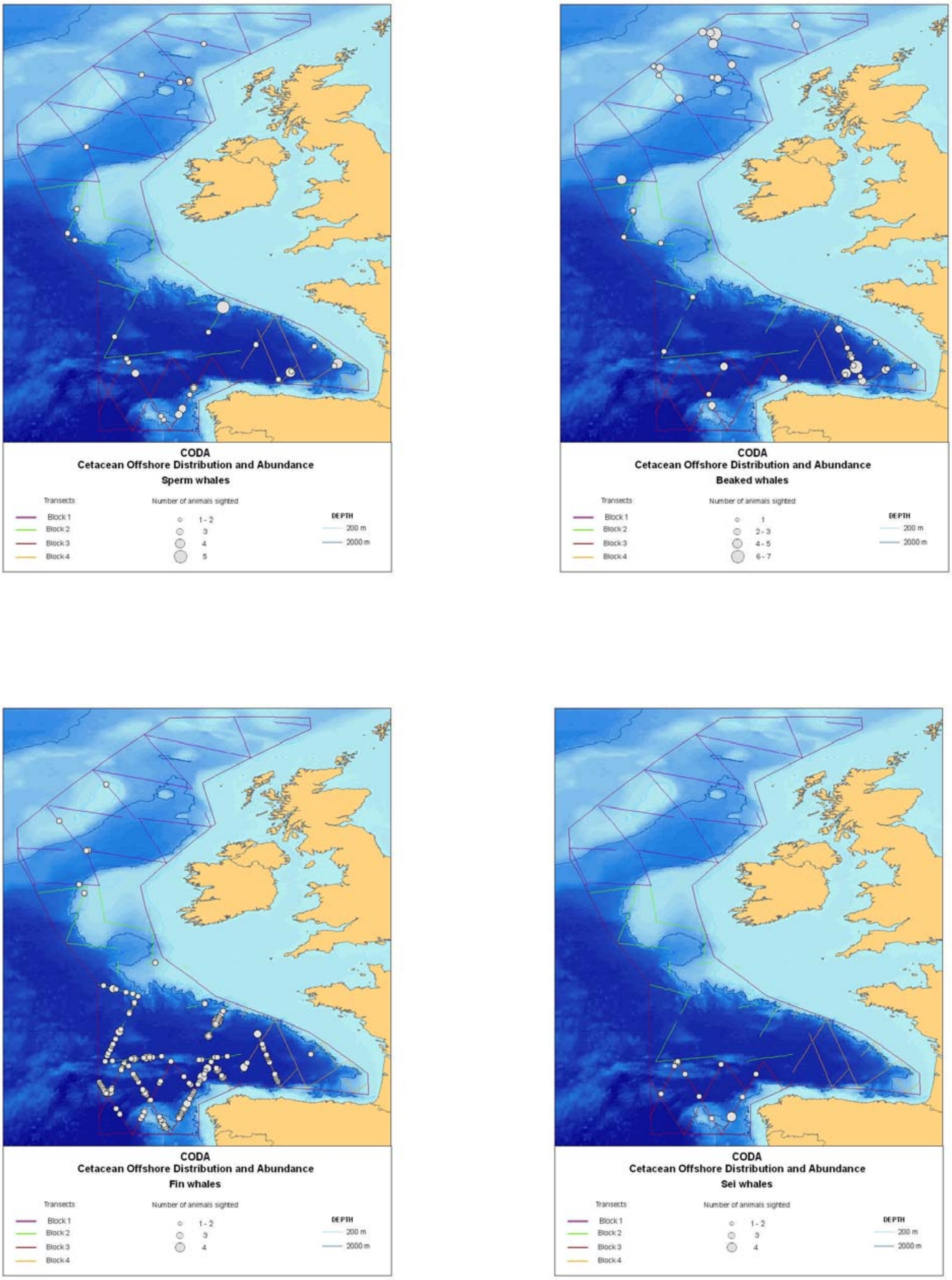


Figure 2: Distribution of sightings (circles proportional to group size) of species or species groups: common dolphin, striped dolphin, bottlenose dolphin, long-finned pilot whale, sperm whale, beaked whales, fin whale and sei whale.

Acoustic survey

Acoustic data from the *Mars Chaser*, the vessel operating in Block 1 (the UK sector) were too noisy for acoustic analysis. A total of 6,238 km of data were collected in blocks 2, 3 and 4 (Figure 3). In total, 247 sperm whales were detected. Although occurring mostly in groups of up to tens of animals, most sperm whales could be individually tracked and a perpendicular distance calculated.

Acoustic data analysis for other species is ongoing.

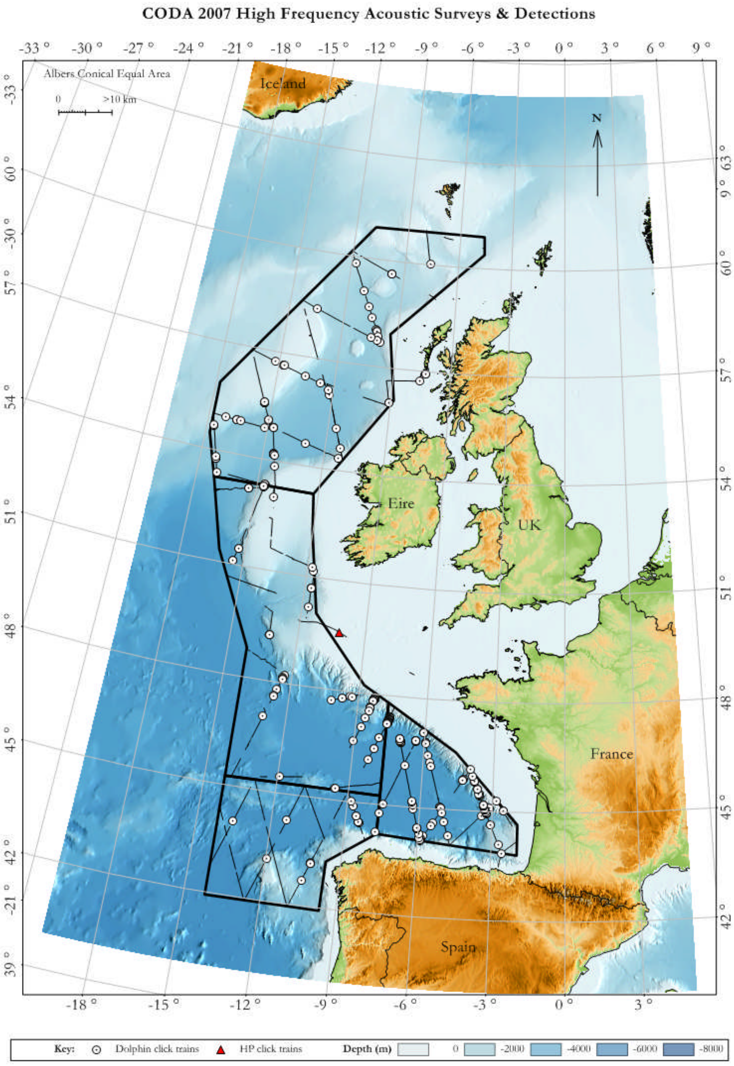


*Figure 3: Distribution of acoustic effort and high frequency acoustic detections. Detections are classified as click trains from one or more animals and include clicks from harbour porpoise (*Phocoena phocoena*) and various unidentified delphinid species.*

6.1.2 Design-based abundance estimates from visual data

For all species, only data collected during Beaufort sea state 0-4 were used. Truncation of perpendicular distance was necessary for some species to be able to fit reliable detection function models. Care was taken not to truncate Tracker detections within distances at which Primary detection probability is greater than zero because this can result in positively biased abundance estimates. Several explanatory covariates were explored, in addition to perpendicular distance, to fit the detection function models. These were: group size, vessel, primary platform height, Beaufort sea state, swell, glare, visibility, cue, sightability, precipitation and cloud cover.

