Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys

SCANS-III

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INTRODUCTION

A series of large scale surveys for cetaceans in European Atlantic waters was initiated in 1994 in the North Sea and adjacent waters (SCANS 1995; Hammond et al. 2002) and continued in 2005 in all shelf waters (SCANS-II 2008; Hammond et al. 2013) and 2007 in offshore waters (CODA 2009). In the mid-1990s, the primary need for a large-scale survey was to obtain the first comprehensive estimates of abundance of harbour porpoise in the North Sea and adjacent waters so that estimates of bycatch could be placed in a population context. The motivation for ongoing surveys is to provide the information on distribution and abundance of cetaceans required by Member States to report on Favourable Conservation Status under the Habitats Directive and on Good Environmental Status (GES) under the Marine Strategy Framework Directive (MSFD).

The frequency of these surveys was intended to be approximately decadal and a new survey was thus scheduled for the mid-2010s. The previous SCANS projects had been supported by the European LIFE Nature programme but a proposal for a SCANS-III project with a survey to take place in 2015 was rejected without review. Member States nevertheless remained committed to the project and sufficient resources were secured to conduct the SCANS-III survey in summer 2016. The supporting countries were: Denmark, France, Germany, the Netherlands, Norway, Portugal, Spain, Sweden and the UK. An independent project supported by Ireland, ObSERVE, is conducting surveys in Irish waters during the period 2015-2017.

A primary aim of SCANS-III was to provide robust large-scale estimates of cetacean abundance to inform the upcoming MSFD assessment of GES in European Atlantic waters in 2018. Some surveys generating robust estimates of abundance have been conducted since the SCANS-II/CODA in 2005/2007, as detailed in WGMME (2016), but these do not provide comprehensive estimates of abundance for multiple species over the whole of European Atlantic waters.

This report summarises design-based estimates of abundance for those cetacean species for which sufficient data were obtained during SCANS-III: harbour porpoise, bottlenose dolphin, Risso's dolphin, white-beaked dolphin, white-sided dolphin, common dolphin, striped dolphin, pilot whale, all beaked whale species combined, sperm whale, minke whale and fin whale.

METHODS

Study area and survey design

The initial objective of SCANS-III was to survey all European Atlantic waters from the Strait of Gibraltar in the south to 62°N in the north and extending west to the 200 nm limits of all EU Member States. The final surveyed area excluded offshore waters of Portugal and also excluded waters to the south and west of Ireland which were surveyed by the Irish ObSERVE project. Coastal waters of Norway north to Vestfjorden were included (Figure 1).

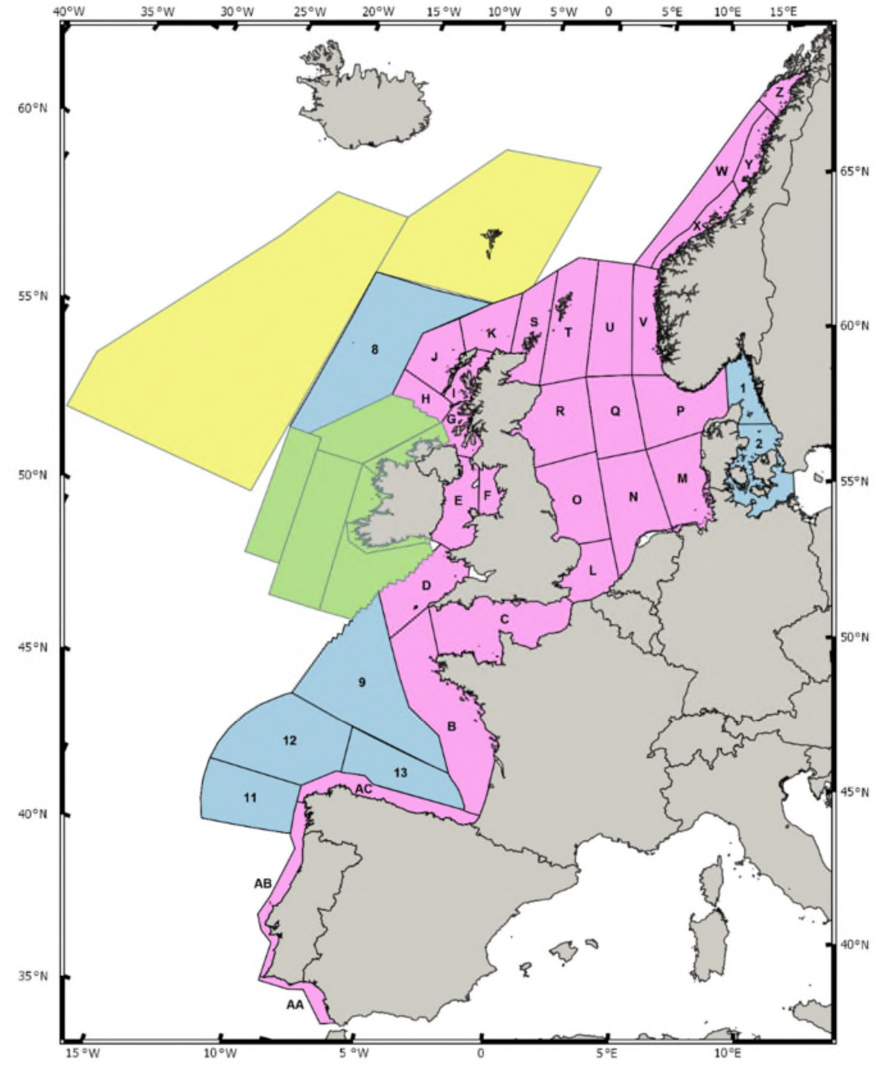


Figure 1. Area covered by SCANS-III and adjacent surveys. SCANS-III: pink lettered blocks were surveyed by air; blue numbered blocks were surveyed by ship. Blocks coloured green to the south, west and north of Ireland were surveyed by the Irish ObSERVE project. Blocks coloured yellow were surveyed by the Faroe Islands as part of the North Atlantic Sightings Survey in 2015.

Shelf waters were surveyed by seven aircraft (Fig 1, blocks A-Z), except the Skagerrak, Kattegat and Belt Seas, which were surveyed by the ship R/V Aurora (Fig 1, blocks 1 and 2). During the survey, the weather during the time available to be allocated to block 1 was poor, so little ship survey effort was possible. As a result, this block was also surveyed by air (block P1) with design and coverage equivalent to the other aerial survey blocks – see below).

Offshore waters west of Scotland and in the central Bay of Biscay were surveyed by the ship M/V Skoven (Fig 1, blocks 8 and 9). Offshore waters to the north and west of Spain were surveyed by the ship B/O Angeles Alvariño (Figure 1, blocks 11-13). The size and boundaries of survey blocks were determined primarily by logistics but also to encompass designated/proposed protected areas in some cases. The relatively small size of the aerial survey blocks compared to the size of the ship survey blocks in the SCANS and SCANS-II surveys improves, to some extent, the efficiency of the survey for abundance estimation for species with a patchy distribution within the study area, as discussed by MacLeod (2014) and Hammond et al. (2014).

Surveys within blocks were designed to provide equal coverage probability, using the equal spaced zig-zag option in the survey design engine in software DISTANCE (Thomas et al. 2010). This ensures that each point within a block has the same probability of being surveyed, allowing unbiased abundance estimation by extrapolating estimated sample density to the entire block.

For the aerial surveys, overall coverage probability was determined by available resources (total flying hours). Searching effort was distributed equally to all blocks (approximately in the case of blocks AA, AB and AC), with the exception of blocks W and Z in Norwegian waters which were assigned approximately half and double that probability, respectively, because of expected differences in relative density. Within each aerial block, three sets of random transect lines were generated with the minimal aim that at least one set would be covered in each block. If weather permitted, additional sets of transect lines would be covered; which blocks would receive additional coverage depended on resources remaining, weather and national priorities. Additional small survey blocks were created in two Norwegian fjords (Bognafjord near Stavanger (SVG) and Trondheim Fjord (TRD)) as a trial to survey in these challenging areas.

For the ship surveys, overall coverage probability for each ship was determined by available resources (survey days), accounting for some time expected to be unavailable for surveying due to poor weather. Some of the blocks were sub-divided to improve survey design efficiency. Block 2 was sub-divided into five sub-blocks to minimize time wasted off effort while transiting around islands in inner Danish waters. Each sub-block was allocated equal coverage probability so they could be combined for analysis. The triangular NE corner of block 8 and SE corner of block 9 were treated separately for survey design purposes but with the same coverage probability as the rest of the block so they could be combined for analysis. The SW corner of block 9, a triangular area outside the 200 nm limits of France and Spain, was originally excluded from survey design but was added in the field with the same coverage probability as the rest of the block.

Data collection

Aerial survey

Each of the seven aircraft accommodated three scientific crew members in addition to the pilot. One aircraft had an additional three scientific crew working as an independent team. Target altitude was 600 feet (183 m) and target speed was 90 knots (167 km.h^{-1}). Two observers sat at bubble windows on the left and right sides of the aircraft, and the third team member acted as navigator and data recorder for environmental and sightings data, entering data into a laptop computer running dedicated data collection software. Sighting conditions were classified subjectively as “good”, “moderate” or “poor” based primarily on sea conditions, water turbidity and glare. When detected groups came abeam, data were recorded on time, declination angle to the detected animal or group (from which perpendicular distance was calculated), cue, presence of calves, behaviour, species composition and group size. Further details of field protocol are given in Gilles et al. (2009).

To collect data from which correction could be made for animals missed on the transect line, the circle-back or “racetrack” method of Hiby (1999) was used. In this approach, on detecting a group of animals, the aircraft circles back to resurvey a defined segment of transect. The same method was used in SCANS-II (Hammond et al. 2013) and an equivalent method developed for tandem aircraft (Hiby & Lovell 1998) was used in SCANS (Hammond et al. 2002). Further details of this method are given in Scheidat et al. (2008).

In previous surveys, the circle-back method has only been used for harbour porpoise. In SCANS-III, we also implemented this method for minke whale and for delphinids (bottlenose, common, striped, white-beaked, white-sided, and Risso’s dolphin) with the aim of correcting for animals missed on the transect line for these species.

Ship survey

The method used on ships was a double platform line transect survey with two independent teams of observers on each ship to generate data that would allow abundance estimates to be corrected for animals missed on the transect line and also potentially for the effects of movement of animals in response to the ship (Laake & Borchers 2004). This same approach was also used in SCANS, SCANS-II and CODA (Hammond et al., 2002; CODA 2009; Hammond et al. 2013).

Each survey ship accommodated eight observers working in two teams. Target survey speed was 10 knots (18.5 km.h^{-1}) on all ships but was slower when surveying against heavy swell.

Two observers on one platform, known as Primary, searched with naked eye a sector from 90° (abeam) starboard to 10° port or 90° port to 10° starboard out to 500 m distance. Two observers on the other, higher platform, known as Tracker, searched from 500m to the horizon with high-power (15x80) and 7x50 binoculars. Tracker observers tracked detected animals until they had passed abeam of the vessel. Observers not searching acted as duplicate identifier, data recorder or rested. The duplicate identifier assessed whether or not groups of animals detected by Tracker were re-sighted by Primary. Duplicates were classified as Definite (D: at least 90% likely), Probable (P: between 50% and 90% likely), or Remote (R: less than 50% likely). The data recorder recorded all sightings, effort and environmental data into a laptop computer running the LOGGER software, modified specifically for SCANS surveys (Gillespie et al. 2010). Environmental data included sea conditions measured on the Beaufort scale, swell height and direction, glare, visibility and sightability, a subjective measure of conditions for detecting small cetaceans.

Data on sighting angle and distance for calculation of perpendicular distance were collected automatically, where possible, as well as manually (Gillespie et al. 2010). Sighting angles were measured from an angle board and on Tracker also using a small camera positioned on the underside of the binoculars that took snapshots of lines on the deck parallel to the direction of the ship (Leaper and Gordon 2001). Distance to detected groups was measured on Primary using purpose-designed and individually calibrated measuring sticks and on Tracker as a binocular reticule reading and via a video-range technique (Gordon 2001). Angles and distances were calculated from captured video frames using purpose-written software. Additional data collected from each detected group of animals included: cue, species composition, group size, swimming direction and behaviour. Data validation software was used to check all data at the end of each day, if possible.

Estimation of abundance

Aerial survey

Only survey effort collected under "good" and "moderate" conditions were used in analysis. Using the method of Hiby and Lovell (1998), the effective strip width (ESW), including g(0), was estimated in "good" and "moderate" sighting conditions ($\hat{\mu}_g$ and $\hat{\mu}_m$ respectively). This analysis is described in detail in Hiby & Gilles (2016).

For each species, abundance of animals in stratum *v* was estimated as:

$$\hat{N}_v = \frac{A_v}{L_v}\left(\frac{n_{gsv}}{\hat{\mu}_g} + \frac{n_{msv}}{\hat{\mu}_m}\right)\bar{s}_v \qquad \text{(Equation 1)}$$

where A_v is the area of the stratum, L_v is the length of transect line covered on-effort in good or moderate conditions, n_{gsv} is the number of sightings of groups that occurred in good conditions in the stratum, n_{msv} is the number of sightings of groups that occurred in moderate conditions in the stratum and $\bar{s}_v$ is the mean observed group size in the stratum. Exploratory plots indicated no dependence of group size on perpendicular distance, nor was group size found to be a significant explanatory variable for detection probability.

Group abundance by stratum was estimated by $\hat{N}_{v(group)} = \hat{N}_v / \bar{s}_v$. Total animal and group abundances were estimated by $\hat{N} = \sum_v \hat{N}_v$ and $\hat{N}_{(group)} = \sum_v \hat{N}_{v(group)}$, respectively. Densities were estimated by dividing the abundance estimates by the area of the associated stratum. Mean group size across strata was estimated by $\hat{E}[s] = \hat{N} / \hat{N}_{(group)}$.

