SCANS-IV 2022

Estimates of cetacean abundance in European Atlantic waters in summer 2022 from the SCANS-IV aerial and shipboard surveys

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Contents

INTRODUCTION

In the early 1990s, the high bycatch of harbour porpoise in gillnet fisheries in the North and Celtic Seas prompted researchers from Range States to develop a project to survey these waters with the aim of obtaining the first comprehensive estimates of abundance of harbour porpoise. As a result, the first large-scale line transect (distance) sampling survey for cetaceans (Small Cetaceans in European Atlantic Waters and the North Sea, known as SCANS) was conducted in summer 1994 (Hammond et al. 2002). SCANS generated abundance estimates for harbour porpoise that allowed bycatch (and other anthropogenic pressures) to be assessed in a population context. Abundance was also estimated for white-beaked dolphin and minke whale in the North Sea.

SCANS 1994 was envisaged to be the first in a series of large-scale, long-term surveys with an approximately decadal frequency. Accordingly, a second survey covering all European Atlantic shelf waters was conducted in 2005 (SCANS-II 2008; Hammond et al. 2013), supplemented by a survey in offshore waters in 2007 (CODA 2009). A third survey, SCANS-III, followed in 2016 (Hammond et al. 2021) covering the same area as SCANS-II and CODA combined but excluding waters to the south and west of Ireland, which were surveyed by the ObSERVE project in 2015 and 2016 (Rogan et al. 2018).

The motivation for ongoing surveys continues to be providing robust estimates of abundance to allow an assessment of anthropogenic pressures, such as bycatch. Moreover, there is a need to provide information on distribution and abundance of cetaceans required by Range States to report on Favourable Conservation Status under the Habitats Directive and on Good Environmental Status (GES) under the Marine Strategy Framework Directive (MSFD) (or National equivalent). This information is also needed for impact assessments of offshore industries, especially renewable energy. The Habitats Directive and MSFD have a reporting cycle of six years, and a fourth survey was thus planned for the early 2020s.

A primary aim of SCANS-IV was to provide robust large-scale estimates of cetacean abundance to inform the upcoming MSFD assessment of GES in European Atlantic waters in 2024. Some surveys generating robust estimates of abundance have been conducted since the SCANS-II/CODA surveys in 2005/2007, as detailed in Geelhoed et al. (2022), 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-IV: harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), Risso's dolphin (*Grampus griseus*), white-beaked dolphin (*Lagenorhynchus albirostris*), white-sided dolphin (*Lagenorhynchus acutus*), short-beaked common dolphin (*Delphinus delphis*), striped dolphin (*Stenella coeruleoalba*), long-finned pilot whale (*Globicephala melas*), beaked whales (all species combined; Cuvier's beaked whale (*Ziphius cavirostris*), Sowerby's beaked whale (*Mesoplodon bidens)* and unidentified beaked whale), fin whale (*Balaenoptera physalus*) and minke whale (*Balaenoptera acutorostrata*).

METHODS

Study area and survey design

The initial objective of SCANS-IV 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 included offshore waters of Portugal, which had not previously been surveyed as part of SCANS; but excluded waters to the south and west of Ireland, which were surveyed by the ObSERVE2 project in 2021/2022 (Figure 1). Also, coastal Norwegian waters north to Vestfjorden, which were surveyed as part of SCANS-III, were not included in SCANS-IV. The size and boundaries of survey blocks were determined partly by logistics but also to encompass designated/proposed protected areas or other areas of high probability of species occurrence in some cases.

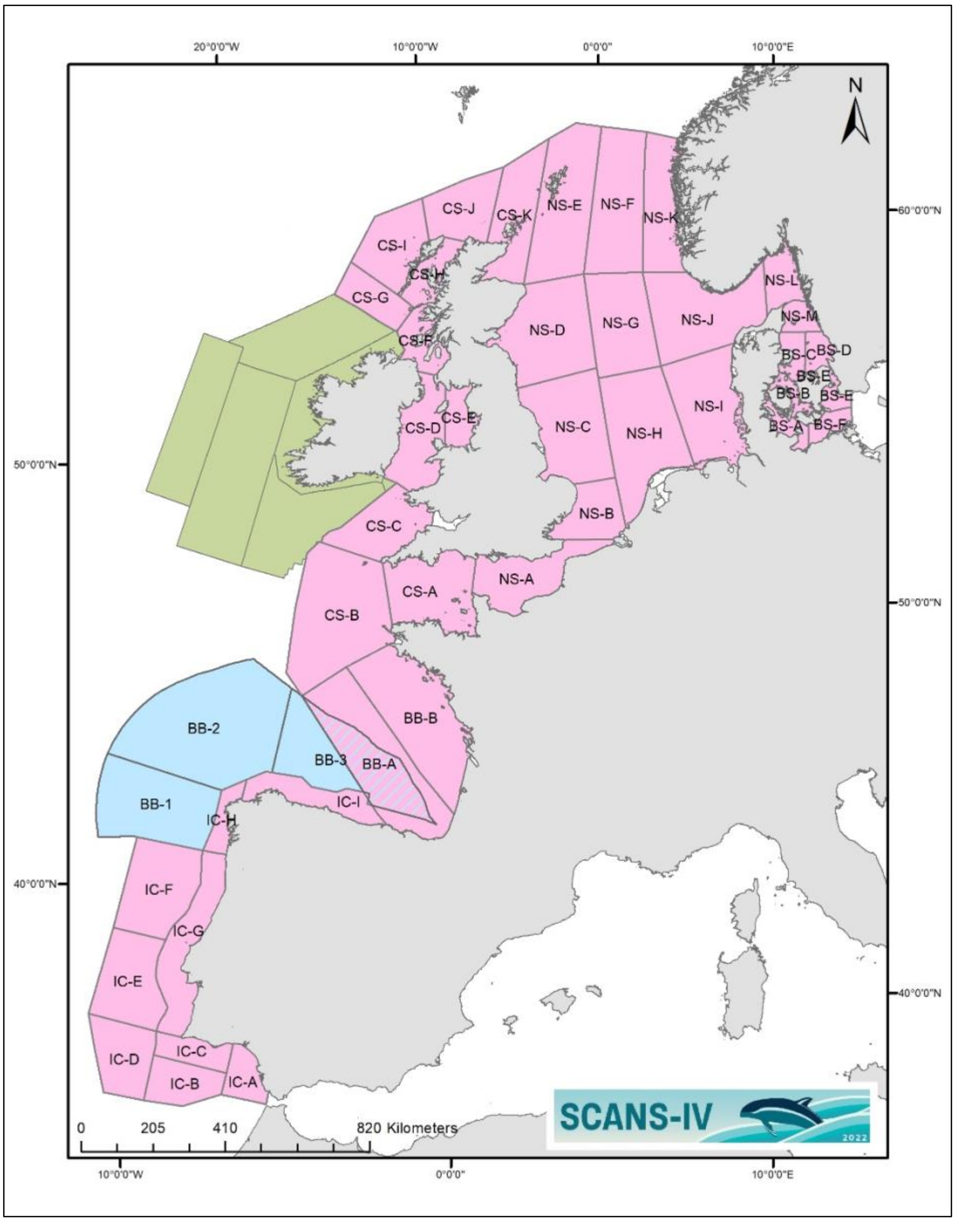

Figure 1. Area covered by SCANS-IV: pink blocks were surveyed by air and blue blocks were surveyed by ship. The cross-hatched area is where the ship survey BB-3 and aerial survey block BB-A overlapped in an area of 39,018 km^2. Blocks coloured green to the south and west of Ireland were surveyed by the Irish ObSERVE2 project.

For the aerial surveys, overall coverage probability was determined by available resources (total flying hours). Searching effort was distributed approximately equally to all blocks. For the ship survey, overall coverage probability was determined by available resources (survey days), accounting for some time expected to be unavailable for surveying due to poor weather.

Surveys within blocks were designed to provide equal coverage probability, using the equal spaced zig-zag option, and in coastal blocks the parallel option, in R 4.0.5 x64 (R Core Team 2021) using the survey design R package dsss (Marshall 2023). 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.

Within each aerial survey block, three sets of random transect lines (replica) were generated with the minimal aim that at least one set would be covered in each block and the expectation that two would be covered in most blocks, depending on the weather and logistic constraints (e.g., active military areas).