Double platform MRDS analyses were carried out for species where duplicate sample size was adequate: common and striped dolphin, pilot whale (long-finned and all pilot whales), large baleen whales (mostly fin whales) and sperm whale (Table 2). Single platform estimates were made for bottlenose dolphins, minke whales and beaked whales using CDS. Density and abundance estimates were generated by survey block and for the entire area.

Table 2: Numbers of schools detected within the truncation distance of the transect line by Primary, Tracker and both (i.e. duplicates) while on search effort (Beaufort sea state 0-4).

Species	Seen by	Number of sightings
Common and striped dolphin	Tracker	173
	Primary	165
	Duplicate	73
Long-finned pilot whale	Tracker	59
	Primary	46
	Duplicate	19
Pilot whale (long and short-finned)	Tracker	62
	Primary	49
	Duplicate	21
Large baleen whale	Tracker	223
	Primary	204
	Duplicate	92
Sperm whale	Tracker	47
	Primary	31
	Duplicate	17

Mark Recapture Distance Sampling (MRDS) estimates

Details of the data processing, whether full or point independence or full independence MRDS models were fitted, and the best detection function models are given in Appendix I. Estimates of abundance for common and striped dolphins, pilot whales, and sperm whales are given in Table 3. Estimates for fin, sei, large baleen whales and unidentified large whales are given in Table 4.

Table 3: Estimates of abundance and density (animals/km²) using the MRDS approach for odontocetes. Figures in parentheses are CVs. Figures in square brackets are 95% confidence intervals.

Species	Block	Animal abundance	Animal density (animals/km²)
Common dolphin	1	3,546 (0.76)	0.010 (0.76)
	2	53,638 (0.54)	0.159 (0.54)
	3	12,378 (1.23)	0.077 (1.23)
	4	48,701 (0.51)	0.400 (0.51)
	Total	**118,264 (0.38) [56,915 – 246,740]**	**0.122 (0.38)**
Striped dolphin	1	519 (1.05)	0.0015 (1.05)
	2	33,254 (1.57)	0.099 (1.57)
	3	7,546 (0.62)	0.047 (0.62)
	4	20,045 (0.56)	0.165 (0.56)
	Total	**61,364 (0.93) [12,323 – 305,568]**	**0.063 (0.93)**
Common and striped dolphin	1	4,065 (0.67)	0.012 (0.67)
	2	115,398 (0.80)	0.343 (0.80)
	3	24,551 (0.66)	0.153 (0.67)
	4	80,152 (0.37)	0.658 (0.37)
	Total	**224,166 (0.48)** [90,979 – 552,331]	**0.232 (0.48)**
Long-finned pilot whale	1	18,709 (0.37)	0.054 (0.37)
	2	5,566 (0.75)	0.016 (0.75)
	3	194 (0.88)	0.001 (0.88)
	4	632 (1.1)	0.005 (1.1)
	Total	**25,101 (0.33) [13,251 - 47,550]**	**0.026 (0.33)**
Pilot whale (long and short-finned)	1	22,034 (0.37)	0.063 (0.37)
	2	4,148 (0.55)	0.012 (0.55)
	3	238 (0.91)	0.001 (0.91)
	4	358 (0.91)	0.003 (0.91)
	Total	**26,778 (0.34) [13,835 – 51,831]**	**0.028 (0.34)**
Sperm whale	1	363 (0.46)	0.001 (0.46)
	2	759 (0.52)	0.002 (0.52)
	3	560 (0.55)	0.003 (0.55)
	4	409 (0.55)	0.003 (0.55)
	Total	**2,091 (0.34) [1,077 – 4,057]**	**0.002 (0.34)**

Table 4: Estimates of abundance and density (animals/km²) using the MRDS approach for baleen whales. Figures in parentheses are CVs. Figures in square brackets are 95% confidence intervals.

Species	Block	Animal abundance	Animal density (animals/km²)
Fin whale	1	248 (0.45)	0.001 (0.45)
	2	3,668 (0.34)	0.011 (0.34)
	3	3,113 (0.22)	0.019 (0.22)
	4	595 (0.72)	0.005 (0.72)
	Total	**7,624 (0.21) [5,028 – 11,563]**	**0.008 (0.21)**
Sei whale	1	0	0
	2	0	0
	3	366 (0.33)	0.002 (0.33)
	4	0	0
	Total	**366 (0.33) [176 – 762]**	**0.0004 (0.33)**
Large baleen whale	1	250 (0.44)	0.0007 (0.44)
	2	3,853 (0.33)	0.011 (0.33)
	3	3,529 (0.22)	0.022 (0.22)
	4	605 (0.72)	0.005 (0.72)
	Total	**8,237 (0.20) [5,476 – 12,390]**	**0.008 (0.20)**
Unidentified large whale	1	352 (0.43)	0.001 (0.43)
	2	5,997 (0.43)	0.018 (0.43)
	3	226 (0.32)	0.001 (0.32)
	4	26 (0.71)	0.0002 (0.71)
	Total	**6,601 (0.40) [3,003 – 14,512]**	**0.007 (0.40)**
Large baleen whale + Unidentified large whale	1	574 (0.27)	0.002 (0.27)
	2	9,648 (0.37)	0.029 (0.37)
	3	3,636 (0.19)	0.022 (0.19)
	4	693 (0.70)	0.006 (0.70)
	Total	**14,550 (0.26) [8,561 - 24,729]**	**0.015 (0.26)**
Fin whale + Unidentified large whale	1	574 (0.27)	0.002 (0.27)
	2	9,493 (0.37)	0.028 (0.37)
	3	3,207 (0.19)	0.020 (0.19)
	4	693 (0.70)	0.006 (0.70)
	Total	**13,966 (0.27) [8,088 – 24,119]**	**0.014 (0.27)**

Conventional distance sampling estimates

Details of the data processing and the best detection function models for those species analysed using CDS are given in Appendix I. Estimates of abundance for bottlenose dolphin, minke and beaked whales are given in Table 5.

Table 5: Conventional line transect abundance estimates for bottlenose dolphin, minke whale and beaked whales. Figures in parentheses are CVs. Figures in square brackets are 95% confidence intervals.

Species	Block	Animal abundance	Animal density (animals/km^2)
Bottlenose dolphin	1	5,709 (0.35)	0.016 (0.35)
	2	11,536 (0.33)	0.034 (0.33)
	3	876 (0.82)	0.005 (0.82)
	4	1,174 (0.45)	0.010 (0.45)
	Total	**19,295 (0.25)** **[11,842 – 31,440]**	**0.020 (0.25)**
Minke whale	1	5,547 (1.03)	0.016 (1.03)
	2	1,218 (1.04)	0.004 (1.04)
	3	0	0
	4	0	0
	Total	**6,765 (0.99)** **[1,239 – 36,925]**	**0.007 (0.99)**
Beaked whales	1	3,512 (0.34)	0.011 (0.34)
	2	785 (0.43)	0.002 (0.43)
	3	597 (0.55)	0.004 (0.55)
	4	2,097 (0.45)	0.017 (0.45)
	Total	**6,992 (0.25)** **[4,287-11,403]**	**0.007 (0.25)**

Exploring Uncertainty in Data Classification

Duplicate classification

An analysis of the effect of duplicate classification was undertaken on the large baleen whale dataset, in which abundance was estimated for: all duplicates (Definite, Probable and Remote); Definite and Probable, and Definite only. Table 6 shows that including Remote duplicates had little effect but that removing Probable duplicates had a greater effect.