Coefficients of variation (CVs) and 95% confidence intervals (CIs) were estimated by bootstrapping within blocks. A parametric bootstrap was used to generate estimates of ESW and these were combined with encounter rates obtained from a nonparametric transect-based bootstrap procedure. The parametric bootstrap procedure was based on the assumption that the ESW estimates in good and moderate conditions were lognormally distributed random variables. Therefore, for each bootstrap pseudo-sample of transect lines, a bivariate lognormal random variable was generated from a distribution with mean and variance-covariance matrix equal to those estimated during the circle-back ("racetrack") analysis (see Hiby & Gilles 2016). 95% CIs were calculated using the percentile method.

Abundance of species (or species groupings) for which the circle-back procedure was not performed was estimated using conventional line transect methods that assume certain detection on the transect line. Estimates for these species are thus underestimated to an unknown degree.

Analysis was conducted in R 3.2.2 x64 (R Core Team 2015) using the package 'Distance' (Miller 2015).

Ship survey

Analysis of the shipboard data followed the double-platform line transect methodology used in the SCANS-II survey (Borchers et al., 1998; Laake & Borchers 2004; Hammond et al., 2002; Hammond et al., 2013) using the mrds analysis engine in software DISTANCE (Thomas et al., 2010). To estimate the probability of detection on the transect line g(0), sightings made from the Tracker platform served as a set of binary trials in which success corresponded to detection by observers on the Primary platform. The probability that a group of animals, at given perpendicular distance x and covariates $\mathbf{z}$, was detected from Primary is denoted $p_1(x,\boldsymbol{z})$ and modelled as a logistic function (see equation 9 in Borchers et al. 1998).

The most robust mrds model for estimating detection probability from double-platform data is the partial (or trackline) independence model, in which it is assumed that Tracker and Primary detection probabilities need only be independent on the transect line (Borchers et al. 2006; Laake & Borchers 2004). This model uses the Primary data to estimate detection probability assuming g(0)= 1, and also the Tracker-Primary mark-recapture data to estimate the conditional detection function to correct detection probability for g(0) < 1 (as described above). This model was used as a default in analysis.

However, if there is undetected movement in response to the survey vessel, it is necessary to assume that detection probabilities on Tracker and Primary are independent at all perpendicular distances and to use the full independence model (Borchers et al. 2006; Laake & Borchers 2004). This model only uses the Tracker-Primary mark-recapture data to estimate the conditional detection function and is less robust because it is sensitive to non-independence of detection probabilities between Tracker and Primary at all perpendicular distances (Borchers et al. 2006). Such non-independence typically results in a positive correlation in detection probabilities and causes a negative bias in estimates of abundance. Nevertheless, this model should be used in the presence of responsive movement prior to detection by Primary.

Attraction of common dolphins to survey ships has previously been shown to cause bias if the full independence model is not used (Cañadas et al. 2009; Hammond et al. 2013). To determine whether the full independence model needed to be used for any species, the extent of any responsive movement was explored using data on swimming direction at first sighting using the method of Palka & Hammond (2001) and by comparing perpendicular distances recorded by Tracker and Primary for duplicate sightings.

Explanatory covariates to model detection probability, in addition to perpendicular distance, included sea conditions as indicated by Beaufort, glare, swell, a sightability index, visibility, group size and vessel. Model selection was based primarily on Akaike's Information Criterion (AIC) but by inspection of the QQ plot and the Kolmogorov-Smirnov and Cramer-von Mises goodness of fit tests.

Perpendicular distance data for modelling detection probability were by default truncated at the largest distance recorded by observers on Primary but, for each species, truncation at shorter distances was explored to see if this improved estimation of detection probability. The choice of truncation distance was determined by examining goodness of fit statistics (Kolmogorov-Smirnoff and Cramer-von Mises tests), while minimising the amount of data lost. For harbour porpoise, data obtained while surveying in sea conditions of Beaufort 2 or less were used; for other species data from sea conditions of Beaufort 4 or less were used. Duplicates classified as D and P were considered to be duplicates; those classified as R were not.

The abundance of groups was estimated using a Horvitz-Thompson-like estimator:

$$\hat{N} = \sum_{j=1}^{n_1} \frac{1}{\int_0^W p_1(x, z_j \mid \hat{\theta}) \frac{1}{W} dx} \qquad \text{(Equation 2)}$$

where n_1 is number of detections made from Primary, W is perpendicular truncation distance and $\hat{\theta}$ are the estimated parameters of the fitted detection function.

The abundance of individuals was estimated by replacing the numerator in the equation for estimating abundance of groups with s_{1j}, the group size of the j^{th} group recorded from Primary. However, group sizes recorded on Tracker are typically larger and likely to be more accurate than those recorded on Primary because they were observed through binoculars and typically multiple times. Consequently, estimates of the abundance of individuals were corrected by the ratio of the sum of Tracker group sizes to the sum of Primary group sizes calculated from duplicate observations for each block or combination of blocks, depending on sample size. If the group size correction was estimated as < 1, it was set to 1.

Estimates of mean group size were obtained by dividing abundance of individuals by abundance of groups.

Variances were estimated empirically; encounter rate variance was estimated using the method of Innes et al. (2002).

Where there were insufficient duplicate sightings to support double-platform methods, conventional line transect methods (assuming certain detection on the transect line) were used to obtain the detection function.

Presentation of abundance estimates

Estimates of abundance for each species are presented for each survey block and for the total survey area. In addition, for harbour porpoise, estimates are presented for ICES Assessment Units (AUs) (ICES 2014), see Fig 2, and also for the Norwegian coastal area north of 62°N.

For these estimates, the SCANS-III blocks were matched as closely as possible to the defined AUs, as follows:

- Kattegat and Belt Seas: ship block 2;
- North Sea: aerial blocks L-V, including P1, plus SVG, plus the eastern part of block C;
- West Scotland: aerial blocks G-K;
- Celtic and Irish Seas: aerial blocks B and D-F plus the western half of C;
- Iberian Peninsula: aerial blocks AA, AB and AC;
- Norwegian coast north of 62°N: aerial survey blocks W-Z and TRD.

For these combinations of aerial survey blocks, the subsets of the data were bootstrapped as described above to obtain appropriate estimates of variance.

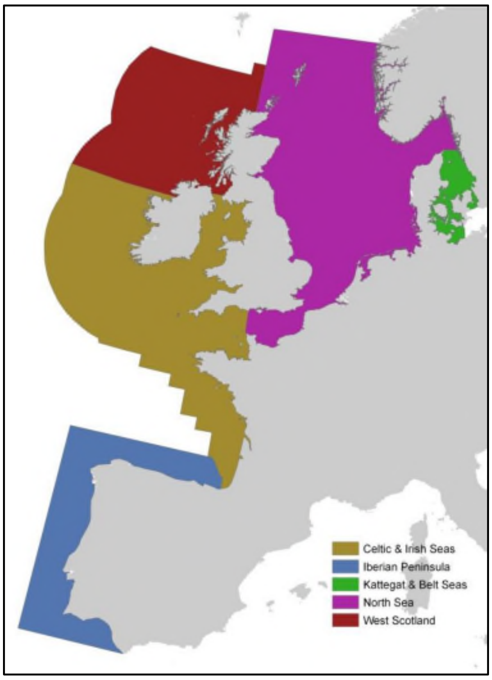


Figure 2. ICES Assessment Units for harbour porpoise (ICES 2014).

For the bottlenose dolphin, ten AUs have been defined for resident or semi-resident coastal/inshore populations, and a single offshore "oceanic area" AU has been defined to cover all waters not covered by the coastal/inshore AUs. It is not appropriate (nor possible) to separate out the coastal/inshore populations in the SCANS-III surveys so the total estimate represents these and the "oceanic area" combined.

For the minke whale, white-beaked dolphin and common dolphin, a single AU covering all European Atlantic waters has been defined. For these, and all other species, the total abundance estimates represent the AU. A very small proportion of the total estimates for minke whale and white-beaked dolphin were in Norwegian coastal waters north of 62°N (2.2% and less than 1%, respectively).

RESULTS

Searching effort and sightings

Seven aircraft surveyed shelf waters of the European Atlantic, including Norwegian coastal waters, between 27 June and 31 July 2016. Table 1 shows the amount of search effort on transect in each of the survey blocks.

Three ships surveyed waters beyond the continental shelf and inner Danish waters. Blocks 1 and 2 were surveyed 5-24 July, block 8 was surveyed 29 June - 14 July, block 9 was surveyed 19 July - 4 August and blocks 11-13 were surveyed 4-28 July. Table 2 shows the amount of search effort on transect in each of the survey blocks. Figure 3 shows the searching effort achieved under all conditions.

Tables 3 and 4 show the total number of sightings of groups of the most commonly detected species on the aerial survey and ship survey, respectively. Figure 4 shows the distribution of sightings of the most commonly detected species.

Table 1. Area and searching effort (in “moderate” or “good” conditions, used in analysis) for each aerial survey block. Primary search effort data were used in analysis to estimate encounter rate and group size (see equation 1). Trailing search effort occurred during circle-back procedures and was used to estimate ESW, including g(0). Block P1 is the same as ship block 1 (Table 2). Blocks SVG and TRD covered parts of Norwegian fjords Bognafjord (near Stavanger) and Trondheim Fjord, respectively. Block SVG is included in the ICES North Sea Assessment Unit (Table 32).

Block	**Region**	**Surface area (km^2)**	**Primary search effort (km)**	**Trailing search effort (km)**
AA	Iberian peninsula	12,015	588.9	5.4
AB	Iberian peninsula	26,668	1,210.1	23.4
AC	Iberian peninsula	35,180	1,393.1	13.0
B	Celtic/Irish Seas	118,471	7,982.9	78.1
C	Celtic/Irish Seas & North Sea	81,297	2,834.2	37.9
D	Celtic/Irish Seas	48,590	1,707.5	16.8
E	Celtic/Irish Seas	34,870	2,252.7	22.5
F	Celtic/Irish Seas	12,322	619.8	4.1
G	West Scotland	15,122	958.0	12.9
H	West Scotland	18,634	812.9	17.0
I	West Scotland	13,979	636.5	16.3
J	West Scotland	35,099	704.4	6.4
K	West Scotland	32,505	2,146.7	17.3
L	North Sea	31,404	1,949.3	20.0
M	North Sea	56,469	1,749.9	57.3
N	North Sea	69,386	2,264.9	56.8
O	North Sea	60,198	3,242.8	62.7
P	North Sea	63,655	2,034.1	33.5
P1	North Sea	23,557	844.4	0.0
Q	North Sea	49,746	1,856.5	75.0
R	North Sea	64,464	2,178.7	40.5
S	North Sea	40,383	1,370.9	15.1
T	North Sea	65,417	2,259.1	24.0
U	North Sea	60,046	1,741.8	15.3
V	North Sea	38,306	1,129.8	11.7
W	Norway	49,778	931.0	3.7
X	Norway	19,496	1,039.4	22.7
Y	Norway	18,779	713.3	7.0
Z	Norway	11,228	1,764.4	29.2
SVG	Norway (North Sea)	714	152.3	0.0
TRD	Norway	966	179.7	2.5
Total		**1,208,744**	**51,568.3**	**748.0**

Table 2. Area and searching effort for each ship survey block. For estimation of harbour porpoise abundance (in blocks 1 and 2), search effort was limited to Beaufort 0-2. For estimation of abundance for all other species (in blocks 8-13), search effort was limited to Beaufort 0-4. Block 1 is the same as aerial block P1 (Table 1).

Block	**Region**	**Surface area (km^2)**	**Search effort Beaufort 0-4 (km)**	**Search effort Beaufort 0-2 (km)**
1	Skagerrak/Kattegat	23,451		215.7
2	Kattegat & inner Danish waters	40,707		1,027.7
8	Atlantic - west of Scotland	159,669	2,084.7	
9	Bay of Biscay	144,352	2,279.9	
11	Atlantic - west of Spain	68,759	981.0	
12	Atlantic - west of Spain / Bay of Biscay	111,115	1,629.7	
13	Bay of Biscay	59,340	1,605.5	

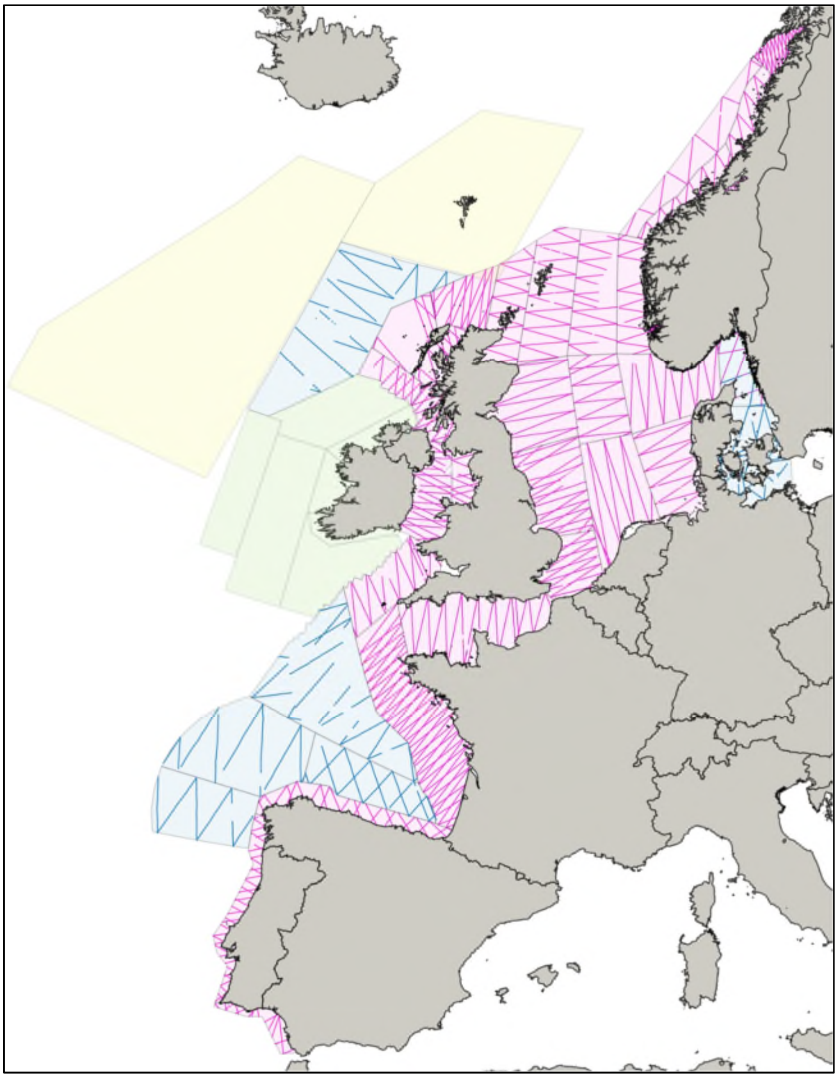


Figure 3. Total search effort achieved under all conditions in aerial (pink) and ship (blue) survey blocks.