Data collection

Aerial survey

Each of the eight aircraft accommodated three scientific crew members in addition to the pilot. Target altitude was 600 feet (183 m) and target speed was 90-100 knots (167-185 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 SCANS-III (Hammond et al. 2021) 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 SCANS-II, the circle-back method has only been used for harbour porpoise. In SCANS-III and SCANS-IV, 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.

Data were recorded with the dedicated software for aerial survey SAMMOA 2.1.3 (SAMMOA 2022). SAMMOA builds on the VOR data collection software used in previous SCANS but offers many enhancements such as being compatible with newest windows version, implementing simultaneous audio recordings and data validation. The same software and field protocol was used in the ObSERVE2 surveys and a week-long joint training session for all cruise leaders was held in May 2022.

The digital STORMM high-definition image acquisition system was deployed by Team 6 in blocks CS-B, BB-A and BB-B (Figure 1) to take pictures for species confirmation in the post-processing data validation step. These digital pictures (Appendix A2) are analysed by a human operator to validate species identification and group size of visual sightings, especially in the case of unidentified common/striped dolphin sightings.

Bird wrecks: Due to the significant impacts of the Highly Pathogenicity Avian Influenza (HPAI) on seabirds in 2022 reported from land-based studies, the *ad-hoc* decision was made shortly before the start of the survey to collect observations of floating dead birds during the aerial surveys to support efforts to understand the scale of impact. These bird wrecks were recorded following the same protocol as other sightings, but as secondary data to the target species for which the surveys were taking place. These data are available for use in subsequent and ongoing analyses into the impacts of Avian Influenza (Appendix A5).

Ship survey

The ship survey used a double platform configuration with two independent teams of observers to generate data that would allow abundance estimates to be corrected not only for animals missed on the transect line, but 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, CODA and SCANS-III (Hammond et al. 2002, CODA 2009, Hammond et al. 2013, Hammond et al. 2021).

The survey ship accommodated eight observers working in two teams. Target survey speed was 10 knots (18.5 km.h^{-1}) 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 datarecorder 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. Distance to detected groups was measured on Primary using purpose-designed and individually calibrated measuring sticks and on Tracker as a binocular reticule reading. 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.

Estimation of abundance

Abundance was estimated using the same methods as for SCANS-III; the following description is taken from the report on design-based estimates of abundance from that survey (Hammond et al. 2021).

Aerial survey

Only survey effort collected under good and moderate sighting 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 block *v* was estimated as:

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

where A_v is the area of the block, 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 block, n_{msv} is the number of sightings of groups that occurred in moderate sighting conditions in the block and s_v is the mean observed group size in the block. Exploratory plots indicated no dependence of group size on perpendiculardistance, nor was group size found to be a significant explanatory variable for detection probability.

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

Coefficients of variation (CVs) and 95% confidence intervals (CIs) were estimated by bootstrapping within blocks (or combinations of blocks for harbour porpoise AUs – see below). 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 assumes 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 4.2.3 x64 (R Core Team 2023) using the package 'Distance' (Miller 2015, Miller et al. 2019).

Ship survey

Analysis of the shipboard data followed the double-platform line transect methodology used in the SCANS-II and SCANS-III surveys (Borchers et al. 1998, Laake & Borchers 2004, Hammond et al. 2013, Hammond et al. 2021) 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 z, was detected from Primary is denoted p1(x, 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 (Laake & Borchers 2004, Borchers et al. 2006). This model uses the Primary data to estimate detection probability assuming g(0) = 1, and 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.

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

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 (Laake & Borchers 2004, Borchers et al. 2006). 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.

To determine whether the full independence model needed to be considered 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. In addition, partial independence and full independence mrds models were compared using AIC. Details of these explorations are given in Appendix A1.

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 (Cramer-von Mises tests), while minimising the amount of data lost. For all species, data from sea conditions of Beaufort 4 or less were used. Duplicates classified as D (Definite) and P (Probable) were considered to be duplicates; those classified as R (Remote) were not.

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

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

where n_1 is number of detections made from Primary, W is perpendicular truncation distance and are the estimated parameters of the fitted detection function.

The abundance of individuals was estimated by replacing the numerator in equation 2 with s_{1j}, the group size of the j^{th} group recorded from Primary. 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).

However, group sizes recorded on Tracker platform are typically larger and likely to be more accurate than those recorded on Primary platform because they were observed through binoculars and typically multiple times. Consequently, a correction factor was estimated as the ratio of the sum of Tracker group sizes to the sum of Primary group sizes calculated from duplicate observations. If the group size correction factor was estimated as > 1, the estimate of abundance of individuals was multiplied by the correction factor. The CV of corrected abundance and group size was estimated using the delta method (Borchers et al. 1998). If the group size correction factor was estimated as < 1, it was set to 1 and no correction was made.

Where there were insufficient duplicate sightings to support double-platform methods, the unique observations from Tracker and Primary platforms were combined and conventional line transect methods (assuming certain detection on the transect line) using the DISTANCE mrds "single observer" option 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.

To avoid double-counting the overlapping survey area (39,018 km^2) between the aerial block BB-A and the ship block BB3 in the Bay of Biscay (Figure 1), the most reliable estimate was prioritised on a species-by-species basis when considering the effort coverage in favourable survey conditions as well as the CV of the estimates in these two blocks. Consequently, the other block was post-stratified, and the overlapping area cut out to finally end up with a representative combined estimate for the two blocks. For bottlenose dolphin, common dolphin, striped dolphin and the category "unidentified common or striped dolphin" the full estimate from the aerial survey block BB-A was considered more reliable (smaller CV, favourable sighting conditions) and the estimate from BB-3 for the overlapping area was subtracted. For fin whale and beaked whales, on the other hand, the estimate from the ship survey in BB3 was considered more reliable since the CVs were smaller and a fully corrected abundance estimate could be produced from the double-platform data; consequently, the estimate from BB-A for the overlapping area was subtracted.

In addition, for harbour porpoise, estimates are presented for the current harbour porpoise Assessment Units (AUs), which have recently been updated (IMR/NAMMCO 2019) and used for the recent OSPAR Quality Status Report 2023 (for indicator "Cetacean abundance and distribution" Geelhoed et al. 2022) as well as the HELCOM HOLAS 3 assessment (HELCOM 2023a) (Figure 2).

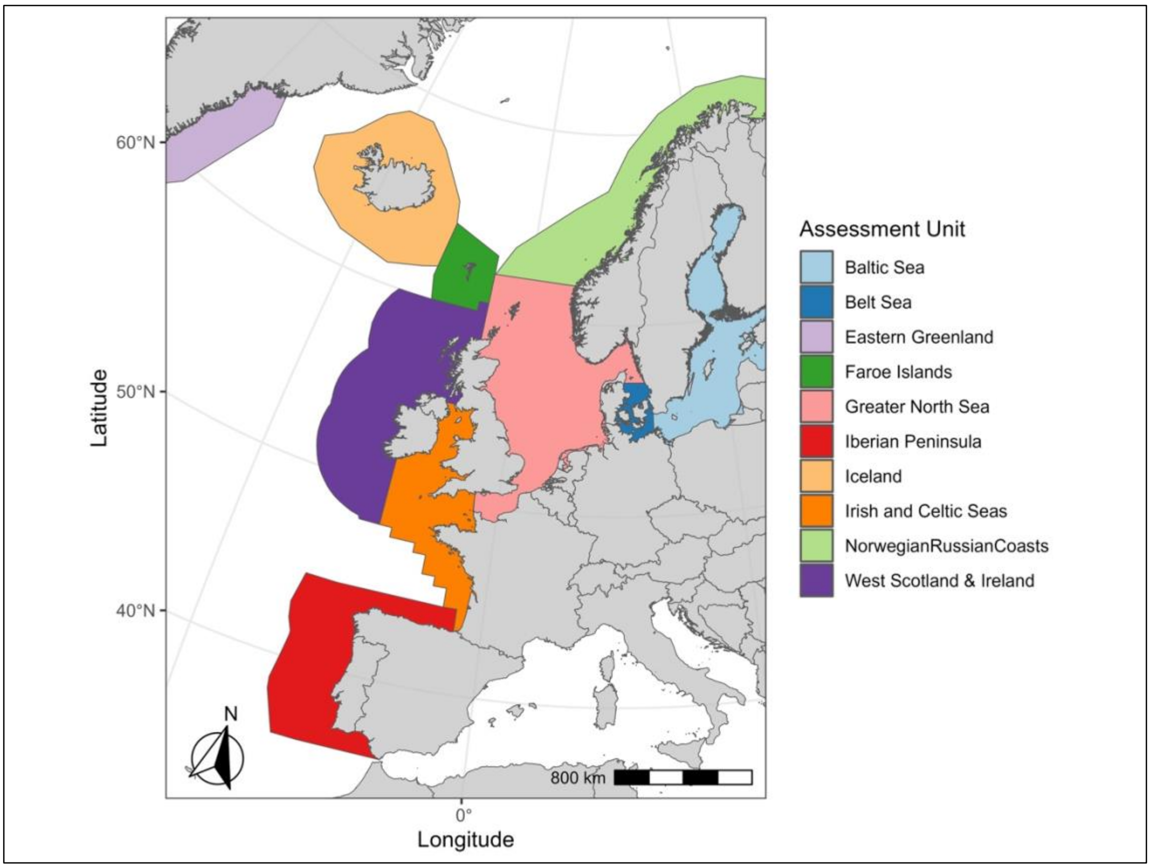

Figure 2. Assessment Units for harbour porpoise in the North-East Atlantic, based on IMR/NAMMCO (2019).