Table 6. Abundance estimates for large baleen whales for different duplicate classifications. Figures in bold show the categories included in the results presented elsewhere.

Duplicate Classification	Abundance (CV)
Definite only	9,164 (0.21)
Definite + Probable	**8,237 (0.20)**
Definite + Probable + Remote	8,107 (0.20)

Large whale identification certainty

Estimates of abundance were generated using the detection function for large baleen whales to look at the effects of identification certainty on the abundance estimates. Table 7 shows that removing low certainty sightings had little effect but that removing medium and assumed high certainty sightings had a large effect.

Table 7. The effects of identification certainty on large baleen whale abundance; H = high, AH = assumed high, M = medium, L = low. Figures in bold show the categories included in the results presented elsewhere.

Identification certainty category	Abundance (CV)
H	3,355 (0.42)
H, AH	5,578 (0.40)
H, AH, M	8,160 (0.21)
H, AH, M, L	**8,237 (0.20)**

6.1.3 Model-based abundance estimates from visual data

The final selected models of abundance of groups and group size are given in Appendix II, Tables 2 and 3. Estimates of abundance for each block are given in Table 8. Surface maps of predicted abundance of animals are given in Figure 4 for common dolphin, striped dolphin, common/striped dolphin combined and long-finned pilot whale, and Figure 5 for sperm whale, beaked whales, fin whale and large baleen whales.

Table 8. Model-based (DSM) abundance estimates.

Species	Block	Abundance of animals (CV)	95% Confidence Interval
Common dolphin	1	4,216 (0.57)	1,478 -12,027
	2	52,749 (0.39)	25,054 – 111,059
	3	21,071 (0.51)	8,270 – 53,689
	4	38,673 (0.46)	16,464 – 90,839
	Total	**116,709 (0.34)**	**61,397 - 221,849**
Striped dolphin	1	272 (0.80)	68 – 1,083
	2	39,534 (0.62)	12,863 – 121,504
	3	10,501 (0.42)	4,772 – 23,105
	4	17,108 (0.44)	7,543 – 38,800
	Total	**67,414 (0.38)**	**32,543 – 139,653**
Common and striped dolphin	1	2,317 (0.74)	637 – 8,428
	2	108,614 (0.35)	57,772 – 211,522
	3	26,010 (0.34)	13,627 – 49,647
	4	122,664 (0.49)	49,212 – 305,745
	Total	**259,605 (0.37)**	**128,818 – 523,175**
Long-finned pilot whale	1	18,255 (0.38)	12,912 – 49,725
	2	6,054 (0.43)	2,714-13,504
	3	429 (0.70)	126-1,465
	4	599 (0.46)	253-1,420
	Total	**25,338 (0.35)**	**12,912- 49,725**
Sperm whale	1	480 (0.33)	254-905
	2	509 (0.38)	249-1,042
	3	611 (0.34)	322 –1,159
	4	477 (0.33)	252 – 904
	Total	**2,077 (0.20)**	**1,404-3,073**
Beaked whales	1	3,889 (0.44)	1,694 –8,927
	2	642 (0.39)	306 – 1,346
	3	656 (0.34)	266 – 1,615
	4	2,156 (0.50)	860 – 5,409
	Total	**7,343 (0.31)**	**4,075-13,230**
Fin whale	1	204	163-255
	2	4,854	3855-6112
	3	3,206	2573-3996
	4	755	585-974
	Total	**9,019 (0.11)**	**7,265 – 11,197**
Large baleen whales	1	206	163-259
	2	5171	4072- 6566
	3	3487	2789-4358
	4	756	592- 965
	Total	**9,619 (0.11)**	**7,760 – 11,924**

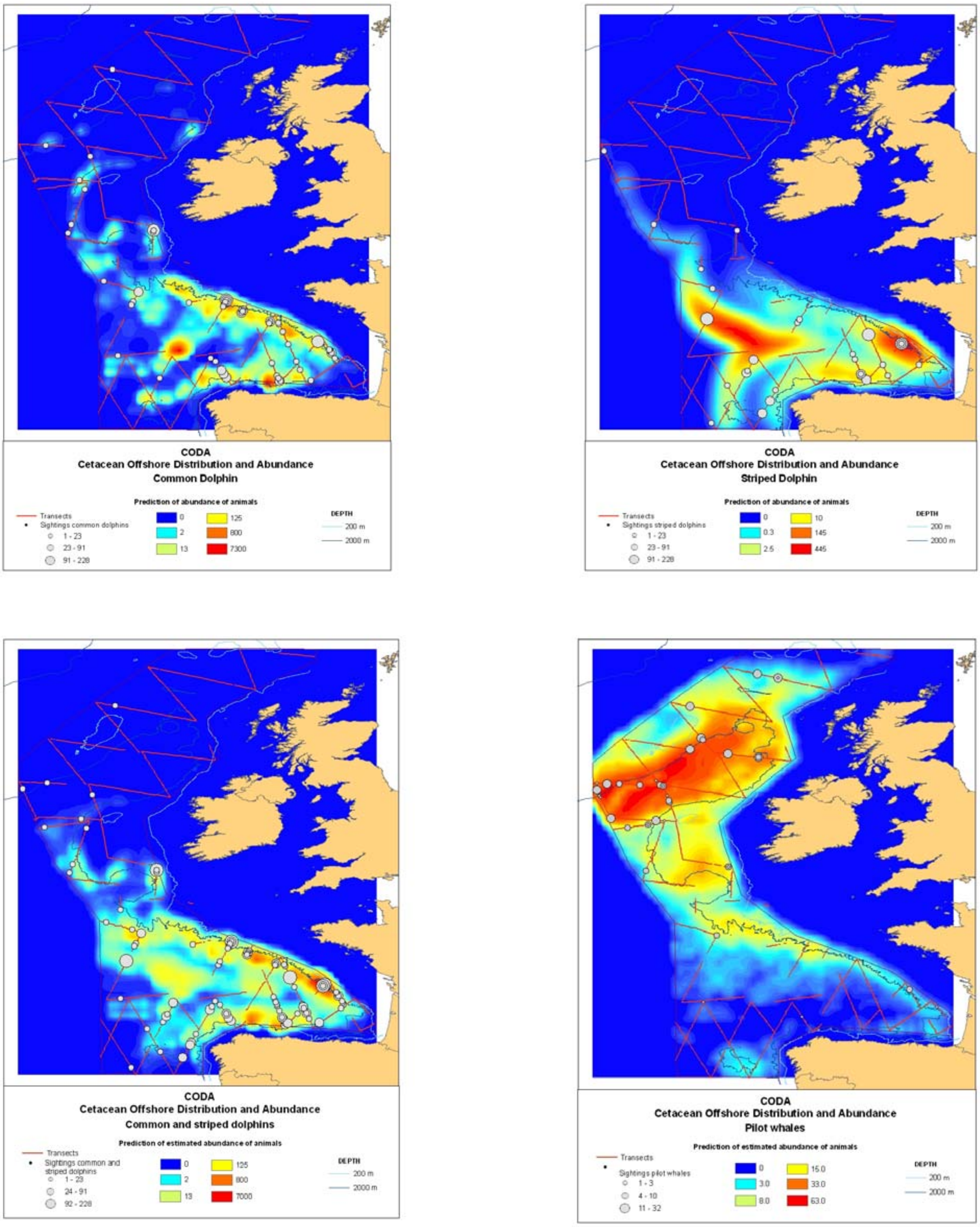


Figure 4: Surface maps of smoothed predicted abundance of animals of common dolphin, striped dolphin, common and striped dolphins combined, and long-finned pilot whales.