Table 3. Total number of sightings of the most commonly detected species (or species groupings) from the aerial survey recorded in "good" and "moderate" sighting conditions. Sightings on trailing search effort were recorded on circle-back procedures and were used only to estimate ESW, including g(0).

Species	**Sightings on primary search effort**	**Sightings on trailing search effort**
Harbour porpoise	1,602	67
Bottlenose dolphin	59	11
Risso's dolphin	16	1
White-beaked dolphin	108	10
White-sided dolphin	7	1
Unid white-beaked or white-sided dolphin	11	0
Common dolphin	502	17
Striped dolphin	20	0
Unid common or striped dolphin	248	9
Unidentified dolphin	196	7
Pilot whale	79	0
Beaked whales (all species)	27	0
Minke whale	73	8

Table 4. Number of sightings of the most commonly detected species from the ship survey (harbour porpoise Beaufort 0-2; all other species Beaufort 0-4). Tracker sightings and duplicates were used in mark-recapture distance sampling analysis only to estimate detection probability and to correct estimates of mean group size. Duplicates shown are Definite and Probable duplicates, as used in analysis.

Species	**Total sightings**	**Primary sightings**	**Tracker sightings**	**Duplicates**
Harbour porpoise	343	167	217	41
Bottlenose dolphin	27	15	18	6
Risso's dolphin	5	4	3	2
White-sided dolphin	16	10	11	5
Unid white-beaked or white-sided dolphin	4	2	2	0
Common dolphin	106	82	52	28
Striped dolphin	104	56	69	21
Unidentified common or striped dolphin	126	44	96	14
Unidentified dolphin	53	17	37	1
Pilot whale	58	37	41	20
Beaked whales (all species)	65	35	38	8
Sperm whale	40	16	25	1
Minke whale	9	7	3	1
Fin whale (blocks 8 & 9)	276	205	133	62
Fin whale (blocks 11, 12 & 13)	708	368	486	146

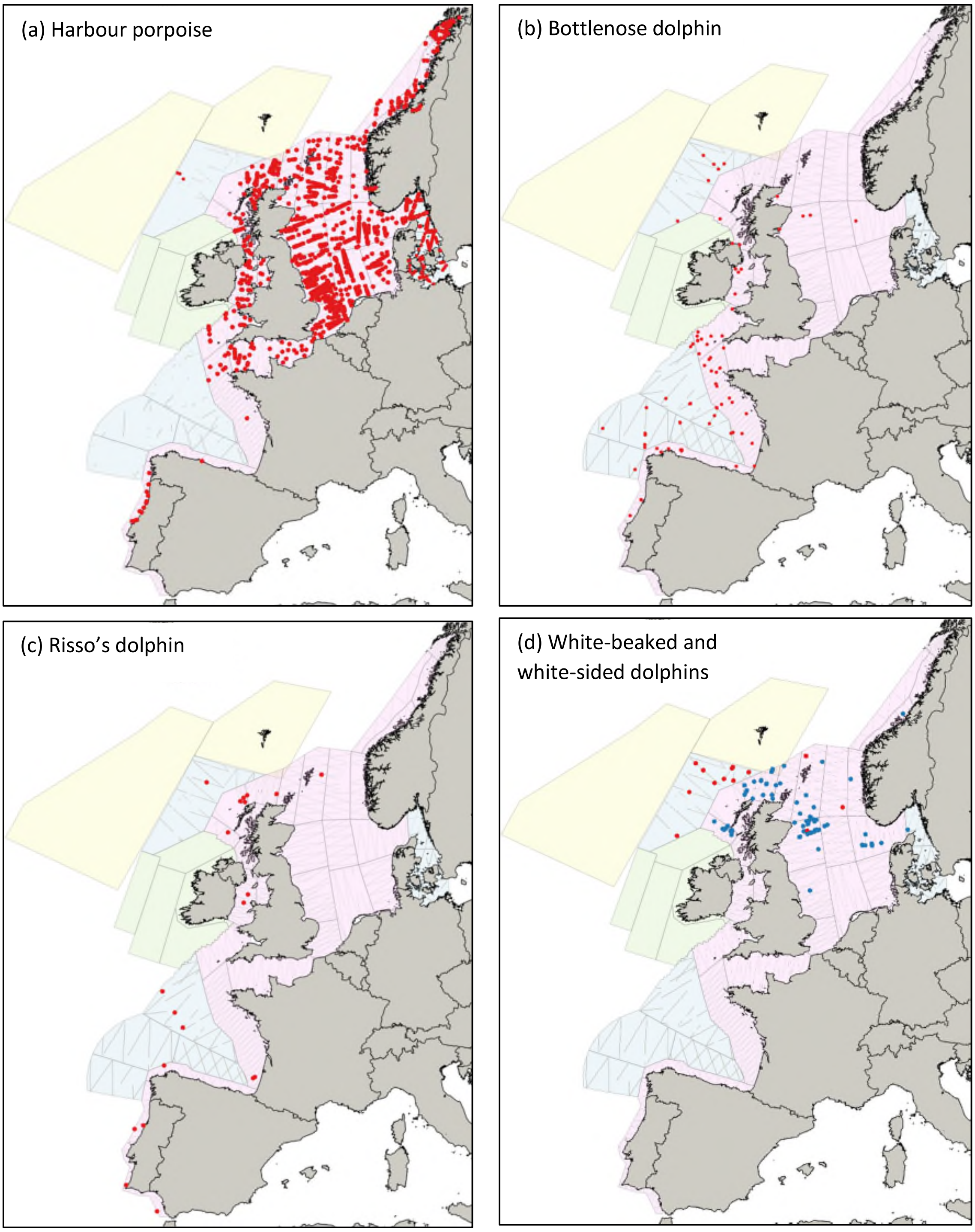
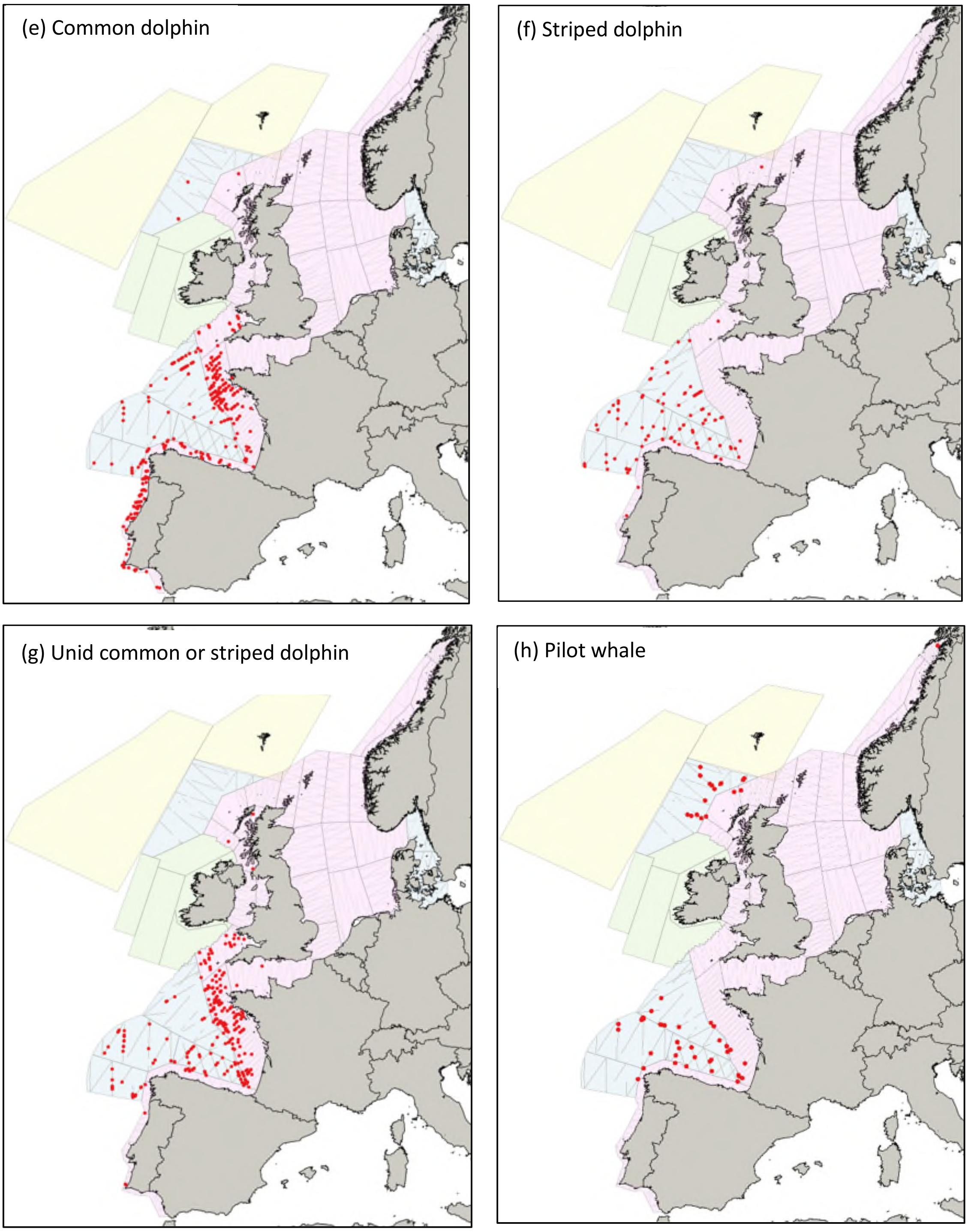


Figure 4. Distribution of sightings used in analysis of the most commonly detected species. Underlying effort is also that used in analysis: aerial survey - good and moderate conditions; ship survey - Beaufort 0-2 for harbour porpoise, Beaufort 0-4 for all other species. (a) harbour porpoise; (b) bottlenose dolphin; (c) Risso's dolphin; (d) white-beaked (blue dot) and white-sided (red dot) dolphins. Continued on following pages.



(e) Common dolphin

(f) Striped dolphin

(g) Unid common or striped dolphin

(h) Pilot whale

Figure 4 (continued). Distribution of sightings used in analysis of the most commonly detected species. Underlying effort is also that used in analysis: aerial survey - good and moderate conditions; ship survey - Beaufort 0-4. (e) common dolphin; (f) striped dolphin; (g) unidentified common or striped dolphin; (h) pilot whale.