For the harbour porpoise estimates, the SCANS-IV blocks were matched as closely as possible to the defined AUs, as follows:

- Belt Sea: aerial blocks BS-A to BS-F;
- Greater North Sea: aerial blocks NS-A to NS-M;
- West Scotland & Ireland: aerial blocks CS-F to CS-K (Note: ObSERVE2 estimates will be added once available);
- Irish and Celtic Seas: aerial blocks CS-A to CS-E, BB-B (Note: ObSERVE2 estimates will be added once available);
- Iberian Peninsula: aerial blocks IC-A to IC-I.

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

For bottlenose dolphin, ten AUs have been defined for resident or semi-resident coastal/inshore populations, and a single offshore "oceanic area" AU was defined to cover all waters not covered by the coastal/inshore AUs (Evans & Teilmann 2009, ICES 2013, ICES 2014a, IAMMWG 2015). It is not appropriate (or possible) to separate out the coastal/inshore populations in the SCANS-IV survey, thus, the total estimate represents these and the "oceanic area" combined. Separate estimates for the coastal/inshore populations are summarized in OSPAR's Quality Status Report 2023 (Geelhoed et al. 2022).

For minke whale, white-beaked dolphin, white-sided dolphin and common dolphin, a single AU covering all European Atlantic waters has been defined (ICES 2014a, b). For fin whales, three management areas defined by the International Whaling Commission overlap with the SCANS area. However, for these species, fin whale included, the total abundance estimates represent a single AU. No AUs have been defined for other species.

RESULTS

Realized survey effort and sightings

Eight aircraft surveyed shelf waters of the European Atlantic, mainly between 28th June and 15th August 2022. Due to bad weather and military restrictions, a second attempt to survey northwest Scotland (blocks CS-I and CS-J had a few missing transects) was conducted between 7th and 12th September 2022. The aerial surveys in the three coastal blocks of Spain (IC-A in the south, as well as IC-H and IC-I in the north) were conducted later than the main survey, from 7th September to 22nd October 2022, due to logistical constraints. Summarising by these three periods: 59,660.5 km (83%) were surveyed between 28th June and 15th August; 1,859.2 km (3%) were surveyed in NW Scotland between 7th and 12th September; and 10,132.2 km (14%) were surveyed in Spanish coastal waters between 7th September and 22nd October.

Table 1 shows the amount of effective aerial search effort on transect in each of the survey blocks.

One ship, B/O Ramón Margalef, surveyed waters beyond the continental shelf of the Bay of Biscay between 3rd and 31st July 2022. Table 2 shows the amount of ship search effort on transect in each of the survey blocks. Data recorded up to Beaufort 4 were used in analyses of the ship data, in conformity with previous SCANS surveys resulting in 8% reduction in realized effort. Figure 3 shows the collective realised survey effort achieved under all conditions.

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

Table 1. Area and search effort (excluding 'poor' sighting conditions data that were not used in the analysis) for each aerial survey block. Primary search effort data were used in the 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	Region	Surface area (km²)	Primary search effort (km)	Trailing search effort (km)
BB-A	Bay of Biscay	84,571	3,252.9	21.6
BB-B		77,930	3,512.3	19.5
BS-A	Kattegat/Belt Sea	7,974	968.9	24.4
BS-B		5,929	983.7	31.8
BS-C		8,283	431.8	16.8
BS-D		7,709	928.6	39.9
BS-E		5,157	514.7	7.9
BS-F		7,212	450.8	7.7
CS-A	Celtic Sea	48,861	2,069.3	38.1
CS-B		89,632	3,960.8	43.2
CS-C		36,031	2,471.1	26.6
CS-D		34,867	2,375.2	59.2
CS-E		12,274	740.8	-
CS-F		15,244	948.0	3.5
CS-G		20,105	800.3	3.6
CS-H		13,985	736.5	-
CS-I		35,097	658.7	9.5
CS-J		32,499	882.2	7.9
CS-K		40,378	1,123.4	-

Block	Region	Surface area (km²)	Primary search effort (km)	Trailing search effort (km)
IC-A	Iberian Coast	14,628	2,930.0	19.4
IC-B		23,371	751.4	-
IC-C		15,743	1,227.2	-
IC-D		32,906	317.9	-
IC-E		44,822	965.8	-
IC-F		50,974	1,361.1	-
IC-G		43,175	4,144.1	3.6
IC-H		9,926	2,338.2	89.1
IC-I		33,291	4,864.1	68.4
NS-A	North Sea	38,782	1,743.1	42.8
NS-B		25,785	1,719.9	-
NS-C		60,203	3,792.2	65.0
NS-D		64,455	1,703.8	15.7
NS-E		65,423	1,603.9	11.7
NS-F		60,051	1,195.9	-
NS-G		49,672	1,264.7	37.8
NS-H		69,317	3,393.4	11.7
NS-I		56,098	3,512.5	58.1
NS-J		63,546	1,940.5	29.7
NS-K		38,339	1,253.4	18.9
NS-L		15,135	913.7	29.0
NS-M		7,979	905.4	44.1
Total		**1,467,358**	**71,651.9**	**906.3**

Table 2. Area and search effort for each ship survey block. For estimation of abundance, search effort was limited to Beaufort 0-4.

Block	Region	Surface area (km²)	Search effort Beaufort 0-4 (km)
BB1	Atlantic - west of Spain	68,366	1,354.8
BB2	Atlantic – west of Spain / Bay of Biscay	126,889	1,464.8
BB3	Bay of Biscay	75,429	1,245.6
Total		**270,684**	**4,065.2**