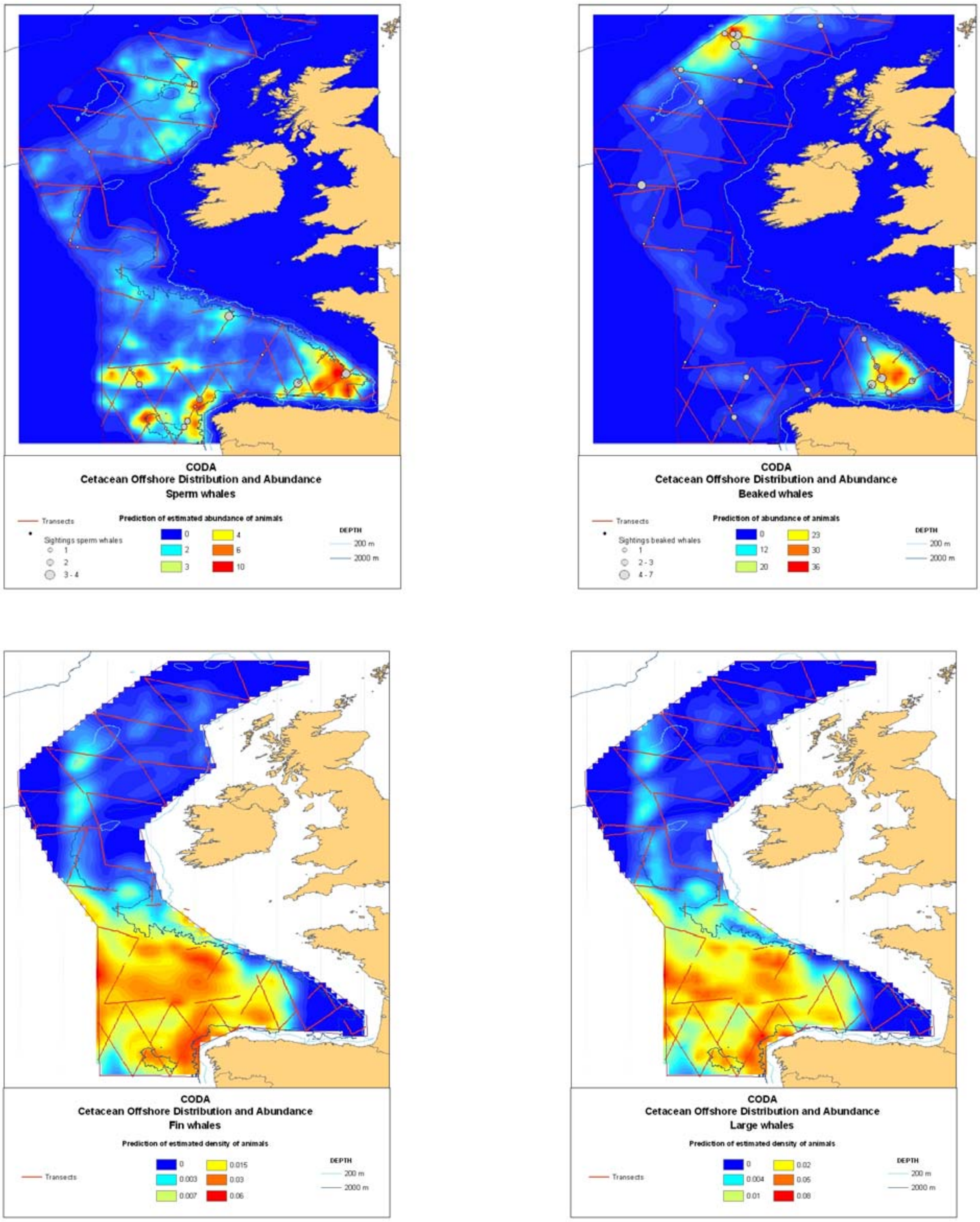


Figure 5: Surface map of smoothed predicted abundance of animals of sperm whales, beaked whales and fin whales, and large baleen whales.

6.1.4 Final abundance estimates: design-based or model based?

The abundance estimates generated by the two methods were comparable for each species, which gives confidence that the model-based (DSM) estimates were robust. Generally, the precision of the abundance estimates was improved by using model-based methods; the exceptions to this were for the long-finned pilot whales and beaked whales (Table 9). Model-based abundance estimation was not possible for bottlenose dolphin or minke whale The best estimates for each species were therefore model-based for common and striped dolphins, sperm and fin whales; and design-based for bottlenose dolphin, minke, long-finned pilot and beaked whales.

Table 9. Design-based and model-based abundance estimates for the main species in the whole survey area. Best estimates (based on lower CV) are shown in bold.

Species	Design-based abundance estimate (CV)	Model-based abundance estimate (CV)
Common dolphin	118,264 (0.38)	**116,709 (0.34)**
Striped dolphin	61,364 (0.93)	**67,414 (0.38)**
Common and striped dolphin	224,166 (0.48)	**259,605 (0.37)**
Sperm whale	2,091 (0.34)	**2,077 (0.20)**
Fin whale	7,641 (0.21)	**9,019 (0.11)**
Bottlenose dolphin	**19,295 (0.25)**	**-**
Minke whale	**6,765 (0.99)**	**-**
Long-finned pilot whale	**25,101 (0.33)**	25,338 (0.35)
Beaked whales	**6,992 (0.25)**	7,343 (0.31)

6.1.5 Abundance estimates of sperm whales from acoustic data

Sperm whale abundance for blocks 2, 3 and 4 (the French and Spanish sectors of the survey) was estimated at 2,239 (95% CI: 1,707 – 2,936) animals. Further details are given in Appendix IV. This estimate is similar (slightly higher) to the estimates based on visual data for the whole survey area.

6.2 Habitat use

6.2.1 Spatial Modelling of Abundance

Common and striped dolphin

In general, there is considerable similarity in the modelled distribution patterns of common and striped dolphins, in that predicted densities of both species are higher in the southern half and lower in the northern half of the study area. Within the southern half, both species also have higher predicted densities within the Gulf of Biscay, especially along the continental slope both on the northern and southern edges of the Gulf, and less so towards the south, to the west of Galicia. The main difference between the species is that striped dolphins have a predicted high density area in the deep waters of the western part of the Gulf of Biscay and relatively less over the slope, compared to common dolphins.

There is one area that is predicted as high density for both species, around the centre of the Gulf of Biscay in the southern part of Block 2 in an area with no effort. This predicted high density area has steeper slopes and shallower depths than the surrounding areas, corresponding to some seamounts. In addition, it is an area with the optimum sea surface temperature for both species according to the models. Therefore, this area seems to have the right environmental characteristics for holding high densities for both species and would be interesting to investigate further.

Pooling together different species for modelling density is generally not a good idea because different species may be expected to have different relationships with their habitats and therefore be distributed differently. This may cause difficulties in model fitting and obscure the relationship between a species distribution and its environment. However, the model for common and striped dolphins combined worked well because of the relatively coarse similarities in their distribution over a large area, as described above. In addition, those groups in which the species could not be determined between striped or common dolphins could be included. This model thus provides a good picture of the distribution and high density areas of small dolphins in the study area.