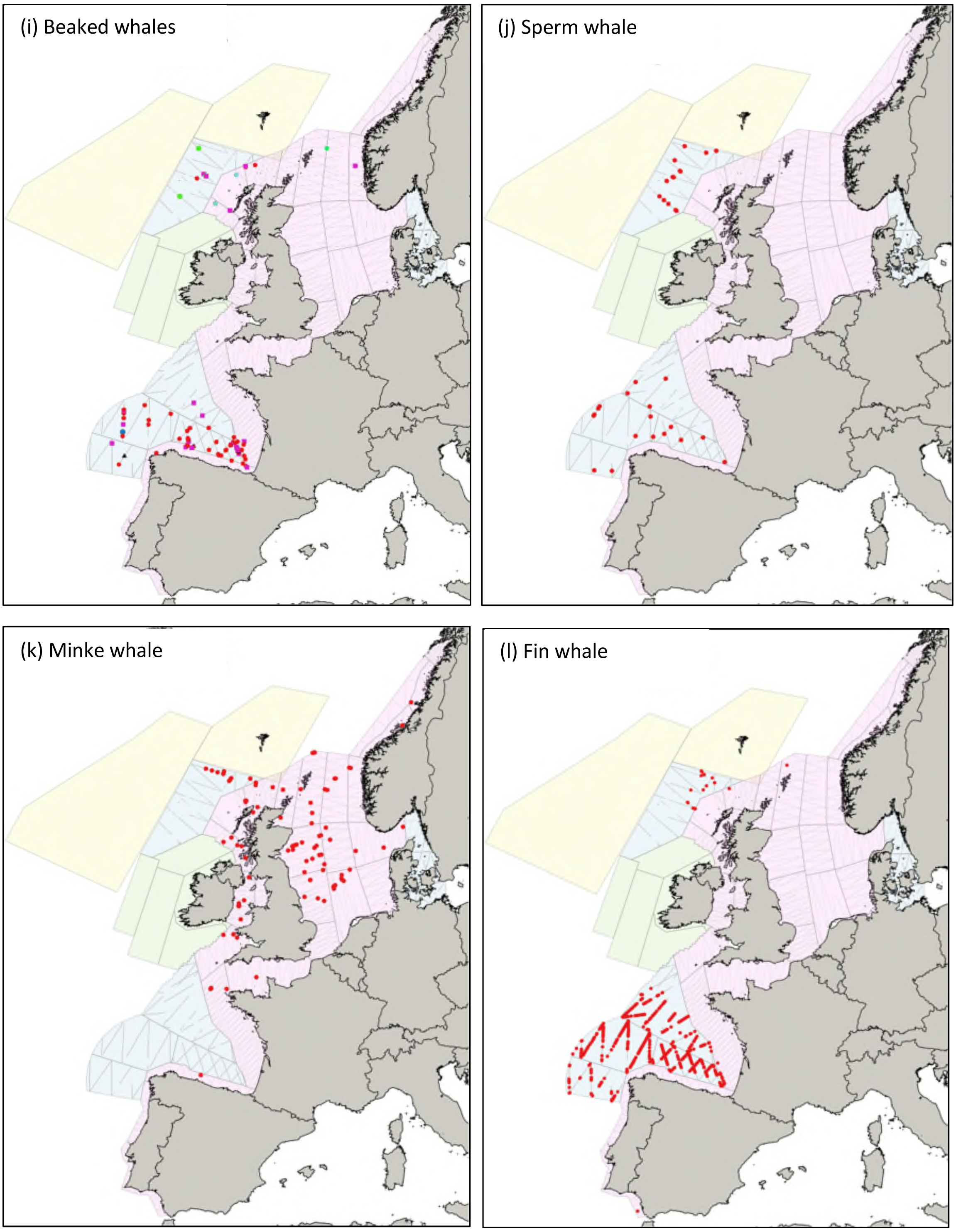


Figure 4 (continued). Distribution of sightings used in analysis of the most commonly detected species. Underlying effort is also that used in analysis: aerial survey - good and moderate conditions; ship survey - Beaufort 0-4. (i) beaked whales (Cuvier's beaked whale - red dot; Gervais beaked whale - blue dot; Unidentified beaked whale - pink square; Unidentified Mesoplodon - black triangle; Sowerby's beaked whale - green dot; Bottlenose whale - turquoise dot); (j) sperm whale; (k) minke whale; (l) fin whale.

Estimates of abundance

Aerial survey

A total of 290 circle-back ("racetrack") procedures were achieved. Estimates of ESW, including g(0), were made using the combined data from all seven aircraft for harbour porpoise, all dolphin species combined (excluding pilot whale and killer whale) and minke whale. Estimates for harbour porpoise stratified by aircraft were also investigated. However, the numbers of potential re-sightings by individual aircraft were in most cases too small to estimate robust aircraft-based ESWs; therefore, the pooled ESW based on all seven aircraft, stratified by good and moderate conditions, was preferred (see Hiby & Gilles 2016 for details). For the minke whale, there were only eight potential re-sightings on trailing effort, which precluded robust estimation of ESW for good and moderate conditions separately; therefore, ESW was estimated pooled across all conditions (see Hiby & Gilles 2016 for details).

Table 5 shows the estimates of ESW, including g(0), for harbour porpoise, all dolphin species combined (excluding pilot whale and killer whale) and minke whale.

Tables 6-16 show estimates of abundance for each block for harbour porpoise, minke whale, common dolphin, striped dolphin, unidentified common or striped dolphin, bottlenose dolphin, white-beaked dolphin, white-sided dolphin, Risso's dolphin, pilot whale and beaked whales (all species combined).

Table 5. Estimates of ESW (CV in parentheses) and g(0) for harbour porpoise, all dolphin species combined (excluding pilot whale and killer whale) and minke whale, for good and moderate sighting conditions during the aerial survey. Note that ESW is the total effective strip width on both sides of the aircraft.

	ESW (in meters), including g(0)		**g(0)**	
Conditions	***good***	***moderate***	***good***	***moderate***
Harbour porpoise	138 (0.16)	109 (0.17)	0.364	0.279
Dolphins (all species)	390 (0.13)	213 (0.14)	0.805	0.414
Minke whale	154 (0.42)		0.302	

Table 6. Harbour porpoise abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Block P1 was also covered by ship block 1 (see Table 20).

Block	**Abundance**	**Density**	**Mean group size**	**CV**	**CL low**	**CL high**
AA	0	0	0	0.00	0	0
AB	2,715	0.102	1.21	0.31	1,350	4,737
AC	183	0.005	1.00	1.02	0	669
B	3,374	0.028	2.23	0.59	102	8,078
C	17,323	0.213	1.76	0.30	8,853	29,970
D	5,734	0.118	1.35	0.49	1,697	12,452
E	8,320	0.239	1.31	0.28	4,643	14,354
F	1,056	0.086	1.00	0.38	342	2,010
G	5,087	0.336	1.52	0.43	1,701	10,386
H	1,682	0.090	2.00	0.74	0	5,154
I	5,556	0.397	1.15	0.35	2,403	9,961
J	2,045	0.058	1.25	0.72	0	5,313
K	9,999	0.308	1.44	0.27	5,643	16,306
L	19,064	0.607	1.28	0.38	6,933	35,703
M	15,655	0.277	1.23	0.34	6,295	28,589
N	58,066	0.837	1.28	0.26	32,372	91,372
O	53,485	0.888	1.31	0.21	37,413	81,695
P	52,406	0.823	1.36	0.31	27,247	94,570
P1	25,367	1.077	1.39	0.30	10,114	41,642
Q	16,569	0.333	1.31	0.35	6,919	31,247
R	38,646	0.599	1.38	0.29	20,584	66,524
S	6,147	0.152	1.35	0.28	3,401	10,065
T	26,309	0.402	1.33	0.29	14,219	45,280
U	19,269	0.321	1.31	0.30	10,794	34,922
V	5,240	0.137	1.24	0.37	2,165	9,714
W	8,978	0.180	1.47	0.57	1,427	21,507
X	6,713	0.344	1.50	0.31	3,496	11,767
Y	4,006	0.213	1.24	0.40	1,603	8,209
Z	4,556	0.406	1.51	0.27	2,686	7,631
SVG	423	0.593	1.71	0.39	157	834
TRD	273	0.282	1.75	0.48	59	583
Total	**424,245**	**0.351**	**1.35**	**0.17**	**313,151**	**596,827**

Table 7. Bottlenose dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no bottlenose dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AB	735	0.028	3.25	0.70	0	1,932
AC	4,210	0.120	4.82	0.48	997	8,529
B	6,926	0.058	7.05	0.38	2,713	13,389
D	2,938	0.060	2.60	0.45	914	5,867
E	288	0.008	1.50	0.57	0	664
G	1,824	0.121	9.67	0.68	0	4,474
H	59	0.003	1.00	1.01	0	214
P	147	0.002	1.00	0.99	0	488
R	1,924	0.030	5.25	0.86	0	5,048
S	151	0.004	2.00	1.01	0	527
Total	**19,201**	**0.016**	**4.53**	**0.24**	**11,404**	**29,670**

Table 8. Risso's dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no Risso's dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AA	575	0.047	6.00	1.03	0	1,902
AB	640	0.024	2.00	0.62	0	1,556
AC	237	0.007	2.00	1.03	0	835
B	799	0.007	10.50	0.98	0	2,770
E	1,090	0.031	7.50	0.69	0	2,843
H	538	0.029	5.00	0.95	0	1,798
J	6,750	0.192	11.33	0.80	0	19,557
K	440	0.014	4.00	0.76	0	1,222
Total	**11,069**	**0.009**	**7.06**	**0.51**	**2,794**	**24,412**

Table 9. White-beaked dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no white-beaked dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
H	5,881	0.316	5.18	0.63	389	14,304
J	1,871	0.053	4.00	0.91	0	5,856
K	7,055	0.217	4.70	0.53	1,799	16,040
O	143	0.002	3.00	0.97	0	490
P	1,938	0.030	2.50	0.38	539	3,524
P1	72	0.003	1.00	0.88	0	196
R	15,694	0.243	3.70	0.48	3,022	33,340
S	868	0.021	3.00	0.69	0	2,258
T	2,417	0.037	3.43	0.46	593	5,091
V	261	0.007	3.00	0.98	0	933
X	88	0.005	1.00	0.92	0	275
Total	**36,287**	**0.030**	**3.86**	**0.29**	**18,694**	**61,869**

Table 10. White-sided dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no white-sided dolphin sightings are excluded. Density of 0.00 means that density was less than 0.005 animals/km^2.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
R	644	0.010	3.00	0.99	0	2,069
T	1,366	0.021	3.25	0.98	0	5,031
U	177	0.003	2.00	0.99	0	559
Total	**2,187**	**0.002**	**3.02**	**0.70**	**0**	**6,071**

Table 11. Common dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no common dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AA	18,458	1.536	17.94	0.64	3,297	51,064
AB	63,243	2.371	8.67	0.27	34,978	103,337
AC	71,082	2.020	12.00	0.31	36,898	124,302
B	92,893	0.784	7.49	0.27	52,766	149,494
D	18,187	0.374	10.06	0.41	4,394	33,077
J	4,679	0.133	20.00	0.95	0	16,108
Total	**268,540**	**0.222**	**9.36**	**0.19**	**186,851**	**390,528**

Table 12. Striped dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no striped dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AB	3,039	0.114	19.00	0.90	0	10,486
AC	15,581	0.443	15.20	0.46	3,302	31,195
B	228	0.002	6.00	0.98	0	748
D	262	0.005	2.00	0.92	0	883
K	142	0.004	2.00	0.91	0	444
Total	**19,253**	**0.016**	**13.51**	**0.40**	**6,774**	**36,849**

Table 13. Unidentified common or striped dolphin abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no unidentified common or striped dolphin sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AB	6,239	0.234	19.5	0.76	0	17,771
AC	5,504	0.156	9.4	0.84	0	16,252
B	61,741	0.521	6.2	0.21	38,143	90,843
C	1,765	0.022	12.0	0.85	0	5,494
D	31,800	0.654	7.0	0.34	14,703	55,014
I	206	0.015	2.0	0.92	0	713
Total	**107,255**	**0.089**	**6.8**	**0.20**	**69,880**	**155,460**

Table 14. Pilot whale abundance and density (animals/km^2) estimates from the aerial survey using conventional distance sampling methods. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no Pilot whale sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AA	76	0.006	1.00	1.09	11	517
AC	1,917	0.054	3.80	1.24	273	13,442
B	1,317	0.011	4.43	0.58	448	3,867
J	79	0.002	1.00	1.16	10	641
K	1,733	0.053	4.50	1.06	271	11,084
Total	**5,121**	**0.004**	**3.95**	**0.61**	**1,654**	**15,855**

Table 15. Beaked whale (all species) abundance and density (animals/km^2) estimates from the aerial survey using conventional distance sampling methods. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no beaked whale sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AC	581	0.017	1.83	0.530	212	1,593
B	101	0.001	1.50	0.774	26	400
H	100	0.005	2.00	1.106	14	733
J	325	0.009	1.50	0.621	91	1,163
K	211	0.006	2.00	0.904	41	1,091
U	75	0.001	1.00	1.040	12	457
V	97	0.003	1.00	1.020	16	607
Total	**1,489**	**0.001**	**1.69**	**0.376**	**719**	**3,085**

Table 16. Minke whale abundance and density (animals/km^2) estimates from the aerial survey. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no minke whale sightings are excluded.

Block	Abundance	Density	Mean group size	CV	CL low	CL high
AC	164	0.005	1.00	1.14	0	792
B	289	0.002	1.00	0.84	0	962
C	186	0.002	1.00	1.12	0	819
D	543	0.011	1.00	0.75	0	1,559
E	603	0.017	1.00	0.62	134	1,753
G	410	0.027	1.33	0.70	0	1,259
H	149	0.008	1.00	1.07	0	638
I	285	0.020	1.00	0.79	0	1,004
J	647	0.018	1.00	1.04	0	2,994
K	295	0.009	1.00	0.81	0	994
N	1,392	0.020	1.00	0.50	450	3,459
O	603	0.010	1.00	0.62	109	1,670
P	610	0.001	1.00	0.66	0	1,849
Q	348	0.007	1.00	0.76	0	1,121
R	2,498	0.039	1.18	0.61	604	6,791
S	383	0.010	1.00	0.75	0	1,364
T	2,068	0.032	1.10	0.81	290	6,960
U	895	0.015	1.00	0.85	0	3,139
V	440	0.011	1.00	1.14	0	1,979
X	122	0.006	1.00	1.09	0	496
Y	171	0.009	1.00	1.10	0	756
Total	**13,101**	**0.011**	**1.05**	**0.35**	**7,050**	**26,721**

Ship survey

For species with sufficient duplicate sightings, mark-recapture distance sampling methods were used to estimate detection probability and consequently abundance. There was no compelling evidence of movement in response to the ship in any species, so the partial independence model of detection probability was used in all cases. For sperm whale and minke whale, there were insufficient duplicate sightings to use mark-recapture distance sampling methods to estimate detection probability so conventional “single observer” distance sampling methods, in which Tracker and Primary sightings are combined into a single dataset, were used. Data from both ships were analysed together to obtain common estimates of detection probability.

An exception to the above was for large baleen whales (including mostly fin whales), for which the perpendicular distance data were distributed very differently in blocks 8 and 9 (survey by M/V Skoven) compared to blocks 11, 12 and 13 (surveyed by B/O Angeles Alvariño). Consequently, the large baleen whale data were analysed separately for blocks 8 and 9, and for blocks 11, 12 and 13.

For blocks 11, 12 and 13, the partial independence mrds model of detection probability was used as described above. For blocks 8 and 9, however, the conditional probability of detection (Primary detection of sightings first made by Tracker) increased with increasing perpendicular distance, making the application of mrds models of detection probability inappropriate. For blocks 8 and 9, therefore, the Tracker data were disregarded and a conventional analysis of Primary data only was conducted, assuming g(0) = 1. Estimates for fin whales for blocks 8 and 9 are thus expected to be negatively biased.