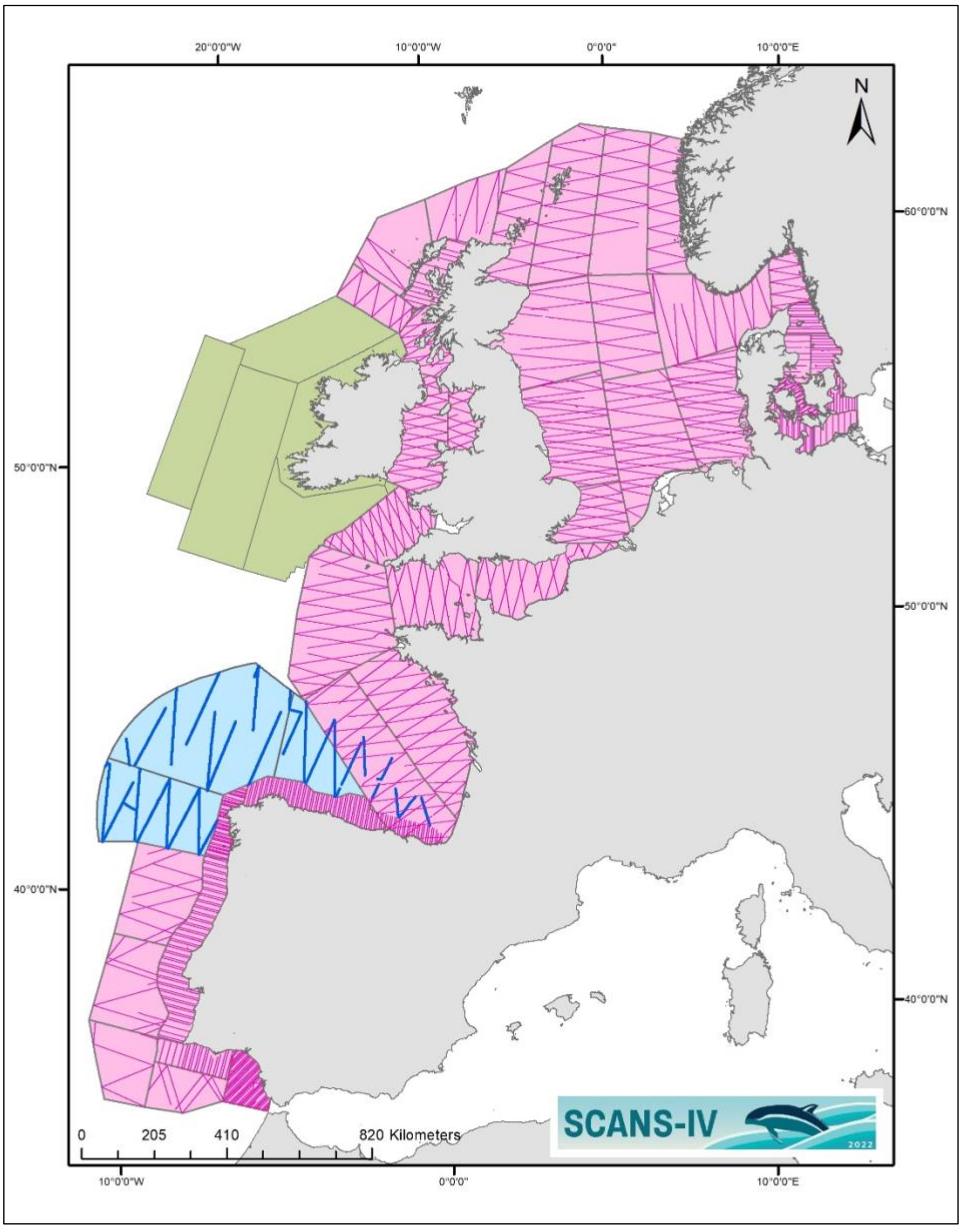

Figure 3. Total search effort achieved under all conditions in aerial (pink) and ship (blue) survey blocks. Blocks coloured green to the south and west of Ireland were surveyed by the Irish ObSERVE2 project.

Table 3. Total number of sightings of the most commonly detected species (or species groupings) from the aerial survey recorded in good or 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 / species grouping	Sightings on primary search effort	Sightings on trailing search effort
Harbour porpoise	2,045	76
Bottlenose dolphin	339	17
Risso's dolphin	30	-
White-beaked dolphin	104	6
White-sided dolphin	11	-
Common dolphin	992	31
Striped dolphin	87	3
Unidentified common or striped dolphin	330	15
Unidentified dolphin	149	2
Pilot whale	26	-
Cuvier's beaked whale	15	-
Sowerby's beaked whale	2	-
Unidentified beaked whales	13	-
Fin whale	134	5
Minke whale	78	2

The following species were sighted in the aerial surveys but with too low a sighting rate to determine abundance estimates (number of sightings in parenthesis): killer whale (6), false killer whale (3), pygmy or dwarf sperm whale (10), sperm whale (6), sei whale (1) and blue whale (1).

Table 4. Number of sightings of the most commonly detected species or species groupings from the ship survey in sea conditions 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 the analysis.

Species / species grouping	Total sightings	Primary sightings	Tracker sightings	Duplicates
Bottlenose dolphin	39	26	24	11
Common dolphin	84	64	46	26
Striped dolphin	30	20	20	10
Unidentified common or striped dolphin	91	27	79	15
Beaked whales (all species)	29	12	20	3
Sperm whale	12	3	10	1
Fin whale	263	159	180	76

As in the aerial survey, the following species were sighted in the ship survey but with a too low a sighting rate to determine abundance estimates (number of sightings in parenthesis): pilot whale (3), Risso's dolphin (3), minke whale (1), sei whale (1) and blue whale (1).

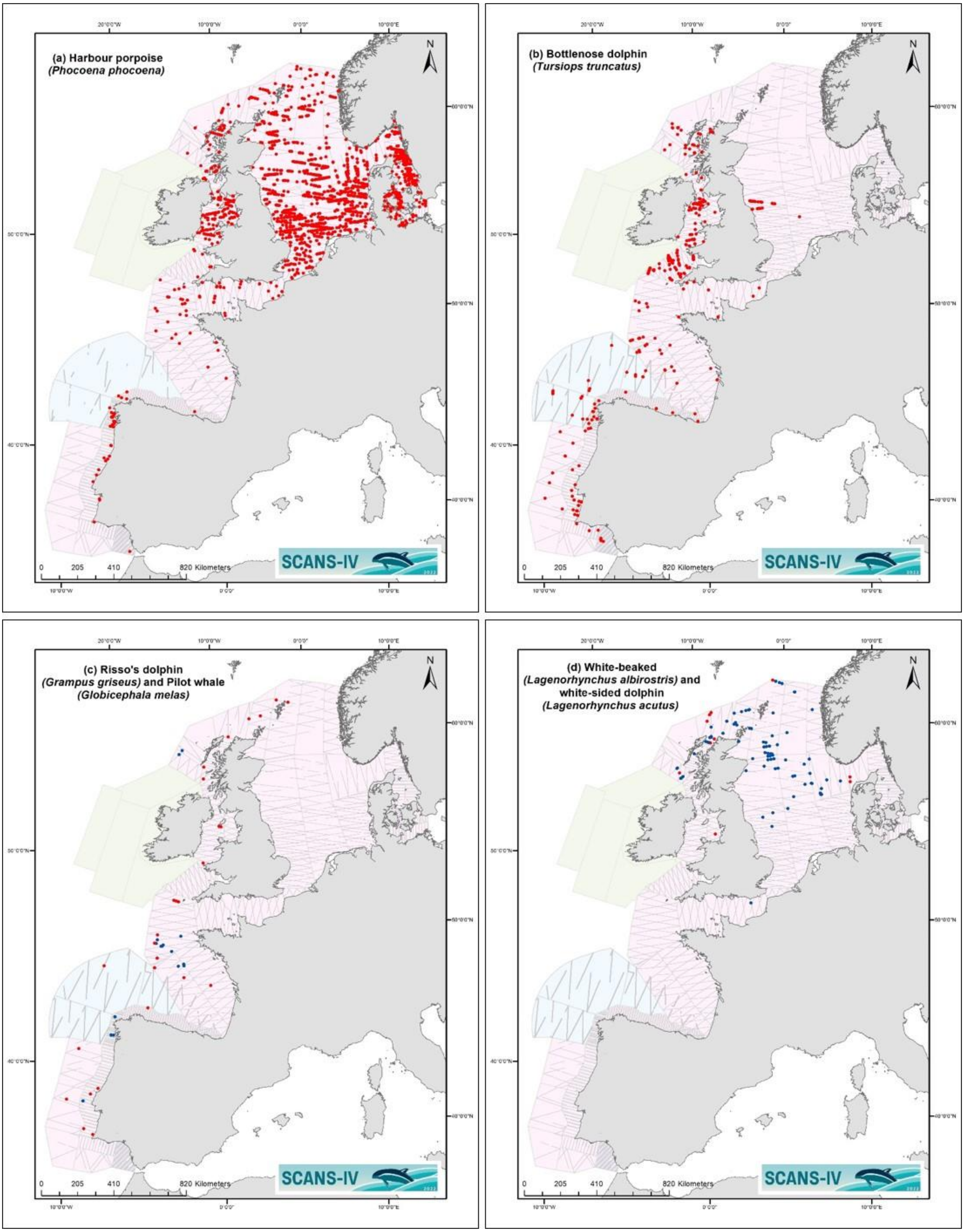

Figure 4. Distribution of sightings used in the analyses of the most commonly detected species. Underlying effort is that used in the analysis: aerial survey - good and moderate sighting conditions; ship survey - Beaufort 0-2 for harbour porpoise, Beaufort 0-4 for all other species. (a) harbour porpoise;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