Long-finned pilot whale

Long-finned pilot whales were predicted to occur mainly in the northern part of the survey area. The highest densities were predicted between 53º and 58ºN, offshore from Ireland and Scotland. The model predicted that higher densities occurred in deep waters, seabed slopes with a south-easterly orientation, and warmer temperatures.

Fin whale

Predicted fin whale densities were highest in the southern part of the survey area. There were two areas in particular that had the highest densities: the southern part of Block 2 and the north-eastern part of Block 3 off the Galician coast.

Four covariates were found to be important in predicting fin whale density: sea surface temperature, average depth, longitude and distance to the 2000m contour. Density was predicted to be higher in areas of sea surface temperature 16-19˚C and depths 1,000-3,500m. Peak density was predicted within 50m of the 2000m contour.

There were very few sightings of large baleen whales in the northern part (Block 1) of the survey area. Occurrence of fin whales in this area during July may be variable, having been recorded in this region during some previous surveys (Pollock *et al.*, 2000; Macleod *et al.*, 2006) but not in others (Joyce *et al.*, 1990).

Sperm whale

The spatial model predicted a clear pattern of higher densities of sperm whales towards the southern part of the study area: the Gulf of Biscay and north-western waters of the Iberian Peninsula. There was a second medium-density area in the northern part, west of the Hebrides. In the Gulf of Biscay, these results coincide with previous reports showing that the habitat of sperm whales in this area comprises the complex canyon area of the lower northern Celtic-Biscay shelf edge, the edge of the Biscay abyssal plain and the Santander canyon, near Bilbao (Lewis *et al.* 2007).

Beaked whales

The spatial model predicted two high density areas for beaked whales in the study area: the most south-easterly section (the Gulf of Biscay), and the most north-westerly section. These widely segregated areas probably correspond to different species or groups of species. In the north-west, all sightings of beaked whales identified to species level were of Sowerby's beaked whale and Northern bottlenose whale, with only one sighting of Cuvier's beaked whale. In the Gulf of Biscay, all sightings identified to species level were of Cuvier's beaked whale; there was one sighting of Sowerby's beaked whale in Block 3.

The Gulf of Biscay, and particularly its south-eastern part, is known from previous surveys in more coastal waters of Spain and from the observations from the ferries crossing from the UK to Spain as an important habitat for beaked whales, especially Cuvier's beaked whale (SCANS-II, 2008; Williams *et al.*, 1999; Cresswell & Walker 2001, 2003; Walker *et al.*, 2004; Smith *et al.* 2007). However, two known important local areas, the Cap Breton and Torrelavega canyons (Vázquez *et al.*, 2004, 2007, 2008; Evans 2008) were not covered in this survey.

6.2.2 Geostatistical models of fin whale distribution

Spatial structure of the data

The spatial models to identify the environmental parameters affecting fin whale distribution were built using raw data, uncorrected for variation in detection probabilities. The uncorrected data correlated well to the corrected data and therefore it was considered unlikely that visibility bias induced spatial heterogeneities in the data that could lead to misidentification of species-environment relationships with uncorrected data. In contrast, artefacts resulting from correction (i.e. overly increasing fin whale local densities in some cases) could have prevented species-environment relationships from being identified when using corrected data.

A positive spatial autocorrelation was found in the first distance class (up to 0.5 decimal degrees), and also up to 2.5 decimal degrees. Therefore, two spatial scales for the distribution of fin whale, one at around 30km and another at around 150 km were evident. The nugget component of the filtering kriging (i.e. the expected non-spatial basal relative density of fin whales in the area) was equal to 0.33 individuals per segment.

Scale dependent modelling of fin whale distribution

The spatial covariates were divided into two groups in order to construct two models, one for each spatial scale. Covariates tested for inclusion in the large scale model were: bathymetry (TOPO), sea surface chlorophyll a (CHLA) and its associated gradient (CHLAg), sea surface temperature (SST), sea surface height anomaly (SSHg), and wind vector modulus (wind strength, WINM). Covariates tested for inclusion in the small scale model were bathymetry gradient (TOPOg), sea surface temperature gradient (SSTg), sea surface height anomaly gradient (SSHg), wind divergence (index of Eckman pumping, WIND) and its associated gradient (WINDg), and wind vector modulus gradient (WINMg).

Covariates retained for the large-scale model were WINM, CHLA, TOPO, SST and SSH. The large-scale model explained 42% of the deviance in the data. Covariates retained for the small-scale model were WINDg, SSHg and SSTg. This small-scale model explained only 8.3% of the deviance in the data.

Model predicted fin whale distribution was generated at small-scale, large-scale and also "globally" from a combination of the expected basal density and from both spatial models (see Appendix III). These models predict that fin whale distribution varies temporally with changes in environmental parameters. Results from the large-scale model are shown in Figure 6, in which three areas are predicted as providing environmental conditions suitable for fin whales. These areas are in the south-western corner of the study area, in the northern, central part and in the western-central part.

At the large-scale, there was a strong positive relationship between fin whale distribution and wind strength (WINM), sea surface temperature (with an optimum in sea surface temperature around 19°C), and extreme values of the sea surface height anomaly. We can hypothesize that strong winds are a good index of surface water mixing that may enhance productivity in the water-column. In terms of sea surface temperature, the 19°C optimum may be related to an optimum for the growth, reproductive success or survival success of their main prey. Extreme SSH values indicate retention areas where resources may be aggregated. At a small scale however, the identified relationships between fin whales and oceanic covariates were less convincing, probably because this species distribution is more likely to be influenced by other biological covariates that are closer to fin whales in the pelagic food web, such as zooplankton or small schooling fishes.

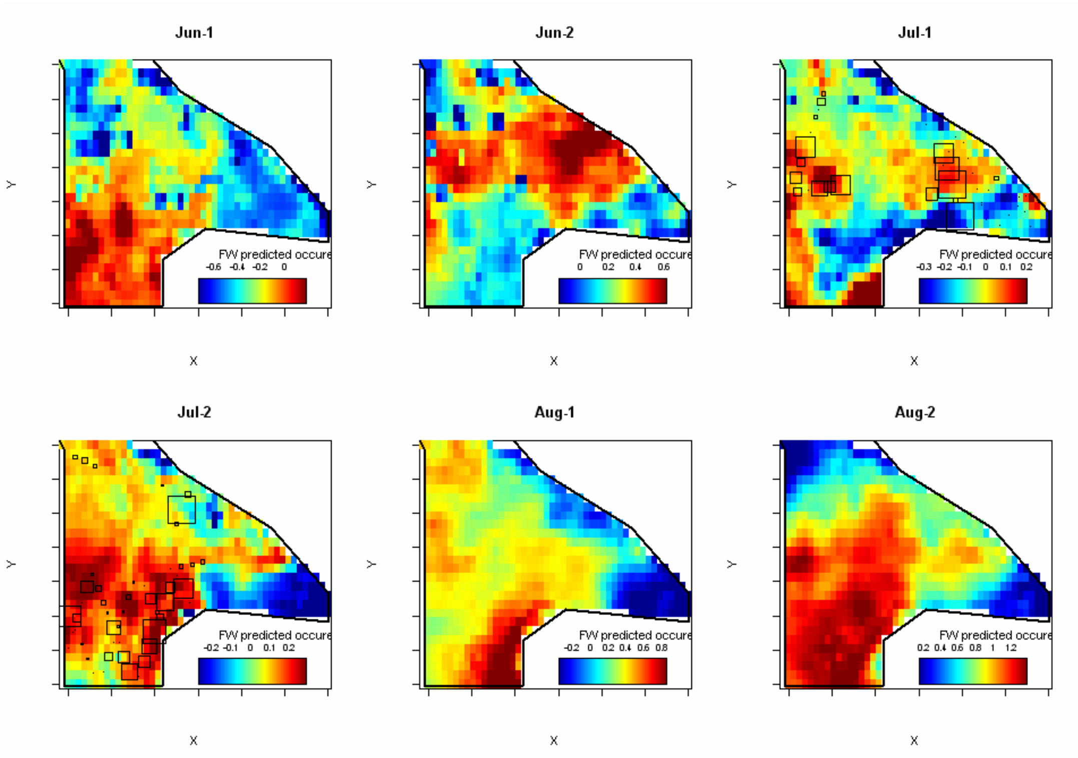


Figure 6: Spatial prediction of fin whale distribution from the large-scale spatial model, for different time periods of 15 days (first and second half of June, July and August). Black squares show the data collected in July.