Table 17 gives, for each species or species grouping, the perpendicular distance truncation selected, the method used to estimate detection probability, and details of the best fitting detection probability models.

Table 18 gives the detection probabilities estimated using the models described in Table 17.

Table 19 gives the group size correction factors for each species or species grouping.

Table 17. Summary of data and models used to estimate detection probability for each species or species grouping in the ship survey. Method: pi = mark-recapture distance sampling point (trackline) independence model; ds = conventional distance sampling model using Primary data only; so = “single observer” conventional distance sampling model using Primary and Tracker data combined. Detection function model: HR = hazard rate.

Species / species grouping	Truncation distance (m)	Method	Primary detection function model (ds) & covariates	Conditional detection function (mr) covariates
Harbour porpoise	600	pi	HR: Swell	Beaufort
Bottlenose + Risso’s dolphin	885 (max)	pi	HR: null	Perpendicular distance
White-sided dolphin	343 (max)	pi	HR: null	null
Common + striped dolphin	2,000	pi	HR: Beaufort	Perpendicular distance
Pilot whale	1,500	pi	HR: null	Perpendicular distance
Beaked whales (all species)	2,000	pi	HR: Sightability	Perpendicular distance
Sperm whale	9,197 (max)	so	HR: Beaufort	-
Large baleen whales (blocks 8 & 9)	2,302 (max)	ds	HR: Swell	-
Large baleen whales (blocks 11, 12 & 13)	3,000	pi	HR: Swell	Perpendicular distance, Beaufort, Swell
Minke whale	208 (max)	so	Uniform: null	-

Table 18. Estimated detection probabilities within the truncation distance (see Table 17) for each species or species grouping in the ship survey. ESW is the estimated effective strip half-width. Figures in parentheses are coefficients of variation (CV). The CV of ESW is the same as for overall probability of detection.

Species / species grouping	Average probability of detection assuming g(0)=1	Probability of detection on the transect line, g(0)	Overall average probability of detection	ESW (m)
Harbour porpoise	0.709 (0.051)	0.221 (0.177)	0.156 (0.186)	93.6
Bottlenose + Risso's dolphin	0.427 (0.146)	0.400 (0.348)	0.171 (0.377)	151
White-sided dolphin	0.829 (0.614)	0.455 (0.330)	0.377 (0.697)	129
Common + striped dolphin	0.131 (0.117)	0.421 (0.115)	0.055 (0.164)	110
Pilot whale	0.318 (0.173)	0.491 (0.217)	0.156 (0.277)	234
Beaked whales (all species)	0.217 (0.386)	0.263 (0.375)	0.057 (0.541)	114
Sperm whale	0.0095 (0.296)	-	0.0095 (0.296)	87
Large baleen whales (blocks 8 & 9)	0.343 (0.061)	-	0.343 (0.061)	789
Large baleen whales (blocks 11, 12 & 13)	0.505 (0.047)	0.614 (0.073)	0.310 (0.088)	933
Minke whale	1.0	-	1.0	208

Table 19. Group size correction factors (CV in parentheses) for each species or species grouping used to correct Primary group sizes in analysis.

Species	Blocks	Group size correction	Sample size
Harbour porpoise	1-2	1.204 (0.150)	42
Bottlenose dolphin	8, 9, 12, 13	1.571 (0.265)	7
Risso's dolphin	9	1	2
White-sided dolphin	8	0.826 (0.409) = 1	5
Common dolphin	8-13	0.956 (0.241) = 1	29
Striped dolphin	8, 9, 12, 13	1.993 (0.197)	20
Unid common or striped	8, 9, 12, 13	1.362 (0.205)	16
Pilot whale	8-13	1.156 (0.261)	20
Beaked whales (all species)	8-13	1.000 (0.427)	11
Sperm whale	8-13	1	1
Fin whale	8-9	1.057 (0.130)	62
Fin whale	11-13	1.059 (0.084)	171
Minke whale	8	1	9

Tables 20-31 show estimates of abundance for each ship block for harbour porpoise, bottlenose dolphin, Risso's dolphin, white-sided dolphin, common dolphin, striped dolphin, unidentified common or striped dolphin, pilot whale, beaked whales, sperm whale, minke whale and fin whale. Note that in Table 20 a shipboard estimate is given for block 1 but the coverage was poor and uneven so the estimate subsequently used in Tables 32 and 33 for this block is that from the aerial survey (block P1 in Table 6).

Table 20. Estimates of density (animals/km^2) and abundance for harbour porpoise from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
1	0.854	0.354	1.56	0.137	1.33	0.472	31,249	6,111	159,786
2	0.686	0.292	1.52	0.036	1.04	0.304	42,324	23,368	76,658
Total	**0.748**	**0.252**	**1.53**	**0.063**	**1.15**	**0.285**	**73,573**	**39,383**	**137,443**

Table 21. Estimates of density (animals/km^2) and abundance for bottlenose dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.0048	0.634	1.57	0.265	0.007	0.634	1,195	363	3,933
9	0.0087	0.557	4.71	0.404	0.041	0.633	5,928	1,818	19,334
12	0.0081	0.632	6.68	0.267	0.054	0.685	603	161	2,265
13	0.0041	1.056	3.14	0.265	0.013	1.056	769	122	4,840
Total	**0.0053**	**0.478**	**3.61**	**0.291**	**0.019**	**0.532**	**8,496**	**3,089**	**23,369**

Table 22. Estimates of density (animals/km^2) and abundance for Risso's dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
9	0.0058	0.720	3.00	0.629	0.017	0.818	2,515	579	10,927
Total	**0.0058**	**0.720**	**3.00**	**0.629**	**0.017**	**0.818**	**2,515**	**579**	**10,927**

Table 23. Estimates of density (animals/km^2) and abundance for white-sided dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.0148	0.826	5.63	0.248	0.083	0.826	13,322	2,797	63,448
Total	**0.0148**	**0.826**	**5.63**	**0.248**	**0.083**	**0.826**	**13,322**	**2,797**	**63,448**

Table 24. Estimates of density (animals/km^2) and abundance for common dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.005	0.787	13.86	0.280	0.07	0.940	10,601	1,958	57,405
9	0.152	0.594	6.84	0.202	1.04	0.718	150,208	39,190	575,716
11	0.062	0.701	8.09	0.160	0.50	0.633	34,570	8,154	146,570
12	0.012	0.559	5.03	0.532	0.06	0.543	643	206	2,007
13	0.009	0.695	5.99	0.393	0.05	0.653	3,110	861	11,236
Total	**0.062**	**0.493**	**7.21**	**0.147**	**0.45**	**0.564**	**199,133**	**67,320**	**589,041**

Table 25. Estimates of density (animals/km^2) and abundance for striped dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	**Density (groups)**	**CV**	**Group size**	**CV**	**Density (animals)**	**CV**	**Abundance**	**CL low**	**CL high**
9	0.051	0.461	22.45	0.337	1.14	0.593	164,023	52,376	513,662
11	0.056	0.380	33.21	0.122	1.87	0.408	128,559	50,882	324,818
12	0.027	0.406	25.34	0.309	0.69	0.588	7,682	2,245	26,288
13	0.022	0.404	39.63	0.299	0.89	0.565	52,823	17,094	163,228
Total	**0.029**	**0.313**	**27.56**	**0.175**	**0.80**	**0.346**	**353,087**	**178,935**	**696,736**

Table 26. Estimates of density (animals/km^2) and abundance for unidentified common or striped dolphin from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	**Density (groups)**	**CV**	**Group size**	**CV**	**Density (animals)**	**CV**	**Abundance**	**CL low**	**CL high**
9	0.006	0.605	3.91	0.367	0.02	0.665	3,377	956	11,932
11	0.059	0.460	7.71	0.439	0.46	0.619	31,298	7,609	128,737
12	0.009	0.666	28.43	0.133	0.25	0.758	2,822	613	12,986
13	0.027	0.421	8.30	0.160	0.23	0.403	13,414	5,948	30,255
Total	**0.015**	**0.327**	**7.67**	**0.279**	**0.11**	**0.414**	**50,912**	**20,312**	**127,613**

Table 27. Estimates of density (animals/km^2) and abundance for pilot whale from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	**Density (groups)**	**CV**	**Group size**	**CV**	**Density (animals)**	**CV**	**Abundance**	**CL low**	**CL high**
8	0.0133	0.439	5.96	0.240	0.079	0.484	12,662	4,963	32,302
9	0.0075	0.654	2.89	0.189	0.022	0.770	3,125	763	12,801
11	0.0022	1.111	1.16	0.000	0.003	1.111	173	19	1,599
12	0.0066	0.528	4.39	0.439	0.029	0.718	320	77	1,322
13	0.0133	0.559	5.55	0.137	0.074	0.638	4,377	1,283	14,938
Total	**0.0095**	**0.373**	**4.90**	**0.164**	**0.047**	**0.403**	**20,656**	**9,501**	**44,908**

Table 28. Estimates of density (animals/km^2) and abundance for beaked whales (all species combined) from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	**Density (groups)**	**CV**	**Group size**	**CV**	**Density (animals)**	**CV**	**Abundance**	**CL low**	**CL high**
8	0.0161	0.747	1.37	0.220	0.022	0.698	3,505	983	12,499
9	0.0085	1.005	1.16	0.171	0.010	0.927	1,416	289	6,928
11	0.0070	0.825	1.00	0.000	0.007	0.825	484	108	2,171
12	0.0193	0.671	1.19	0.097	0.023	0.633	255	78	834
13	0.0442	0.629	1.62	0.161	0.072	0.632	4,244	1,317	13,683
Total	**0.0160**	**0.603**	**1.39**	**0.126**	**0.022**	**0.576**	**9,905**	**3,364**	**29,162**

Table 29. Estimates of density (animals/km^2) and abundance for sperm whale from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.0601	0.471	1.00	0.000	0.060	1.083	9,599	3,866	23,835
9	0.0099	0.546	1.00	0.000	0.010	0.546	1,427	505	4,035
11	0.0056	1.083	2.00	0.000	0.011	1.083	777	88	6,819
12	0.0226	0.735	1.66	0.017	0.038	0.740	417	99	1,761
13	0.0171	0.557	1.28	0.179	0.022	0.640	1,298	382	4,406
Total	**0.0286**	**0.411**	**1.07**	**0.040**	**0.030**	**0.405**	**13,518**	**6,181**	**29,563**

Table 30. Estimates of density (animals/km^2) and abundance for minke whale from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.0104	0.549	1.00	-	0.010	0.826	1,657	555	4,949
Total	**0.0104**	**0.549**	**1.00**	**-**	**0.010**	**0.826**	**1,657**	**555**	**4,949**

Table 31. Estimates of density (animals/km^2) and abundance for fin whale from the ship survey. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	CV	Group size	CV	Density (animals)	CV	Abundance	CL low	CL high
8	0.0040	0.474	1.30	0.135	0.005	0.493	820	308	2,188
9	0.0531	0.288	1.38	0.036	0.073	0.290	10,600	5,861	19,171
11	0.0247	0.201	1.21	0.041	0.030	0.220	2,052	1,254	3,358
12	0.0692	0.195	1.33	0.065	0.092	0.212	1,025	648	1,620
13	0.0383	0.183	1.60	0.060	0.061	0.205	3,645	2,374	5,594
Total	**0.0294**	**0.313**	**1.40**	**0.058**	**0.041**	**0.322**	**18,142**	**9,796**	**33,599**

Table 32 gives the total estimates of abundance for all the main species over the whole survey area.

Table 32. Estimates of total abundance and density (animals/km^2) in the whole survey area for all species.

Species	Abundance	Density	CV	CL low	CL high
Harbour porpoise	466,569	0.381	0.154	345,306	630,417
Bottlenose dolphin	27,697	0.015	0.233	17,662	43,432
Risso's dolphin	13,584	0.008	0.441	5,943	31,047
White-beaked dolphin	36,287	0.020	0.290	18,694	61,869
White-sided dolphin	15,510	0.009	0.717	4,389	54,807
Common dolphin	467,673	0.261	0.264	281,129	777,998
Striped dolphin	372,340	0.208	0.329	198,583	698,134
Unid common or striped	158,167	0.088	0.188	109,689	228,069
Pilot whale	25,777	0.014	0.345	13,350	49,772
Beaked whales (all species)	11,394	0.006	0.503	4,494	28,888
Sperm whale	13,518	0.008	0.405	6,181	29,563
Minke whale	14,759	0.008	0.327	7,908	27,544
Fin whale	18,142	0.010	0.322	9,796	33,599

ICES Assessment Units

Estimates of harbour porpoise abundance for each ICES Assessment Unit (AU) are given in Table 33. For the Kattegat and Belt Seas, ship block 2 is approximately equivalent to the AU but includes some waters to the south and excludes some waters to the north. For the North Sea, the combined area of the aerial survey blocks used is very similar (within a few percent) to the area of the AU.

For the West Scotland AU, offshore waters to the west of Scotland were covered by ship block 8, where abundance has not been estimated because there were only 3 sightings of harbour porpoise in the west of the area. Only a part of the Celtic/Irish Seas AU was covered by SCANS-III so the estimate for this area is not representative of the whole AU. Waters to the south and west of Ireland were covered by Irish project ObSERVE and estimates of abundance for these waters are not yet available.

For the Iberian peninsula, the aerial survey covered all continental shelf waters; the AU includes waters off the shelf, which is unlikely to include harbour porpoises (none were seen in ship blocks 11, 12 and 13).