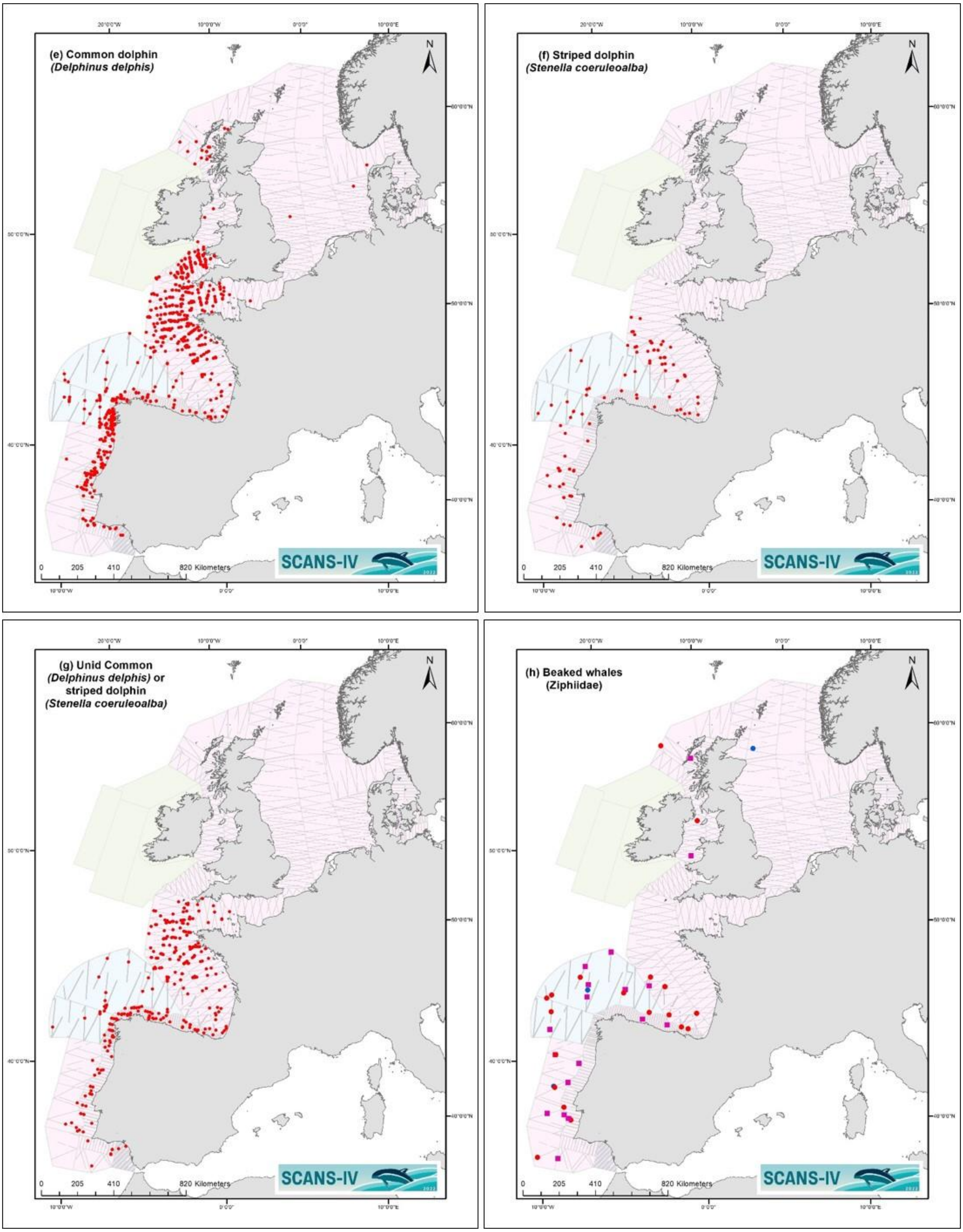

Figure 4 (continued). Distribution of sightings used in the analyses of the most commonly detected species. Underlying effort is also that used in the analysis: aerial survey - good and moderate sighting conditions; ship survey - Beaufort 0-4. (e) common dolphin; (f) striped dolphin; (g) unidentified common or striped dolphin; h) beaked whales (Cuvier's beaked whale - red dot; Sowerby's beaked whale - blue dot; unidentified beaked whale - pink square).

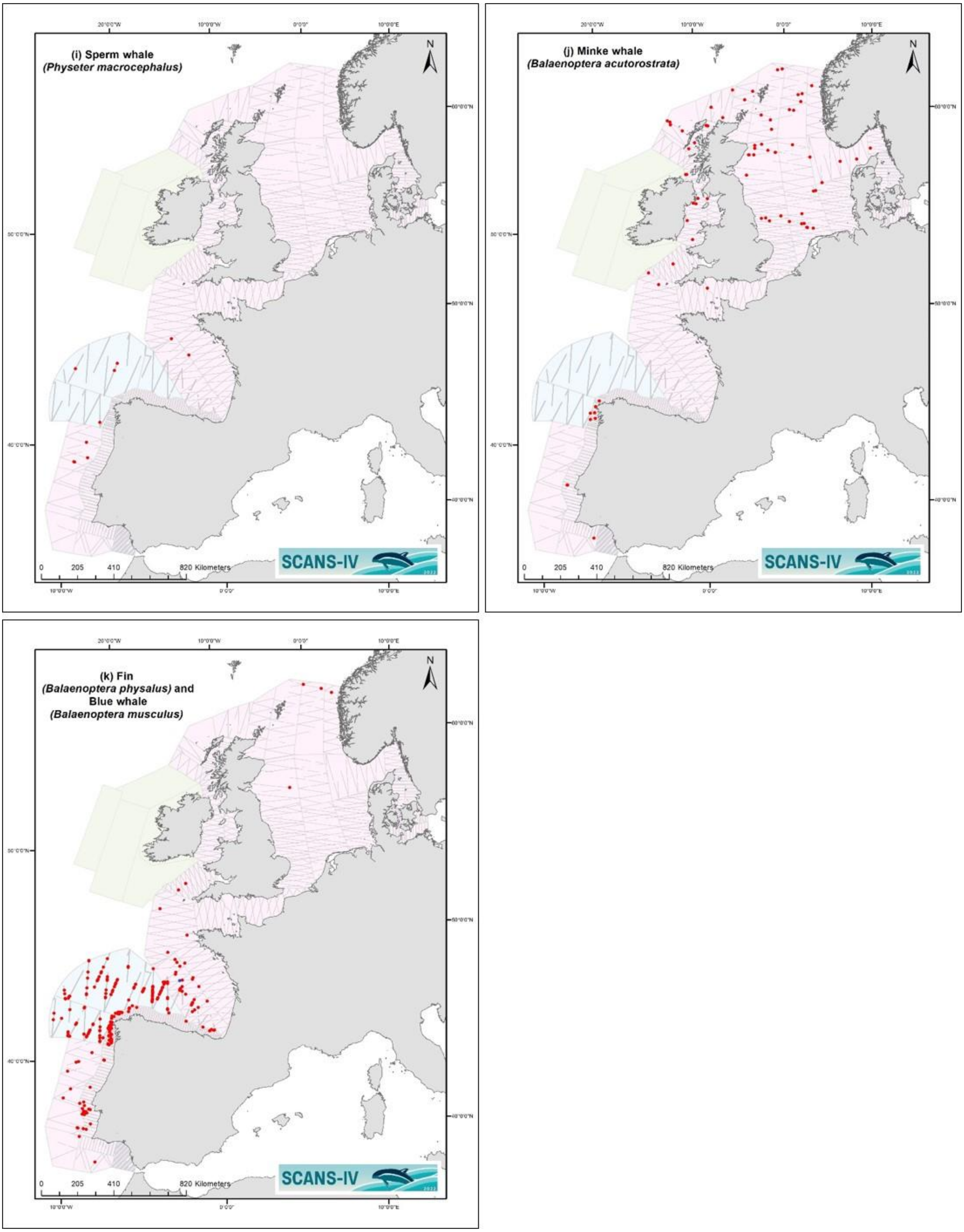

Figure 4 (continued). Distribution of sightings used in the analyses of the most commonly detected species. Underlying effort is also that used in the analysis: aerial survey - good and moderate sighting conditions; ship survey - Beaufort 0-4. (i) sperm whale; (j) minke whale; (k) fin (red dot) and blue whale (blue dot).

Species identification from digital photos (STORMM)

STORMM was deployed on 15 survey flights from 1st to 28th July 2022, representing some 5,500 km of effort from Team 6 in blocks CS-B, BB-A and BB-B (Figure 5). These digital photos (see Appendix A2 for examples) were then analysed by a human operator to validate species identification, especially in the case of common or striped dolphin sightings.