6.3 Bycatch assessment and safe limits

6.3.1 Assessment

The integrated population dynamics model developed for assessing the state and dynamics of the common dolphin population subjected to bycatch, combined with the available data, did not provide useful information about the main population parameters of interest. The posterior probability distributions for maximum birth rate, carrying capacity and initial population size were wide and uninformative. The model fitted the single estimate of abundance reasonably well, but there were large uncertainties in estimated population size during the study period. As a result of these uninformative posterior distributions the posterior distributions for population growth rate and maximum population growth rate were also uninformative. The model fitted the data on pregnancy rate and age at sexual maturity reasonably well but the estimation of natural survival rates was problematic; it was difficult to obtain convergent estimates for some of the survival parameters with either method. Details are given in Appendix V. Ways in which the assessment could be most improved are described in Section 9.

6.3.2 Management procedures

The difference in the three versions (tunings) of the PBR and CLA management procedures are illustrated in Figure 7. In the first version, PBR1 and CLA1, the population is maintained at 80% of carrying capacity, as defined by the conservation objective. In the second version, PBR2 and CLA2, the population is maintained at a higher percentage of carrying capacity (85-90%) because of the requirement to achieve the conservation objective 95% of the time. In the third version, PBR3 and CLA3, the population is maintained at an even higher percentage of carrying capacity (~95%) because of the additional requirement to achieve the conservation objective under a “worst-case” scenario.

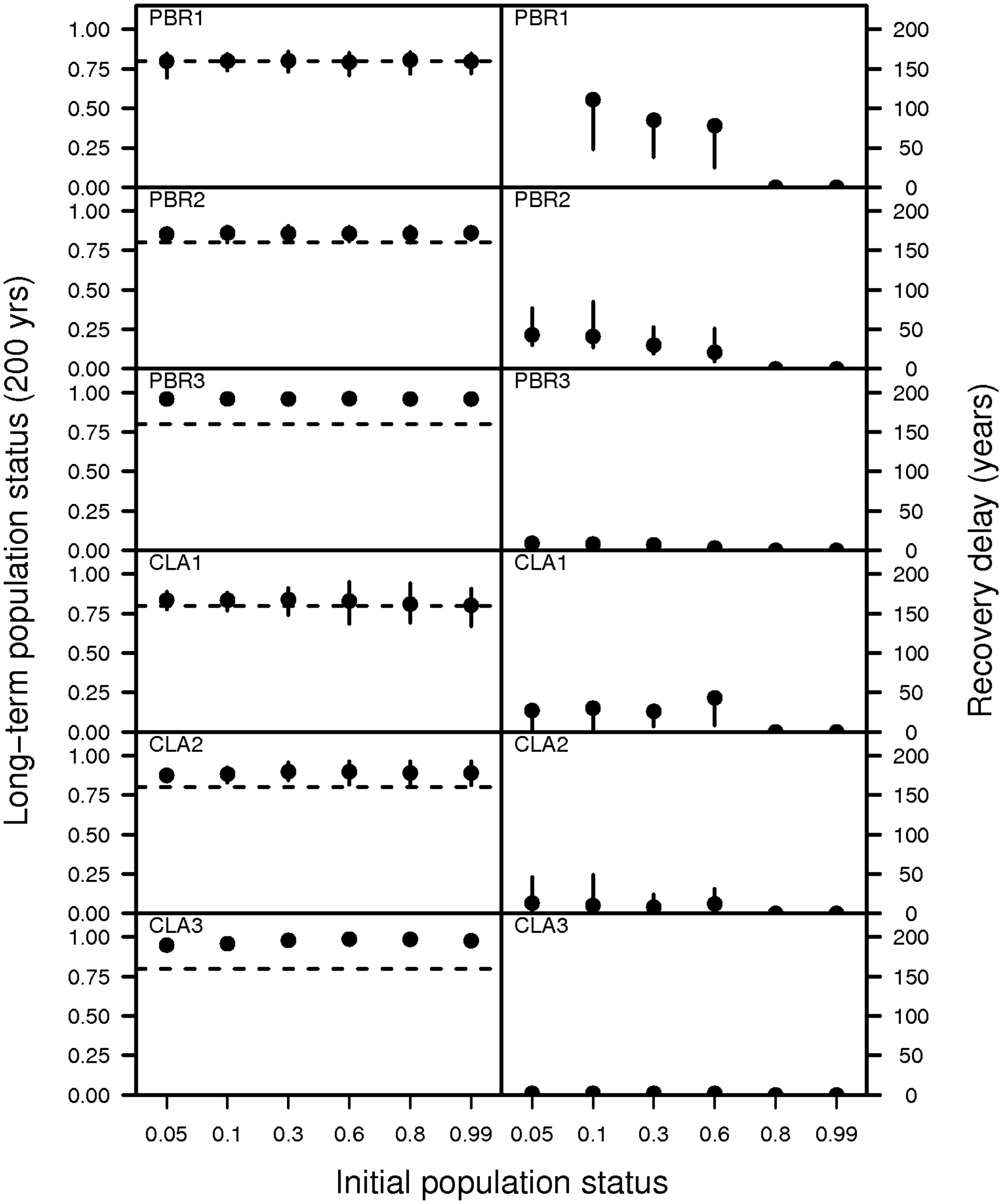


Figure 7. Performance of three tunings of the PBR and CLA management procedures under the baseline scenario with respect to achieving the conservation objective (long-term population status) and recovery delay. Points represent median results from 100 simulations and error bars represent the 90% interval of simulation outcomes. Population status is defined as population size as a proportion of carrying capacity. The horizontal dashed lines indicate the conservation objective: population status = 80%. Recovery delay is defined as the delay in recovery of a population to 80% of carrying capacity relative to a scenario without bycatch.

The delay in recovery of depleted populations to 80% of carrying capacity under the CLA procedure tended to be shorter than under the PBR procedure for a given tuning and initial population status (Figure 7). This was because of the faster short-term recovery of highly depleted populations under the CLA procedure because of its internal protection mechanism.

More details are given in Appendix V.

PBR or CLA management procedure?

The tuned PBR and CLA management procedures developed here are similar but there are some key differences. The only input to the PBR procedure is a single estimate of abundance, whereas the CLA procedure makes use of information on bycatch and on multiple estimates of abundance, if available, to give a more informed assessment of population status. As documented, there are estimates of previous common dolphin bycatch available for several fisheries the Northeast Atlantic and there are estimates of historical abundance of common dolphins in the Northeast Atlantic that could potentially be used. The availability and possible future use of historical data on bycatch and abundance confers an advantage to using the CLA procedure.