Table 33. Estimates of harbour porpoise abundance and density (animals/km^2) in ICES Assessment Units, and Norwegian coastal waters north of 62°N. CV is the coefficient of variation of abundance and density. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. All estimates are from aerial survey except for the Kattegat and Belt Seas AU, which is from ship survey block 2. Note that the sum of the estimates for the Celtic/Irish Seas and North Sea AUs (372,073) is slightly smaller than the sum of the contributing bocks (372,452); this is because block C spanned both AUs and was post-stratified in analysis.

Assessment Unit	Abundance	Density	CV	CL low	CL high
Celtic/Irish Seas (partial coverage only)	26,700	0.11	0.25	16,055	42,128
North Sea	345,373	0.52	0.18	246,526	495,752
West Scotland	24,370	0.21	0.23	15,074	37,858
Iberian peninsula	2,898	0.04	0.32	1,386	5,122
Kattegat and Belt Seas	42,324	1.04	0.30	23,368	76,658
Norwegian coastal waters	24,526	0.25	0.28	14,035	40,829

Distribution of estimated density over the survey area

Modelling of the new data from 2016 to investigate fine scale distribution and habitat use is in progress and will form a subsequent project report. For those species with sufficient data, a coarse idea of how abundance was distributed over the survey area can be seen from maps of estimated density by survey block. Maps for harbour porpoise; bottlenose, common and striped dolphin; and minke and fin whale are shown in Figure 5.

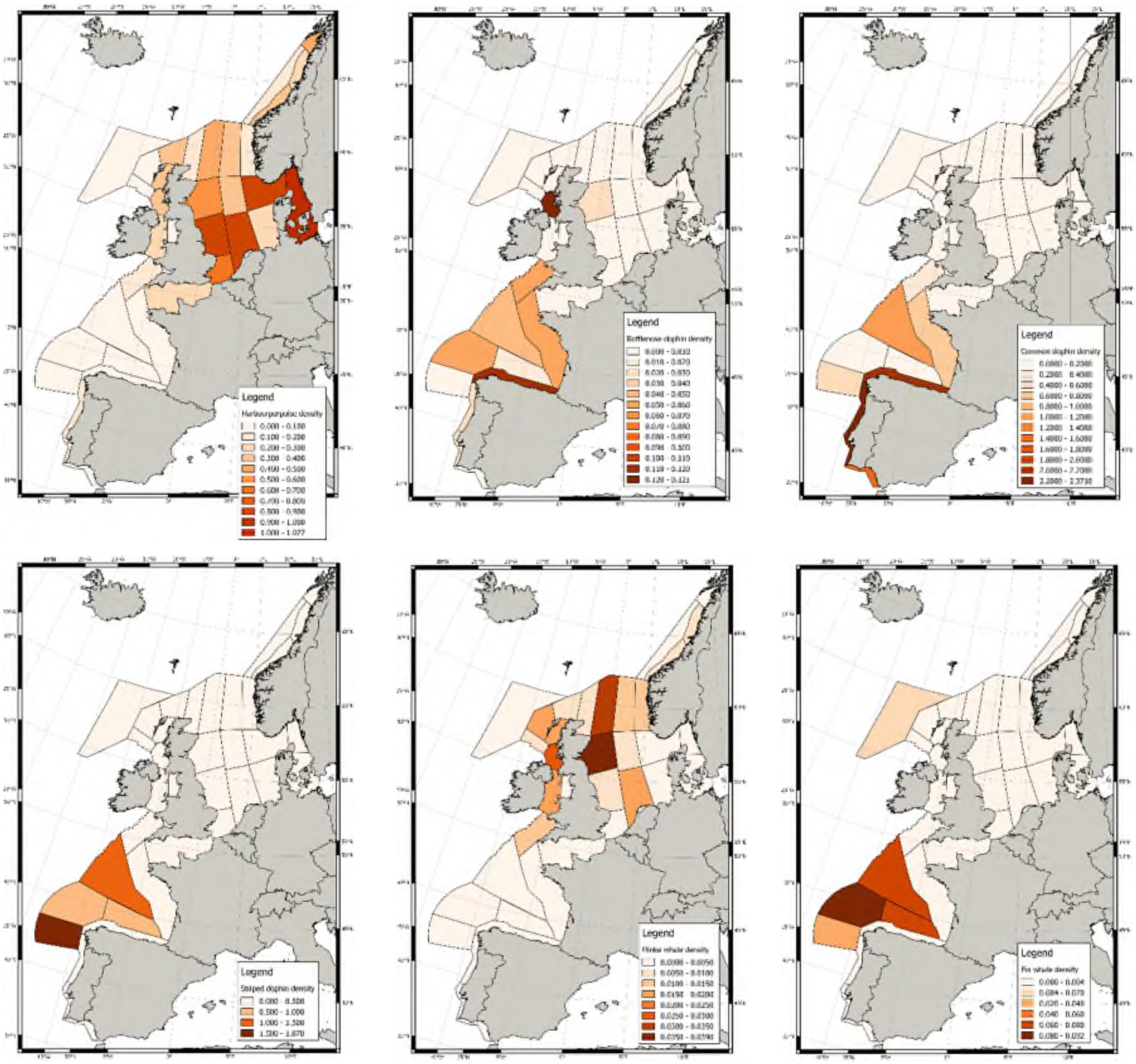


Figure 5. Estimated density in each survey block for harbour porpoise (top left), bottlenose dolphin (top middle), common dolphin (top right), striped dolphin (bottom left), minke whale (bottom middle) and fin whale (bottom right).

Responsive movement to survey ships and reanalysis of data from 1994 and 2005

There was no evidence of movement in response to the survey ships for any species in SCANS-III and, accordingly, point (trackline) independence models (Laake & Borchers 2004) were used to estimate detection probability for all species. In 2005, there was strong evidence of attraction for common dolphins and weak evidence of avoidance for harbour porpoise, white-beaked dolphin and minke whale so the full independence detection probability model that allows for responsive movement (Borchers et al. 1998; Laake & Borchers 2004) was used for all species (Hammond et al. 2013). In 1994, the only method of analysis available for two-team data was the full independence model.

Use of full independence models for all species was the only option in 1994 and justified in 2005, but this creates a potential problem for comparison with abundance estimates from 2016. The full independence model, while necessary if responsive movement needs to be accounted for, is not robust to any unmodelled heterogeneity (non-independence) in the probability of detection by the Tracker and Primary teams; this non-independence is likely to be a positive correlation, which generates negatively biased estimates. It is therefore likely that published estimates of abundance for 1994 and 2005 are negatively biased. The point independence model (used for SCANS-III shipboard analysis) assumes non-independence only on the transect line and is thus more robust and less likely to generate negatively biased estimates.

An additional consideration is that responsive movement in the form of avoidance, as suggested for harbour porpoise, white-beaked dolphin and minke whale in 2005, leads to negative bias. Accounting for this by using the full independence detection probability model should therefore lead to a higher estimate than using the point independence model. However, this was not the case (see below).

In summary, if estimates from 1994 and 2005 are subject to negative bias and estimates from 2016 are not, assessment of trends in abundance over time would be confounded with this difference and trends could appear more positive than they are.

Consequently, it was decided to reanalyse the SCANS and SCANS-II shipboard data using the more robust point independence model of detection probability to create a comparable time series of estimates from 1994, 2005 and 2016. Abundance was re-estimated for harbour porpoise, white-beaked dolphin and minke whale in 1994 and 2005. Abundance was not re-estimated for common dolphin in 2005 because of the strong evidence of attraction to the survey vessels in this species on SCANS-II, which could cause a substantial overestimate if not accounted for using the full independence model (e.g. Cañadas et al. 2009). Abundance was also not re-estimated for bottlenose dolphin in 2005 because there were insufficient data to use any form of two-team analysis methods.

Aerial surveys are not subject to responsive movement - the tandem aircraft method used in 1994 and the circle-back method used in 2005 and 2016 provide consistent estimates for harbour porpoise in all of the aerial surveys.

However, the availability for the first time of g(0) estimates for dolphin species and for minke whale estimated for the SCANS-III aerial survey provided an opportunity to improve estimates of abundance for white-beaked dolphin, common dolphin, bottlenose dolphin and minke whale from the SCANS-II aerial survey in 2005. Published estimates had previously been corrected only for availability, based on dive data from studies in other areas (Hammond et al. 2013).

Table 34 shows the revised estimates of abundance for 1994 and 2005 compared to those previously published in Hammond et al. (2002, 2013). Revised ship estimates are similar for minke whale but 20-50% larger for harbour porpoise and three times larger for white-beaked dolphin. These results confirm that abundance was previously underestimated for harbour porpoise and, especially, for white-beaked dolphin. Revised aerial estimates using the SCANS-III estimates of g(0) are similar for dolphin species but smaller for minke whale.

Table 34. Revised estimates of abundance for 1994 and 2005 compared with previously published estimates (Hammond et al. 2002; 2013). Species: HP = harbour porpoise; WB = white-beaked dolphin; MW = minke whale; BD = bottlenose dolphin; CD = common dolphin. All previously published ship estimates used the full independence (fi) model of detection probability except for bottlenose dolphin in 2005 for which the data were sufficient only for a conventional “single observer” (so) analysis. All revised estimates used the point independence model of detection probability, except for bottlenose dolphin and common dolphin in 2005 (see above). Revised aerial estimates used SCANS-III estimates of g(0) for dolphins and minke whale. There were no aerial estimates for white-beaked dolphin or minke whale in 1994.

			Revised estimates			***Previously published estimates (Hammond et al. 2002; 2013)***		
Year	**Species**	**Area**	**N**	**CV**	**95% CI**	***N***	***CV***	***95% CI***
1994	HP	Ship	358,807	0.20		*292,995*	*0.16*	
1994	HP	Aerial	48,370	0.30		*48,371*	*0.30*	
1994	**HP**	**Total**	**407,177**	**0.18**	**288,920 - 573,838**	***341,366***	***0.14***	***260,000 - 449,000***
1994	**WB**	**Ship**	**23,716**	**0.30**	**13,440 - 41,851**	***7,856***	***0.30***	***4,000 - 13,300***
1994	**MW**	**Ship**	**9,685**	**0.23**	**6,199 - 15,132**	***8,445***	***0.24***	***5,000 - 13,500***
2005	HP	Ship	409,774	0.27		*265,268*	*0.24*	
2005	HP	Aerial	110,090	0.17		*110,090*	*0.17*	
2005	**HP**	**Total**	**519,864**	**0.21**	**343,521 - 786,730**	***375,358***	***0.20***	***256,304 - 549,713***
2005	WB	Ship	33,119	0.41		*11,659*	*0.34*	
2005	WB	Aerial	4,569	0.54		*4,878*	*0.57*	
2005	**WB**	**Total**	**37,689**	**0.36**	**18,898 - 75,164**	***16,536***	***0.30***	***9,245 - 29,586***
2005	MW	Ship	13,383	0.36		*13,640*	*0.37*	
2005	MW	Aerial	1,866	0.33		*5,317*	*0.74*	
2005	**MW**	**Total**	**15,249**	**0.31**	**8,352 - 27,842**	***18,958***	***0.35***	***9,798 - 36,680***
2005	BD	Ship (so)	14,515	0.47		*14,515*	*0.47*	
2005	BD	Aerial	2,126	0.82		*1,971*	*0.54*	
2005	**BD**	**Total**	**16,641**	**0.42**	**7,618 - 36,351**	***16,485***	***0.42***	***7,463 - 36,421***
2005	CD	Ship (fi)	36,225	0.21		*36,225*	*0.21*	
2005	CD	Aerial	18,730	0.47		*19,995*	*0.51*	
2005	**CD**	**Total**	**54,955**	**0.21**	**36,607 - 82,498**	***56,221***	***0.23***	***35,748 - 88,419***

Trends in abundance

Following the successful completion of the SCANS-III survey in 2016, there are now three estimates of abundance for harbour porpoise, white-beaked dolphin and minke whale in the North Sea from SCANS, SCANS-II and SCANS-III, and it is justifiable to investigate trend over time. For minke whale in the North Sea, there are five additional estimates from the Norwegian Independent Line Transect Surveys (NILS) (Bøthun et al. 2009; Schweder et al. 1997; Skaug et al. 2004; Solvang et al. 2015). All these estimates relate to the North Sea bounded by 62°N to the north but the earlier Norwegian estimates of minke whale abundance covered a smaller area between 56°N and 61°N. The most recent Norwegian minke whale estimate for 2009 includes waters south to 53°N.

Although not covering exactly the same area, there are also three comparable estimates of abundance for harbour porpoise in the Skagerrak/Kattegat/Belt Seas area in 1994, 2005 and 2016, and two comparable estimates for 2012 (Viquerat et al. 2014) and 2016 for the smaller Kattegat/Belt Seas area. Figure 6 shows the areas covered in these surveys compared to the area believed to represent a separate population (Sveegaard et al. 2015).

In any assessment of trend, it is important to consider the statistical power to detect a change in abundance of a given magnitude. Simple power analyses were conducted to determine the annual rate of decline that could be detected with high (80%) power from the available estimates of abundance. Power was calculated using the simplified inequality:

$r^2n^3 > 12CV^2 (Z_{\alpha/2} + Z_{\beta})^2$

where r = rate of change over the time period in question, n = the number of surveys during the time period, CV = coefficient of variation of abundance, $Z_{\alpha/2}$ = the value of a standardised random normal variable for the probability of making a Type I error, α (set to 0.05), Z_{β} is the value of a standardised random normal variable for the probability of making a Type II error, β, and power is (1-β) (Gerrodette, 1987).