A total of 346 visual sightings of marine mammals were matched to digital photos taken with the STORMM digital system: these visual sightings were within the swath of the digital system (2 x 200 m) and were candidates for digital recapture. 286 visual sightings of cetaceans were recaptured on digital photos (286 / 346 = 83%).

Of these 286 sightings, 2 were rescinded because of mixed-species association, 169 (59%) were congruent between *in-situ*/visual and *ex-situ*/digital species identification, 74 (26%) were identified to full species level (*e.g.* a sighting of the category "unidentified common or striped dolphin" was identified as common dolphin on the digital photo), and only 15 sightings (5%) were corrected because of for species misidentification during the survey. For the remaining 30 sightings, their corresponding digital photos were of insufficient quality for any species identification. The comparison of *in-situ* identification from visual observers and *ex-situ* identification from STORMM digital system is presented in Figure 5.

From this digital analysis, the ratio between the number of common dolphin individuals versus striped dolphin individuals in the three covered blocks with most effort amounts to: CS-B: 100% of common dolphins, BB-A: 19% of common and 81% of striped dolphin, and BB-B: 93% of common and 7% of striped dolphin (Van Canneyt et al., in prep).

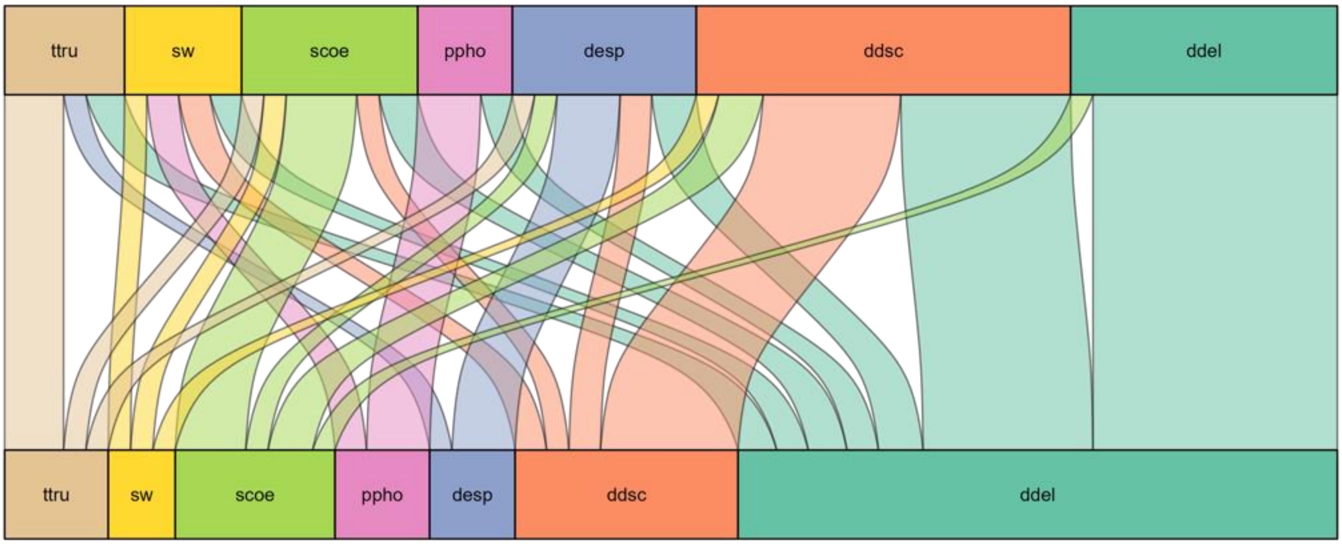

Figure 5. Graphical representation of species "re-identification" with STORMM digital photos: *in-situ* species identification from visual observers (top row) and *ex-situ* identification from photos of digital system STORMM (bottom row). Species codes - ttru: Bottlenose dolphin; sw: small whale species; scoe: Striped dolphin; ppho: Harbour porpoise; desp: unidentified delphinid species; ddsc: unidentified common or striped dolphin; ddel: Common dolphin.

Estimates of abundance

Aerial survey

A total of 271 circle-back (or racetrack) procedures were achieved. Estimates of ESW, including g(0), were made using the combined data from all eight aircraft for harbour porpoise and all dolphin species combined (excluding pilot whale and killer whale) (see Appendix A3). There were not enough racetracks made for minke whales, with only two potential re-sightings.

Estimates for harbour porpoise stratified by aircraft/team were also investigated. However, the numbers of potential re-sightings by individual aircraft were in most cases too small to robustly estimate aircraft/team-specific ESWs; therefore, the pooled ESW based on all eight aircraft, stratified by good and moderate conditions, was preferred (see Appendix A3 for details). Out of the leading sightings for the dolphin category, the large majority were common or striped dolphin (or unidentified common or striped). It was therefore deemed more appropriate to use the results of these racetracks only for those two species (see Dolphins-1 in Table 5). However, this also meant that the new results are probably not suitable for the other (more northern) dolphin species, and it was decided to correct these with the values as obtained for SCANS-III (see Dolphins-2 in Table 5). For the minke whale, there were only two potential re-sightings on trailing effort, which precluded robust estimation of ESW and therefore the estimates for ESW and g(0) from SCANS-III were used.

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 as used for the computation of presented abundances estimates.

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), incorporating the effect of g(0) on detection probability		**g(0)**	
Species	***good***	***moderate***	***good***	***moderate***
Harbour porpoise	167 (0.16)	114 (0.16)	0.415	0.298
Dolphins-1 (common dolphin, striped dolphin, unid. common or striped dolphin)	495 (0.18)	187 (0.19)	0.969	0.322
Dolphins-2* (bottlenose dolphin, white-beaked dolphin, white-sided dolphin, Risso's dolphin)	390 (0.13)	213 (0.14)	0.805	0.414
Minke whale*	154 (0.42)		0.302	

* from SCANS-III

Tables 6-17 show estimates of abundance for each block for harbour porpoise, bottlenose dolphin, Risso's dolphin, white-beaked dolphin, white-sided dolphin, common dolphin, striped dolphin, unidentified common or striped dolphin, long-finned pilot whale, beaked whales (all species combined; Cuvier's beaked whale, Sowerby's beaked whale, unidentified beaked whale), fin whale and minke whale.

Table 6. Harbour porpoise density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no harbour porpoise sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0037	1.00	-	0.0037	0.741	311	2	888
BB-B	0.0109	1.80	0.324	0.0196	0.530	1,529	312	3,496
BS-A	0.1737	1.48	0.072	0.2568	0.297	2,048	1,086	3,573
BS-B	0.3255	1.43	0.074	0.4667	0.236	2,767	1,758	4,344
BS-C	0.1580	1.60	0.167	0.2528	0.369	2,094	818	3,963
BS-D	0.4913	1.33	0.059	0.6550	0.278	5,050	2,868	8,572
BS-E	0.1675	1.54	0.174	0.2576	0.628	1,329	364	3,540
BS-F	0.1124	1.38	0.133	0.1546	0.481	1,115	205	2,285
CS-A	0.0548	1.28	0.085	0.0700	0.450	3,420	832	6,902
CS-B	0.0340	1.73	0.087	0.0587	0.399	5,258	1,967	10,039
CS-C	0.0157	1.00	-	0.0157	0.506	564	104	1,183
CS-D	0.2109	1.33	0.062	0.2803	0.316	9,773	4,764	18,125
CS-E	0.4466	1.15	0.044	0.5153	0.250	6,325	3,663	10,162
CS-F	0.1541	1.30	0.140	0.2010	0.425	3,064	688	5,906
CS-G	0.0150	1.00	-	0.0150	0.725	301	2	937
CS-H	0.2980	1.31	0.080	0.3911	0.337	5,470	2,354	9,880
CS-I	0.0182	2.00	-	0.0364	0.907	1,276	4	4,246
CS-J	0.0841	1.18	0.103	0.0994	0.569	3,231	620	7,758
CS-K	0.1790	1.57	0.129	0.2813	0.354	11,357	4,946	21,173
IC-A	0.0030	5.00	-	0.0150	1.043	219	5	785
IC-C	0.0071	1.00	-	0.0071	1.025	113	1	412
IC-G	0.0186	1.27	0.111	0.0236	0.411	1,021	371	2,040
IC-H	0.0510	3.37	0.254	0.1719	0.374	1,707	642	3,242
IC-I	0.0037	8.00	0.753	0.0296	0.866	984	24	2,937
NS-A	0.0685	1.53	0.136	0.1045	0.388	4,053	1,805	8,337
NS-B	0.2714	1.14	0.038	0.3096	0.239	7,982	4,865	13,033
NS-C	0.4108	1.47	0.035	0.6027	0.228	36,286	23,346	56,118
NS-D	0.4249	1.41	0.053	0.5985	0.367	38,577	18,017	76,361
NS-E	0.3719	1.39	0.046	0.5156	0.208	33,735	21,757	50,324
NS-F	0.3046	1.44	0.077	0.4393	0.341	26,383	13,562	49,008
NS-G	0.7640	1.36	0.041	1.0398	0.242	51,646	30,773	79,506
NS-H	0.6169	1.30	0.032	0.8034	0.241	55,691	33,836	87,685
NS-I	0.4874	1.26	0.029	0.6158	0.196	34,547	23,383	50,798
NS-J	0.3446	1.37	0.048	0.4729	0.263	30,050	16,513	48,211
NS-K	0.0707	1.75	0.200	0.1236	0.450	4,740	1,337	9,414
NS-L	0.4135	1.25	0.058	0.5189	0.354	7,853	3,431	14,608
NS-M	0.6652	1.39	0.057	0.9243	0.355	7,375	3,136	13,944
All	**0.2031**	**1.37**	**0.015**	**0.2789**	**0.171**	**409,244**	**298,194**	**578,505**