Another feature of the CLA procedure is its internal protection mechanism, which enhances the recovery of depleted populations by setting bycatch to zero if the population is estimated to be, in our version, <50% of carrying capacity. The PBR procedure cannot implement such an internal protection mechanism because it relies on a single estimate of population size and cannot, therefore, estimate the level of the population relative to carrying capacity. An advantage of the PBR procedure is its simplicity but this simplicity does not give any advantage in the context of its use within the management framework presented here.

We conclude that the features of the CLA procedure and the advantages that these confer are sufficient for it to be considered as the best management procedure for common dolphins in the Northeast Atlantic.

Which version (tuning) of management procedure?

The three tunings developed allow for three interpretations of the conservation objective adopted from ASCOBANS (to allow populations to recover to and/or maintain 80% of carrying capacity in the long term). The first tuning of the management procedures is a robust mechanism for setting limits to bycatch to achieve the conservation objective of allowing a population to recover to and be maintained *at* 80% of carrying capacity. The second tuning achieves the conservation objective of maintaining a population *at or above* 80% of carrying capacity. Satisfactory performance of the first and second tunings depends on the availability of data series of historical and current estimates of abundance and bycatch that are essentially unbiased. The third tuning is a highly conservative approach to maintaining a population *at or above* 80% of carrying capacity *in a worst case situation* where time series of estimates of abundance and bycatch are considerably biased upwards and downwards, respectively.

If input data are judged to be of sufficient accuracy then either the first or the second tuning is appropriate. If consistent bias of the magnitude tested in either abundance or bycatch were considered plausible, then the third tuning would be more appropriate. We recommend that for application/implementation for any species in a particular region, the judgement of which tuning to use be based on an assessment of the available information. This may include conducting more simulation testing in cases where it is not clear whether or not a procedure is robust to plausible uncertainties. If the third tuning were adopted because of such uncertainty, more information on, in particular, bycatch, would allow a re-evaluation in the future.

6.3.3 Safe bycatch limits for common dolphin

The bycatch limits generated from the operating model and management procedures are given in Table 10.

These bycatch limits are entirely dependent on the stated conservation objective, on the tunings used to achieve it under different interpretations, and on the data that were used to initiate the procedure. These bycatch limits are therefore indicative and cannot immediately be used for management purposes. Before that can happen a series of steps must be taken (see Section 7), initiated by agreeing conservation objective(s) at the policy level.

Table 10. Bycatch limits for common dolphin in the combined SCANS-II/CODA survey area calculated using three versions (tunings) of the PBR and CLA management procedures. Tuning 1: population to recover to and/or be maintained at 80% of carrying capacity. Tuning 2: population to recover to and/or be maintained at or above 80% of carrying capacity. Tuning 3: population to recover to and/or be maintained at or above 80% of carrying capacity in a worst case scenario. The PBR procedure used only the abundance estimate. Two sets of limits are given for the CLA procedure: one based solely on the abundance estimate and one based on the abundance estimate and the time-series of historical bycatch up to mid-2006.

Historical bycatch data used	**PBR tuning**			**CLA tuning**		
	1	2	3	1	2	3
No	1,524	1,092	345	1,909	1,061	280
Yes	-	-	-	1,547	860	227

7 Conclusions

7.1 Conservation benefits

Abundance

For species that live primarily in deeper waters (striped dolphin, pilot whale, fin whale, sperm whale and beaked whales), the abundance estimates presented here represent the first robust information for a wide area of European Atlantic waters off the continental shelf. For species that inhabit shelf waters and also deeper waters (common dolphin, bottlenose dolphin, minke whale), the new estimates provide more comprehensive knowledge of abundance when added to the SCANS-II estimates for the European Atlantic continental shelf. Together, the SCANS-II and CODA projects have generated information that will have an immediate and lasting conservation benefit.

For most species, the estimates are corrected for animals missed on the transect line and any movement in response to the survey ships, and should thus be unbiased. This is particularly important for species that respond to survey ships by approaching them because uncorrected estimates can be biased upwards to a considerable degree, thus decreasing their conservation benefit. Evidence for such attractive movement was found and corrected for, for common and striped dolphins (strong response), pilot and large baleen whales (some response). For species for which insufficient data were available to make these corrections (bottlenose dolphin, minke whale, beaked whale), there is no evidence that they approach survey vessels; indeed minke whales in the North Atlantic are known to avoid them (SCANS-II 2008, Palka & Hammond 2001). The uncorrected estimates for these species are thus likely to be underestimates because they have not been corrected for animals missed on the transect line. The estimate for fin whales is also likely considerably underestimated because it excludes any unidentified large whale sightings, many of which were likely to have been fin whales.

There is clear conservation benefit in having these new results to inform assessments of conservation status and the impact of bycatch and other human activities on cetacean species. They will contribute to national reporting under the EU Habitats Directive to the work of international organisations (OSPAR, ICES, ASCOBANS, IWC) with a responsibility for and/or interest in the conservation of cetaceans.

Distribution and habitat use

The new information on summer distribution and habitat use of cetaceans in offshore waters should also be a benefit to conservation, particularly for species subject to impact from human activities. Common dolphins are subject to bycatch in pelagic trawls. Our results show that common dolphins were concentrated in the southern half of the survey area and densities were lower in the northern half of the survey area. Trawlers operating in the surveyed area in summer are thus more likely to encounter common dolphins in the southern part than in the northern part, which could influence the likelihood of bycatch occurring.

Sperm and beaked whales are deep diving species and are vulnerable to the effects of sound generated by industrial and military seismic and sonar operations. The same may be true for pilot whales. Our results provide new information on areas of high use in summer, which should be of value when considering the impact of these activities. Sperm whales were mainly concentrated in the eastern Bay of Biscay, off Galicia and west of the Hebrides off Scotland. Beaked whales were strongly concentrated in Bay of Biscay and west of the Hebrides. Strategies to avoid deep-diving species being subjected to potentially damaging underwater sound generated by industrial and military operations will benefit from this new information.

Bycatch management

The development of the bycatch management procedures under this project and previously under project SCANS-II has great potential for conservation benefit. The procedures provide a means to calculate safe limits to bycatch that will allow conservation objectives to be met in the long term. They can thus form part of long-term strategies to manage bycatch. However, the benefits are not immediate because there are policy decisions to be made before a particular procedure can be implemented (see Section 7.2).

7.2 Policy implications

Abundance surveys

The SCANS-II and CODA surveys were major exercises that took a lot of organisation and resources. They were designed to obtain estimates of absolute (unbiased) abundance so that human impacts can be put in a population context. Monitoring the status of populations to investigate short-term variation in distribution and abundance does not necessarily require estimates of absolute abundance so it is not necessary to conduct SCANS/CODA type surveys on a frequent basis. However, ground-truthing abundance on an approximately decadal scale is highly desirable. The implication for policy is that another SCANS/CODA survey should be anticipated for 2015, and a project proposal will need to be organised for submission to the European Commission and to EU Member States in 2013.

Bycatch management

A major implication for policy arising from this project relates to bycatch management.