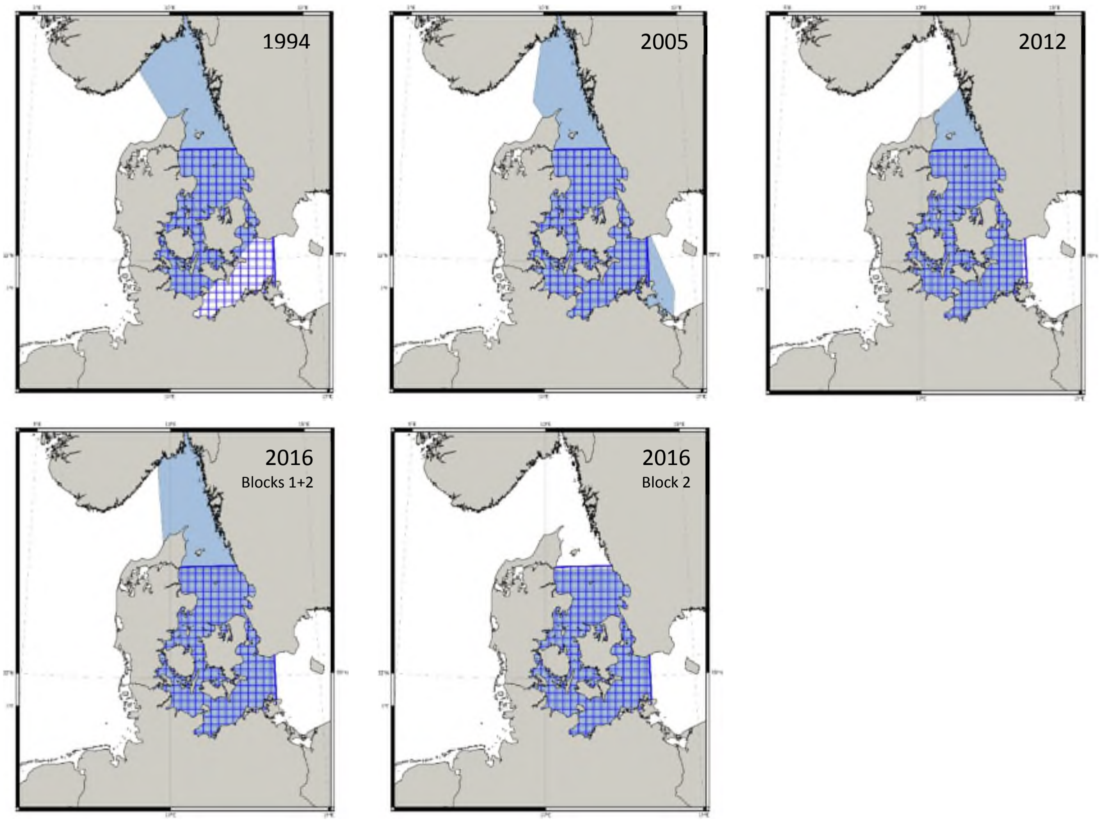


Figure 6. Areas covered during the three SCANS surveys and the “MiniSCANS” survey in 2012 (Viquerat et al. 2014) in the Skagerrak/Kattegat/Belt Seas (coloured light blue) compared with the area believed to represent a separate population (Sveegaard et al. 2015) (cross-hatched dark blue).

Figure 7 shows the estimates and trend lines fitted to three or more comparable estimates of abundance and Table 35 gives details of the fitted lines and the results of the power calculations. These results show that there is no statistical support for a change in abundance over the period covered by the surveys for any species/region.

The annual rates of decline that can be detected with 80% power from the three estimates in the North Sea are 1.8% for harbour porpoise and 5% for white-beaked dolphin. For minke whale, the eight estimates for the North Sea are quite variable but have 80% power to detect a 0.5% annual rate of decline.

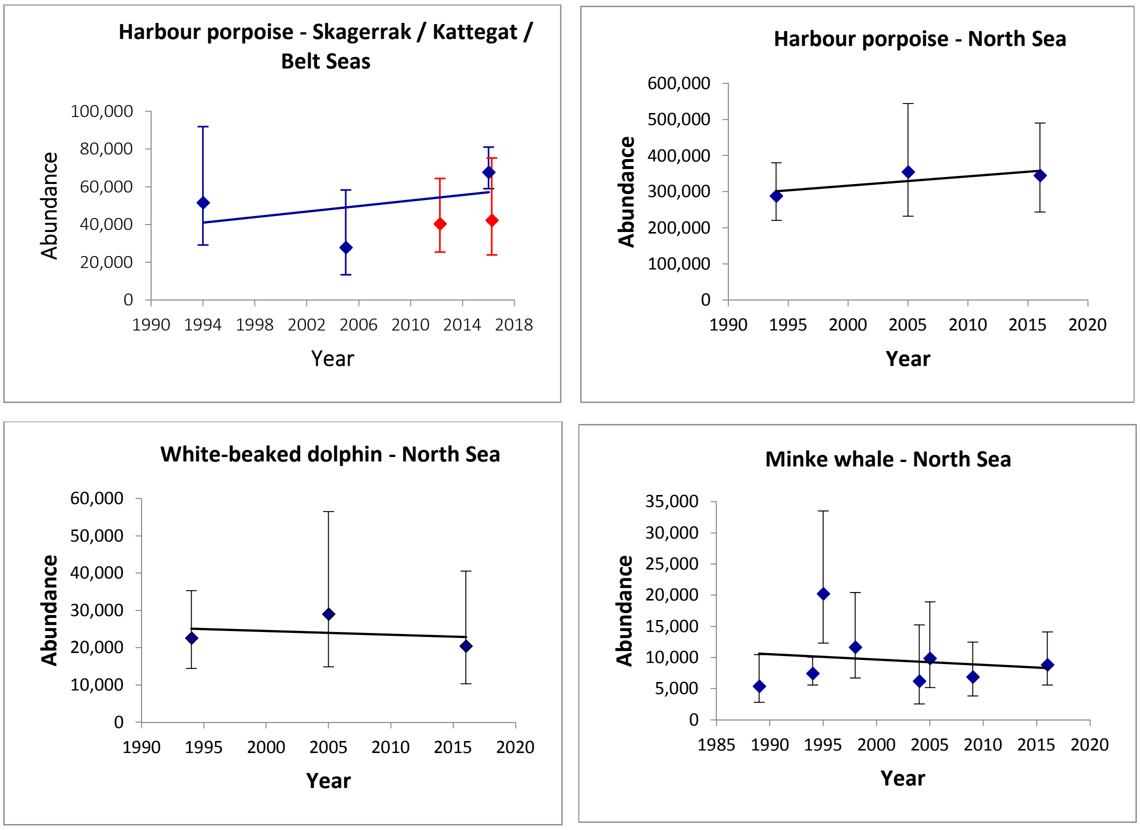


Figure 7. Trend lines fitted to time series of three or more abundance estimates. Top left: harbour porpoise in the Skagerrak/Kattegat/Belt Seas area (blue dots and line). Estimates for the Kattegat/Belt Seas population area (see Figure 6) shown as red dots. Top right: harbour porpoise in the North Sea. Bottom left: white-beaked dolphin in the North Sea. Bottom right: minke whale in the North Sea. Error bars are log-normal 95% confidence intervals.

Table 35. Estimated annual rates of decline for species/regions where there are more than two estimates of abundance, and results of power calculations. n is the number of abundance estimates. p is the probability of obtaining the estimated rate of change by chance (p > 0.05 indicates no significant change).

Species	**Region**	**n**	**Estimated annual rate of change**	**p**	**CV**	**Annual rate of decline detectable at 80% power**
Harbour porpoise	Skagerrak / Kattegat / Belt Seas	3	1.24% (95%CI: -39; 67%)	0.81	0.30	3.7%
Harbour porpoise	North Sea	3	0.8% (95%CI: -6.8; 9.0%)	0.42	0.18	1.8%
White-beaked dolphin	North Sea	3	-0.5% (95%CI: -18; 22%)	0.82	0.36	5%
Minke whale	North Sea	8	-0.25% (95%CI: -4.8; 4.6%)	0.90	0.30	0.5%

Discussion

We present here results from the third in a long-term time series (1994, 2005/07, 2016) of large-scale multinational surveys of cetaceans in European Atlantic waters (Figure 8) allowing a snapshot view of how distribution and abundance have varied over more than two decades. Except for Portuguese offshore waters, and waters to the south and west of Ireland, there are now two comprehensive and comparable summer datasets for European Atlantic waters between 62°N and the Straits of Gibraltar. And there are three such comparable datasets for the North Sea and the Skagerrak/Kattegat/Belt Seas.

For harbour porpoise in the North Sea, a region that can be considered for assessment purposes as a population unit, our results show no evidence for trends in abundance since the mid-1990s. The same is the case for white-beaked dolphin and minke whale in the North Sea, and for harbour porpoise in the Skagerrak/Kattegat/Belt Seas. Power to detect directional changes in abundance from large-scale sightings surveys is generally low (Taylor et al. 2007) but the time span covered by the three SCANS surveys and reasonable precision in estimates means that the data have high power to detect changes of 2-5% per year. For minke whales where more surveys are available, there is high power to detect a 0.5% change in abundance per year.

For most species for which we can estimate abundance from large-scale surveys, European Atlantic waters are at the edge of a wider North Atlantic range. Spatial variation in prey availability may lead to redistribution of animals and the distribution and abundance of these species in European waters may vary as a result of this.

Aerial vs ship survey

All three SCANS surveys have been conducted with a mix of aerial and shipboard surveys. In 1994, nine ships and two aircraft were used and, in 2005, seven ships and three aircraft (Hammond et al. 2002; 2013). In 2016, seven aircraft and three ships were used, with shelf waters being entirely covered by air, except the Kattegat/Belt Seas.

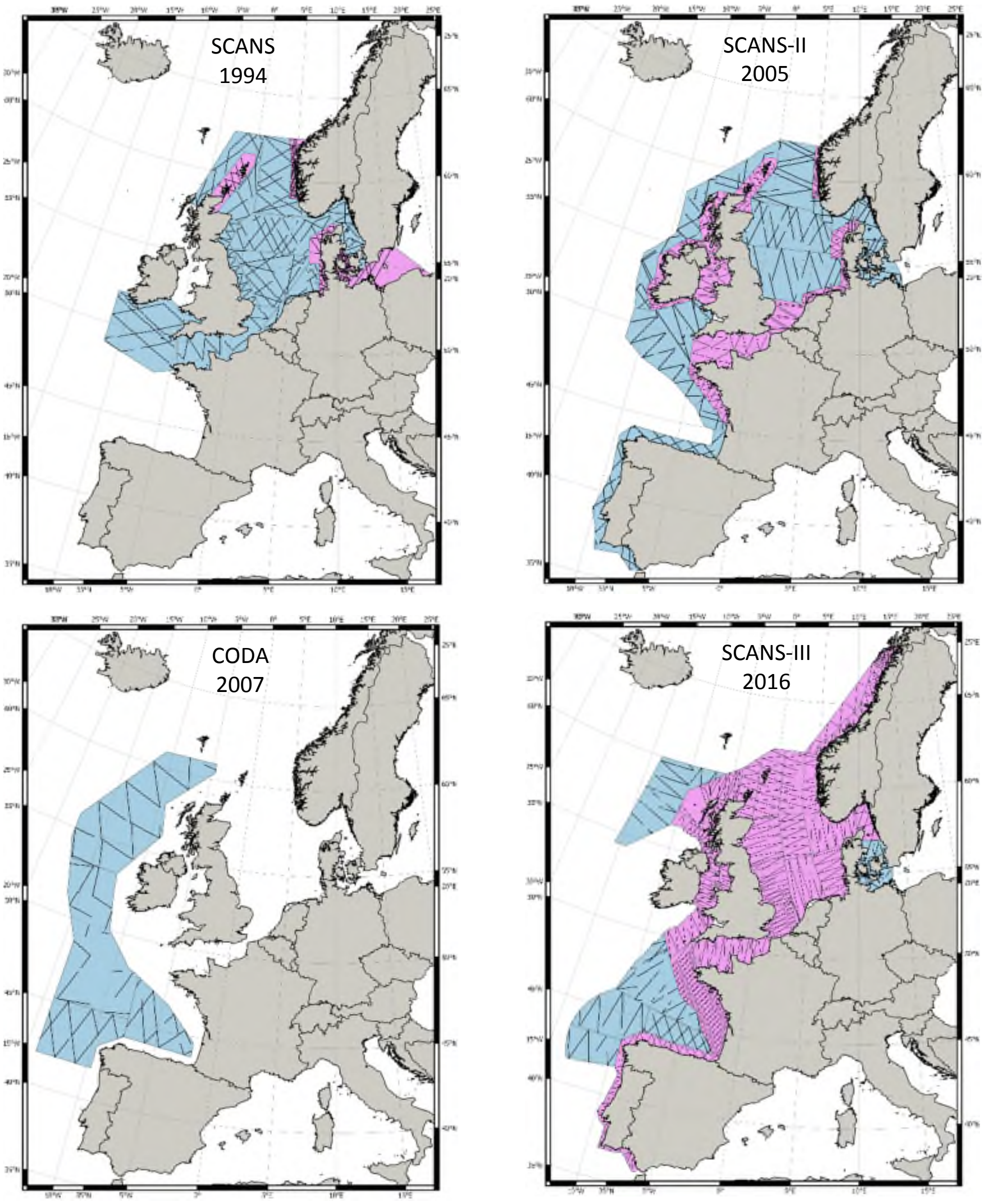


Figure 8. Areas surveyed, with on effort transect lines, by SCANS in 1994 (top left), SCANS-II in 2005 (top right), CODA in 2007 (bottom left) and SCANS-III in 2016 (bottom right).

There were two main reasons for choice of survey platform in 2016, the first of which was cost. Unlike SCANS and SCANS-II, SCANS-III was not supported by the European Commission LIFE programme and funding was limiting. Two ships were available from project partners but additional survey platforms needed to be chartered to cover the large majority of the survey area. Although the cost per flying hour is high, the cost per km searched is about five times higher for a ship than an aircraft due differences in survey speed. Detection probability and, therefore, effective strip width is smaller from an aircraft than from a ship, but aerial survey is still considerably cheaper than ship survey.