Table 7. Bottlenose dolphin density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0085	7.80	0.365	0.0666	0.540	5,632	677	12,948
BB-B	0.0022	1.33	0.250	0.0029	0.595	228	4	571
CS-A	0.0085	4.67	0.465	0.0395	0.583	1,930	203	4,818
CS-B	0.0095	6.31	0.279	0.0599	0.402	5,366	1,699	10,645
CS-C	0.1250	3.36	0.111	0.4195	0.406	15,117	4,966	29,157
CS-D	0.0858	2.74	0.082	0.2352	0.353	8,199	3,595	15,158
CS-E	0.0069	1.50	0.333	0.0104	0.700	127	3	353
CS-F	0.0131	3.25	0.508	0.0425	0.777	647	13	2,198
CS-G	0.0123	4.33	0.428	0.0532	0.742	1,069	13	2,778
CS-H	0.0702	4.88	0.166	0.3421	0.444	4,784	1,177	9,294
CS-I	0.0389	10.40	0.367	0.4048	0.473	14,208	104	29,117
IC-A	0.0051	12.20	0.313	0.0623	0.572	911	83	2,223
IC-C	0.0097	9.33	0.575	0.0909	0.839	1,431	28	5,043
IC-E	0.0172	8.50	0.486	0.1465	0.556	6,567	340	13,297
IC-F	0.0107	11.25	0.311	0.1200	0.502	6,117	45	13,434
IC-G	0.0203	5.07	0.158	0.1030	0.343	4,448	1,893	8,033
IC-H	0.0170	4.15	0.200	0.0706	0.461	701	210	1,499
IC-I	0.0032	5.67	0.222	0.0179	0.480	597	139	1,273
NS-A	0.0029	1.00	-	0.0029	0.715	114	2	306
NS-C	0.0213	1.97	0.109	0.0419	0.683	2,520	57	6,616
NS-H	0.0014	1.00	-	0.0014	0.994	96	1	344
All	**0.0114**	**4.83**	**0.063**	**0.0551**	**0.194**	**80,809**	**52,711**	**117,736**

Table 8. Risso's dolphin density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0030	4.00	0.520	0.0121	0.972	1,022	12	3,575
BB-B	0.0013	1.00	-	0.0013	0.989	104	1	355
CS-B	0.0080	5.33	0.328	0.0425	0.736	3,814	215	11,458
CS-C	0.0019	3.00	-	0.0057	1.004	205	3	721
CS-D	0.0022	1.00	-	0.0022	1.012	75	2	259
CS-F	0.0027	1.00	-	0.0027	1.006	41	1	153
CS-H	0.0035	7.00	-	0.0244	1.000	341	7	1,155
CS-J	0.0082	3.50	0.143	0.0288	0.649	936	7	2,319
CS-K	0.0042	9.00	-	0.0376	0.972	1,519	9	5,099
IC-E	0.0049	1.00	-	0.0049	0.979	218	1	813
IC-F	0.0019	5.00	-	0.0094	0.947	480	5	1,692

IC-G	0.0030	3.00	0.408	0.0090	0.593	387	24	878
IC-I	0.0005	7.00	-	0.0037	1.007	123	7	410
NS-E	0.0045	15.50	0.935	0.0702	0.974	4,589	31	16,458
All	**0.0017**	**5.54**	**0.224**	**0.0094**	**0.429**	**13,854**	**4,887**	**27,867**

Table 9. White-beaked dolphin density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
CS-G	0.0342	7.44	0.300	0.2543	0.815	5,113	67	15,405
CS-H	0.0296	4.67	0.301	0.1380	0.843	1,930	28	6,254
CS-J	0.0513	5.00	0.219	0.2565	0.596	8,335	55	19,218
CS-K	0.0346	3.91	0.354	0.1352	0.608	5,460	191	12,812
NS-A	0.0027	1.00	-	0.0027	1.036	104	1	387
NS-C	0.0025	6.00	0.333	0.0149	0.758	894	12	2,387
NS-D	0.0180	4.43	0.278	0.0799	0.481	5,149	961	10,586
NS-E	0.0413	4.30	0.162	0.1775	0.383	11,611	3,875	21,601
NS-F	0.0311	9.83	0.227	0.3056	1.009	18,350	118	62,112
NS-G	0.0280	3.75	0.240	0.1051	0.331	5,218	2,616	9,736
NS-H	0.0008	3.00	-	0.0023	0.992	157	3	484
NS-J	0.0161	3.88	0.185	0.0622	0.572	3,955	383	9,644
NS-K	0.0037	6.00	-	0.0225	0.957	862	6	2,976
All	**0.0087**	**5.26**	**0.091**	**0.0458**	**0.325**	**67,138**	**33,978**	**119,349**

Table 10. White-sided dolphin density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
CS-G	0.0032	7.00	-	0.0224	0.971	451	7	1,464
CS-H	0.0104	2.67	0.451	0.0279	0.775	390	8	1,130
CS-J	0.0087	2.67	0.625	0.0233	0.737	756	8	2,087
NS-E	0.0029	5.00	-	0.0146	1.028	958	5	3,583
NS-J	0.0037	4.00	-	0.0150	0.938	951	8	3,005
All	**0.0006**	**3.80**	**0.195**	**0.0024**	**0.463**	**3,504**	**940**	**7,495**

Table 11. Common dolphin density (groups or animals/km²) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0180	8.92	0.353	0.1603	0.481	13,554	3,371	29,045
BB-B	0.1048	4.51	0.076	0.4729	0.376	36,855	16,934	70,753
CS-A	0.0783	4.67	0.119	0.3657	0.308	17,867	9,357	32,134
CS-B	0.1817	5.67	0.070	1.0310	0.244	92,409	55,856	149,382
CS-C	0.1573	5.35	0.089	0.8410	0.264	30,301	17,888	51,902
CS-D	0.0026	10.67	0.685	0.0272	0.814	949	32	2,990
CS-F	0.0155	3.50	0.340	0.0544	1.028	829	14	3,244
CS-G	0.0209	3.60	0.242	0.0754	0.496	1,515	280	3,281
CS-H	0.0863	10.73	0.200	0.9266	0.795	12,958	161	41,272
CS-I	0.0112	15.00	-	0.1678	0.886	5,888	30	19,262
IC-A	0.0014	16.00	0.562	0.0221	0.811	323	32	977
IC-C	0.1031	8.85	0.123	0.9126	0.424	14,367	4,556	29,900
IC-E	0.0076	25.00	0.800	0.1907	0.998	8,548	50	39,839
IC-F	0.0099	19.60	0.497	0.1934	0.698	9,857	98	28,905
IC-G	0.0915	11.10	0.088	1.0155	0.265	43,843	26,812	75,330
IC-H	0.1034	21.37	0.152	2.2101	0.337	21,938	11,567	41,334
IC-I	0.0155	7.21	0.131	0.1115	0.360	3,711	1,580	7,223
NS-A	0.0012	12.00	-	0.0139	0.969	539	12	1,736
NS-C	0.0005	6.00	-	0.0032	0.966	192	6	724
NS-I	0.0006	1.00	-	0.0006	1.042	32	1	113
NS-J	0.0028	6.00	-	0.0165	0.948	1,051	6	3,408
All	**0.0314**	**6.89**	**0.051**	**0.2164**	**0.204**	**317,527**	**220,543**	**498,040**