Before a management procedure can be implemented for a particular species in a particular region, the following steps need to be taken:

1. Agreement by policy makers on the exact conservation/management objective(s);
2. Agreement by policy makers to implement the procedure for one or more species in one or more regions;
3. Consideration by scientists of whether or not the available information for each species indicates that there is a need to conduct further simulation testing to examine uncertainties that may not have been fully explored;
4. In particular, if there is evidence for sub-population structure, consideration by scientists of any further simulation testing required and/or identification of any sub-areas that may be considered to contain sub-populations;
5. In addition, if there is evidence of historical bycatch but no data, consideration by scientists of any further simulation testing required including the generation of appropriate data series based on the best available information;
6. Final determination by scientists, based on the results of Steps 3 - 5, of how to implement the procedure for each species/region;
7. Agreement by policy makers to implement the procedure;
8. Generation by scientists of bycatch limits for a specified period (e.g., 5 years);
9. Establishment of a mechanism for feedback of information from bycatch monitoring programmes to inform the next implementation of the procedure when the period for which bycatch limits have been set expires.

Step 1 is clearly best made at the European level. Similarly, Step 2 should ideally be made collectively although most species do not occur in all parts of the European Atlantic. Steps 3 – 6 can be done by the team of scientists that have developed the procedure or by others under their supervision/instruction. The amount of work involved depends on the species. The work accomplished in the SCANS-II and CODA projects for the harbour porpoise and common dolphin means that for these species these steps could be completed fairly rapidly; other species will take longer. Step 7 is another that should be made at the European level; Step 8 can then be taken immediately. Step 9 is very important because removals from a population need to be incorporated when the procedure is re-implemented and this new information (or lack of it) may determine which tuning of the procedure is implemented in the future.

8 Evaluation

8.1 Project management

The project was managed overall by Hammond and Macleod at the University of St Andrews. All preparations for the surveys (ship charter, equipment purchase, construction and transportation, etc) were managed centrally with other participants reporting to St Andrews. Data validation was undertaken and managed in St Andrews.

Management of data analysis was delegated to partners: Macleod - design-based abundance estimation; Cañadas - model-based abundance estimation; Certain - geostatistical modelling; Winship - bycatch assessment and modelling. Analysis of abundance was undertaken by partners on the basis of species. Lead partners were: common and striped dolphin - Cañadas; bottlenose dolphin - Van Canneyt; pilot whale - Santos; sperm and beaked whales - Rogan; baleen whales - Macleod.

Report writing was undertaken by relevant participants and managed through St Andrews.

8.2 Methods, results and cost-effectiveness

Methods

The methods for survey data collection were largely the same as had been used in Project SCANS-II; only relatively minor developments were made. Methods for abundance estimation were also implemented as in SCANS-II but the division of responsibilities for analysis among partner institutes introduced some complications. In particular, minor errors were found in the dataset after analysis had begun requiring reanalysis in some cases. Model-based abundance estimation was undertaken fully in a new beta version 6 of program DISTANCE software by some participants; the need to fix minor but important bugs in the software caused delays in analysis. Geostatistical modelling was developed as part of the project.

Acoustic data collection was developed further over methods used in SCANS-II to acquire data on delphinids and deep-diving whales as well as harbour porpoise. Collaboration with the PAMGUARD project was valuable in this respect. The processing and analysis of much of these data was beyond the scope of the project as specified, but ongoing work will generate valuable results in the future (see Section 9).

Bycatch assessment and modelling methods were developed further over methods used in SCANS-II as part of a specific project objective.

Results

The results for abundance estimation fully met expectations. The weather in July 2007 was worse than average, especially in the north of the survey area, but sufficient data were collected to estimate abundance of all the main species encountered in the area, in most cases corrected for animals missed on the transect line and responsive movement. The density surface modelling analysis exceeded expectations and provided valuable information on summer distribution and habitat use for many species.

Acoustic results also met expectations, with the exception that no results were possible from the northern survey block because the ship chartered, *Mars Chaser*, had been modified since it was used on SCANS-II and was too noisy for useful acoustic data collection. This was frustrating because analysis of the visual data indicated high density areas for sperm and beaked whales in this area.

For the bycatch assessment, the results were uninformative and, therefore, disappointing. Ways of improve the assessment are suggested in Section 9. However, the results on calculation of safe bycatch limits for common dolphin fully met expectations.

Cost-effectiveness

The project was undertaken for around 600K GBP and a contribution in kind of around 1.6M Euro, most of which was the value of the French survey ships. Large-scale cetacean surveys in offshore waters are expensive and, if conducted approximately every 10 years, the realised results and their value for enabling EU Member States to discharge responsibilities under the Habitats Directive make this project good value for money.

8.3 Comparison against project objectives

The specific objectives:

1. To map summer distribution of common dolphin, bottlenose dolphin, fin whale, deep diving whales and other cetaceans in offshore waters of the European Atlantic;
2. To estimate abundance of common dolphin, bottlenose dolphin, fin whale, sperm whale and other species, as data allow, in offshore waters of the European Atlantic;
3. To develop further the bycatch management framework developed under project SCANS-II to assess the impact of bycatch on and calculate safe bycatch limits for common dolphins.
4. To investigate habitat use and preferences of common dolphin and other species, as data allowed, in offshore waters of the European Atlantic;

were fully met.

9 Recommendations for further work

Abundance

For species occurring on and off the shelf, combining the data from SCANS-II and CODA to obtain an overall model-based abundance estimate for the whole area will be a valuable exercise. This is particularly true for common dolphin but also possibly for bottlenose dolphin and minke whale.

SCANS/CODA type absolute abundance surveys are essential for providing input to assessments of the impact of human activities. There is general agreement that the frequency of such surveys should be between 5 and 10 years. If logistics allow, a combined survey of shelf and offshore waters is desirable. Another survey should therefore be anticipated for 2015 at the latest.

Acoustics

While sperm whale and harbour porpoise click trains are easily identified in the acoustic data, separating the clicks of other small and medium sized odontocetes is not so straightforward. As part of a separate project at SMRU, a click classification system for multiple odontocete species has recently been completed and this new method is being applied to the CODA acoustic data. These new methods will allow the isolation of common dolphin, and possibly also beaked whale click trains. We will therefore be able to produce distribution maps for these species and compare with visual data. However, absolute abundance estimates from acoustic data for all species apart from sperm whales are currently not feasible.

Bycatch Assessment

The assessment of the impact of bycatch on common dolphin could be most improved by including one or more historical estimates of abundance and more data on the age structure of natural mortality. Historical estimates of abundance should improve the estimation of population growth rate during the study period, but it is unlikely that there would be sufficient data to estimate maximum population growth rate or carrying capacity. More data on the age structure of natural mortality (obtained from post-mortem examination and analysis of stranded and bycaught individuals, for example) should improve the estimation of natural survival rates and may allow the estimation of age-specific vulnerabilities to bycatch. A different model for age-specific natural survival may also help improve parameter estimation.

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11 List of Appendices

Appendix I: Design-based estimates of cetacean abundance in offshore European Atlantic waters.

K Macleod, ML Burt, A Cañadas, E Rogan, B Santos, A Uriarte, O Van Canneyt, JA Vázquez & PS Hammond.

Appendix II: Model-based estimates of cetacean abundance in offshore European Atlantic waters.

A Cañadas, ML Burt, K Macleod, E Rogan, B Santos, JA Vázquez & PS Hammond.

Appendix III: Scale-dependent spatial modelling of the distribution of a marine predator: fin whale distribution in the Bay of Biscay.

G. Certain, V Ridoux, O Van Canneyt.

Appendix IV: Abundance of sperm whales (Physeter macrocephalus) estimated from acoustic data for Blocks 2, 3 and 4 (French and Spanish sectors).

RJ Swift, D Gillespie, JA Vázquez, K Macleod, & PS Hammond.

Appendix V: Management framework to assess the impact of bycatch and recommend safe bycatch limits for common dolphin and other small cetaceans.

A Winship & PS Hammond.