The second reason to focus on aerial survey was because of confidence in the now well-established data collection and analysis methodology. The tandem aircraft method developed for surveying harbour porpoise in the first SCANS survey in 1994 (Hiby & Lovell 1998) has been superseded by the more efficient circle-back ("racetrack") method first used in SCANS-II in 2005 (Hiby 1999). These methods have since been extensively used in regular surveys in European waters (e.g. Gilles et al. 2009; Scheidat et al. 2008; 2012).

The new development in SCANS-III was to employ the circle-back method for dolphin species (bottlenose, white-beaked, white-sided, common and striped) and for minke whale to obtain more appropriate corrections for missing animals on the transect line (i.e., g(0)). The smaller sample sizes for these species meant that some simplifying assumptions had to be made. In particular, it was assumed that groups of these species spend a similar proportion of time at the surface as harbour porpoise and that the rates and distribution of any displacement between the leading and trailing sections of effort are also similar to harbour porpoise. Nevertheless, these new estimates of g(0) are better than previously used corrections, which were limited to accounting only for availability bias (not perception bias) based on surfacing rates available from other studies and areas (see Hammond et al. 2013). Revised abundance estimates for dolphin species and minke whale from SCANS-II in 2005 using these new estimates of g(0) are therefore a marked improvement.

Overall, while estimates for species not commonly seen in shelf waters have not been corrected, extension of the use of the circle-back method has allowed us to generate unbiased estimates of abundance for harbour porpoise, dolphin species and minke whale.

Anomalous data from M/V Skoven

On one of the ships (M/V Skoven), which surveyed offshore waters west of Scotland and the northern Bay of Biscay, the data for large baleen whales (the large majority of which were fin whales) were compromised by atypical searching patterns by both Tracker and Primary observers. Tracker observers focussed too close to the transect line resulting in their observations being aggregated at small perpendicular distances. This had the effect that the conditional probability of detection by Primary observers was smaller close to the transect line than further away, violating a fundamental principle of line transect sampling.

In addition, Primary observers tended to detect large baleen whales much further ahead of the vessel than dictated by the protocol (searching within 500m of the ship). Even if protocol is followed on the Primary platform, the easily detected blow of the fin whale may be detected in peripheral vision. This led to many fin whale groups either being detected by Tracker and Primary at the same time or being detected by Primary before Tracker, which cannot be included as Tracker "trials" in analysis. The lack of separation of Tracker and Primary searching areas violates the requirement of the two-team tracker method.

The result of these anomalies in the large baleen whale data from M/V Skoven meant that it was not possible to conduct a two-team analysis. Instead, fin whale abundance in areas surveyed by M/V Skoven (blocks 8 and 9) was estimated from Primary platform data in a conventional single platform analysis. Fin whale abundance in these areas is therefore likely underestimated. These problems did not occur on the other ship surveying offshore waters and fin whale abundance in areas surveyed by B/O Angeles Alvariño (blocks 11, 12 and 13) was estimated using the planned two-team analysis.

The difficulty of conducting a two-team survey with the tracker protocol for large baleen whales has been recognised previously. The high visibility of fin whale blows and the long period that they are available to be detected means that g(0) for this species is likely to be relatively close to 1. However, a single platform analysis of the B/O Angeles Alvariño data generated a fin whale abundance estimate around 2/3rd of the size of the two-team analysis, implying that assuming g(0)=1 would lead to an underestimate.

The common and striped dolphin data collected on M/V Skoven were also anomalous in that the large majority of Tracker sightings were made close to the transect line. Primary conditional detection probability also increased with perpendicular distance but the sample sizes at distances greater than 100m were small; 78% of Tracker sightings were made within 100m of the transect line. When data from the two ships were analysed together, the conditional detection probability did not increase with perpendicular distance so a combined analysis was judged to be appropriate for common and striped dolphins.

The anomalous data collected on M/V Skoven illustrate the importance of following data collection protocol. If the large majority of Tracker trials are made very close to the transect line then random movement in either direction will result in perpendicular distance tending to increase by the time the animals become available to be seen by Primary observers. This seems likely to be the explanation for the apparent increase in Primary conditional detection probability with perpendicular distance for fin whale and common/striped dolphins.

New information on distribution and abundance

Harbour porpoise

The observed distribution of harbour porpoises in 2016 was similar to that observed in SCANS-II in 2005 (Hammond et al. 2013) but one notable difference is that more sightings were made throughout the English Channel (block C) in 2016 than previously. In 1994, no sightings were made in the Channel or the southern North Sea (Hammond et al. 2002). In 2005, there were a number of sightings at the far western end of the Channel (Hammond et al. 2013) and in the SAMM survey in 2012 there were sightings in both the western and eastern parts, but not the central part (Laran et al., in press). The sightings throughout the Channel in 2016

In the ICES AUs (see Figure 2), the estimates in 2016 and 2005 are compatible in the Iberian peninsula AU (2,900, CV = 0.32 and 2,880, CV = 0.72, respectively), and in the West Scotland AU (24,400, CV = 0.23 and 26,300, CV = 0.37). The southern part of the West Scotland AU was covered by the Irish ObSERVE project and information for this area is not yet available for 2016. In the Kattegat and Belt Seas AU, the estimate for 2016 of 42,000 (CV = 0.23) is consistent in terms of area surveyed only with the estimate for 2012 of 40,000 (CV = 0.24) (Viquerat et al., 2014). In the North Sea the estimate in 2016 (345,000, CV = 0.18) was similar to the estimate in 2005 (355,000, CV = 0.22; revised from Hammond et al. 2013) and 1994 (289,000, CV = 0.14; revised from Hammond et al. 2002), and to the model-based estimate using data from 2005-2013 of 361,000 (0.20) (Gilles et al. 2016). Results of the trend analysis of estimates in the North Sea and the Skagerrak/Kattegat/Belt Seas show no support for changes in abundance since 1994.

The SCANS-III survey covered only a part of the Celtic and Irish Seas AU; the remaining part of the AU was covered by the Irish ObSERVE project, for which no estimate is available yet. It is thus not possible to present an estimate for this Assessment Unit at this time.

Bottlenose dolphin

The observed distribution of bottlenose dolphins in 2016 was similar to that observed in SCANS-II and CODA in 2005/07 (Hammond et al., 2013; CODA 2009) but most of the offshore sightings in 2007 were made in the ObSERVE survey area, for which information for 2016 is not yet available. The estimate of abundance for 2016 of 27,700 (CV = 0.23) is smaller than that from 2005/07 of 35,900 (CV = 0.21) (WGMME 2017) but a direct comparison between estimates for 2016 and 2005/07 should not be made until estimates are available for equivalent areas.

White-beaked dolphin

The observed distribution of white-beaked dolphins in 2016 is similar to that observed in SCANS-II in 2005 (Hammond et al., 2013) and in SCANS in 1994 (Hammond et al., 2002). The estimate of abundance in 2016 of 36,300 (CV = 0.29) is very similar to the estimate from SCANS-II in 2005 of 37,700 (CV = 0.36) (revised from Hammond et al. 2013) but higher than the estimate from SCANS in 1994 of 22,600 (CV = 0.23) (revised from Hammond et al. 2002). Results of the trend analysis of estimates in the North Sea show no support for changes in abundance since 1994.

Common and striped dolphins

The observed distributions of common and striped dolphins in 2016 are similar to those observed in SCANS-II and CODA in 2005/07 (Hammond et al., 2013; CODA 2009) and in the SAMM surveys in the Channel and French waters of the Bay of Biscay in summer 2012 (Laran et al., in press). Some sightings in 2005 and 2007 were made in the ObSERVE survey area, in which information for 2016 is not yet available. The distribution of common dolphins appears to be strongly concentrated in shelf waters but a substantial number of unidentified common or striped dolphin sightings were also made in offshore waters, at least some of which were likely to have been common dolphins. Striped dolphins appear to be strongly concentrated in offshore waters but some of the unidentified sightings in shelf waters could have been striped dolphins.

The estimates of abundance in 2016 of 468,000 (CV = 0.26) common dolphin, 372,000 (CV = 0.33) striped dolphin and 158,000 (CV = 0.19) unidentified common or striped dolphins sum to almost one million animals. These estimates are substantially larger than the estimates for 2005/2007 of 174,000 (CV = 0.27) common dolphin and 61,400 (CV = 0.93) striped dolphin, respectively (revised from Hammond et al., 2013; CODA 2009). A direct comparison between estimates for 2016 and 2005/07 should not be made until estimates are available for equivalent areas.

However, the estimate of common and striped dolphins in summer 2012 from the SAMM surveys in the Channel and French waters in the Bay of Biscay was around 700,000 animals (Laran et al., in press). The SAMM survey area did not include Spanish waters that were included in SCANS-III in 2016 and the estimate was not corrected for animals missed on the transect line. The estimates from SCANS-III in 2016 and SAMM in 2012 therefore appear to be compatible.

Long-finned pilot whale

The observed distribution of pilot whales was similar in 2016 to that observed in SCANS-II and CODA in 2005/07 (Rogan et al., in press) but the majority of the sightings in 2007 were made in the ObSERVE survey area, for which information for 2016 is not yet available. The absence of information from Irish waters may partly explain why the estimate of abundance for 2016 of 25,800 (CV = 0.35) is considerably smaller than that from 2005/07 of 124,000 (CV = 0.35) (Rogan et al., in press) but a direct comparison should not be made until estimates are available for equivalent areas.

Beaked whales (all species)

The observed distribution of beaked whales was similar in 2016 to that observed in CODA in 2007 (CODA 2009) and from opportunistic sightings (WGMME 2016). Some of these sightings were made in the ObSERVE survey area, for which information for 2016 is not yet available.

The estimate of abundance of all beaked whale species combined for 2016 of 11,400 (CV = 0.50) is similar to the equivalent estimate from SCANS-II and CODA in 2005/2007 of 12,900 (CV = 0.31) (Rogan et al., in press) but a direct comparison should not be made until estimates are available for equivalent areas.

Sperm whale

The observed distribution of sperm whales was similar in 2016 to that observed in CODA in 2007 (Rogan et al., in press). Some of these sightings were made in the ObSERVE survey area, for which information for 2016 is not yet available.

The estimate of abundance of sperm whales in 2016 of 13,500 (CV = 0.41) is larger than the estimate from CODA in 2007 of 2,600 (CV = 0.26) for identified sperm whales and the estimate of 5,600 (CV = 0.32) if a proportion of unidentified large whales is included (Rogan et al., in press). However, a direct comparison should not be made until estimates are available for equivalent areas.

Minke whale

Between 1994 and 2005 there was some evidence that minke whale distribution in the North Sea had shifted to the south (Hammond et al. 2013). The observed distribution of minke whale in 2016 was similar to that observed in 2005 in the North Sea, and similar overall to that in 2005/07 (Hammond et al., 2013; Hammond et al., 2011). However, many sightings in 2007 were made in the Irish ObSERVE survey area, in which information for 2016 is not yet available.

The estimate of abundance in 2016 of 14,800 (CV = 0.33) is smaller than the estimate for 2005/07 from SCANS-II and CODA of 26,800 (CV = 0.35) (revised from Hammond et al. 2011). This may be partly because of the lack of an estimate in Irish waters but a direct comparison should not be made until estimates are available for equivalent areas. The estimate for 2016 in the North Sea was 8,900 (CV = 0.24), which is within the range of previous estimates from SCANS, SCANS-II and Norwegian surveys and results of the trend analysis of estimates in the North Sea show no support for changes in abundance since 1989.

Fin whale

The observed distribution of fin whales in 2016 was similar to that observed in CODA in 2007 (Hammond et al., 2011). The estimate of abundance in 2016 of 18,100 (CV = 0.38) is very similar to the estimate from 2007 of

19,300 (CV = 0.24) for identified fin whales but smaller than the estimate for 2007 that included a proportion of unidentified large whales of 29,500 (CV = 0.21) (Hammond et al., 2011). Analyses to account for unidentified large whales have not yet been undertaken for the SCANS-III data. The 2007 estimate also included waters to the west of Ireland, which SCANS-III did not, and a direct comparison should not be made until estimates are available for equivalent areas.

Concluding remarks - lessons learned from the SCANS experience

Overall, the results from these large-scale international surveys have greatly expanded our knowledge of the distribution and abundance of cetacean species in the European Atlantic, enabling bycatch and other anthropogenic stressors to be placed in a population context and giving a strong basis for assessments of conservation status. The information now available forms a good foundation for a large-scale time series for the coming decades.

SCANS-type surveys as stand-alone projects require considerable resources focussed at one point in time. However, considering their current decadal-scale frequency and the number of countries involved (around 10), the annual cost per country is small. Even if the frequency were increased to match EU Directive reporting cycles of 6 years, they should be readily affordable.

Although there have been three successful SCANS projects, they do not form a programme of surveys; each one has been developed from scratch by a team of dedicated scientists. If European Atlantic range states value the information provided by SCANS it would be more appropriate for future surveys to be driven by government agencies responsible for implementing national and European policy.

The results presented to date will be integral to cetacean assessments undertaken for OSPAR's Quality Status Report and for the Marine Strategy Framework Directive assessments of Good Environmental Status. The results also enable the impact of bycatch and other anthropogenic pressures on cetacean populations to be determined, fulfilling a suite of needs under the EU Habitats Directive and the Agreement on the Conservation of Small Cetaceans in the Baltic, North east Atlantic, Irish and North Seas (ASCOBANS). Estimates of absolute (unbiased) abundance are required for these tasks, at least periodically, and SCANS-type two-team survey methods are needed to achieve this.

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