Table 12. Striped dolphin density (groups or animals/km²) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0221	20.21	0.268	0.4466	0.500	37,770	12,154	87,533
BB-B	0.0017	13.33	0.638	0.0230	0.761	1,793	40	5,408
CS-B	0.0041	7.50	0.335	0.0306	0.664	2,743	117	8,036
IC-A	0.0014	7.50	0.333	0.0103	1.056	151	15	540
IC-B	0.0071	50.00	-	0.3559	0.941	8,317	50	26,583
IC-C	0.0060	18.00	0.667	0.1081	0.995	1,701	36	6,901
IC-D	0.0336	21.00	0.905	0.7064	1.095	23,245	42	134,600
IC-E	0.0221	21.25	0.309	0.4706	0.710	21,095	1,991	63,173
IC-F	0.0153	10.71	0.215	0.1637	0.506	8,344	1,806	19,630
IC-G	0.0100	11.14	0.229	0.1118	0.629	4,828	473	12,879
IC-H	0.0017	2.00	0.500	0.0035	0.806	34	4	97
IC-I	0.0062	12.20	0.285	0.0757	0.462	2,521	748	5,331
All	**0.0042**	**18.19**	**0.142**	**0.0767**	**0.369**	**112,544**	**55,864**	**235,621**

Table 13. 'Unidentified common or striped' dolphin density (groups or animals/km^2) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0292	13.17	0.259	0.3838	0.316	32,462	15,952	58,155
BB-B	0.0558	4.36	0.199	0.2431	0.383	18,943	7,723	36,902
CS-A	0.0098	6.20	0.219	0.0605	0.498	2,957	606	6,711
CS-B	0.0674	5.15	0.107	0.3471	0.311	31,108	14,524	54,382
IC-A	0.0014	15.50	0.032	0.0214	0.722	313	31	831
IC-B	0.0071	15.00	-	0.1068	1.004	2,495	15	8,878
IC-C	0.0169	9.86	0.278	0.1670	0.682	2,630	69	7,274
IC-E	0.0263	14.33	0.379	0.3774	0.730	16,916	787	49,678
IC-G	0.0156	19.37	0.262	0.3016	0.527	13,022	3,392	31,165
IC-H	0.0222	7.00	0.191	0.1551	0.387	1,540	547	3,014
IC-I	0.0275	9.27	0.122	0.2547	0.328	8,478	4,331	15,527
All	**0.0114**	**7.80**	**0.087**	**0.0892**	**0.234**	**130,863**	**83,615**	**210,750**

Table 14. Pilot whale density (groups or animals/km^2) and abundance estimates from the aerial survey using conventional distance sampling methods. The best fitting model was a half-normal detection function with subjective conditions as an additional covariate and without truncation. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0008	2.00	0.990	0.0016	0.990	135	24	752
BB-B	0.0010	1.50	1.015	0.0015	1.015	117	21	664
CS-B	0.0040	4.70	0.493	0.0193	0.619	1,732	533	5,633
CS-G	0.0022	15.00	1.010	0.0326	1.010	655	101	4,245
CS-I	0.0026	1.00	1.240	0.0026	1.240	93	5	1,788
IC-G	0.0021	2.80	1.027	0.0059	1.027	253	46	1,383
IC-H	0.0033	9.80	0.602	0.0330	0.588	328	110	976
All	**0.0005**	**5.12**	**0.369**	**0.0023**	**0.427**	**3,314**	**1,456**	**7,541**

Table 15. Beaked whale (all species) density (groups or animals/km²) and abundance estimates from the aerial survey using conventional distance sampling methods. The best fitting model was a half-normal detection function with no additional covariates and without truncation. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0039	1.20	0.504	0.0047	0.557	394	135	1,150
CS-D	0.0021	1.00	0.702	0.0021	0.702	73	20	267
CS-H	0.0034	1.00	1.038	0.0034	1.038	47	7	306
CS-I	0.0038	1.00	1.227	0.0038	1.227	132	7	2,662
IC-B	0.0033	1.00	1.048	0.0033	1.048	77	10	581
IC-E	0.0051	1.00	0.619	0.0051	0.619	230	61	858
IC-F	0.0073	2.75	0.517	0.0200	0.519	1,018	346	3,001
IC-G	0.0048	2.75	0.560	0.0131	0.688	567	163	1,970
IC-I	0.0015	1.00	0.590	0.0015	0.590	51	17	150
All	**0.0010**	**1.81**	**0.276**	**0.0018**	**0.309**	**2,588**	**1,410**	**4,750**

Table 16. Minke whale density (groups or animals/km²) and abundance estimates from the aerial survey. CV is the coefficient of variation of abundance and density of animals. 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	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
CS-A	0.0031	1.00	-	0.0031	1.048	153	1	678
CS-B	0.0016	1.00	-	0.0016	1.128	147	1	641
CS-C	0.0079	1.00	-	0.0079	0.822	284	3	921
CS-D	0.0137	1.00	-	0.0137	0.632	477	85	1,425
CS-E	0.0088	1.00	-	0.0088	1.145	108	1	491
CS-F	0.0137	1.00	-	0.0137	1.091	209	2	954
CS-H	0.0353	1.00	-	0.0353	0.872	493	4	1,915
CS-I	0.0296	1.00	-	0.0296	0.731	1,038	3	3,759
CS-J	0.0221	1.00	-	0.0221	0.545	718	174	1,857
CS-K	0.0116	1.00	-	0.0116	0.794	467	2	1,655
IC-C	0.0053	2.00	-	0.0106	1.086	167	2	695
IC-G	0.0031	1.00	-	0.0031	1.066	135	2	625
IC-H	0.0139	1.20	0.167	0.0167	0.568	165	31	421
NS-C	0.0068	1.00	-	0.0068	0.881	412	4	1,392
NS-D	0.0381	1.10	0.091	0.0419	0.594	2,702	547	7,357
NS-E	0.0121	1.00	-	0.0121	0.724	795	3	2,673
NS-F	0.0271	1.00	-	0.0271	0.624	1,630	5	4,427
NS-G	0.0103	1.00	-	0.0103	0.808	510	2	1,860
NS-H	0.0153	1.00	-	0.0153	0.552	1,061	231	2,771
NS-J	0.0100	1.00	-	0.0100	0.632	638	3	1,735
NS-L	0.0071	1.00	-	0.0071	1.083	108	1	398
All	**0.0082**	**1.03**	**0.024**	**0.0085**	**0.361**	**12,417**	**7,038**	**26,943**

Table 17. Fin whale density (groups or animals/km^2) and abundance estimates from the aerial survey using conventional distance sampling methods. The best fitting model was a half-normal detection function with no additional covariates and a truncation of 700 m. CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits of abundance. Blocks with no fin whale sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB-A	0.0071	1.00	0.347	0.0071	0.347	604	301	1,212
BB-B	0.0009	1.00	0.689	0.0009	0.689	68	19	247
CS-B	0.0011	1.00	0.546	0.0011	0.546	103	35	299
CS-C	0.0012	1.00	0.696	0.0012	0.696	44	12	162
IC-C	0.0012	1.00	1.042	0.0012	1.042	19	3	116
IC-E	0.0063	1.00	0.676	0.0063	0.676	281	66	1,192
IC-F	0.0045	1.00	0.537	0.0045	0.537	227	73	704
IC-G	0.0091	1.48	0.325	0.0135	0.368	584	286	1,191
IC-H	0.0356	1.11	0.181	0.0395	0.188	392	271	568
IC-I	0.0040	1.00	0.436	0.0040	0.436	135	59	309
NS-D	0.0009	1.00	0.947	0.0009	0.947	57	10	332
All	**0.0016**	**1.14**	**0.170**	**0.0017**	**0.172**	**2,515**	**1,792**	**3,530**

Ship survey

For species with sufficient duplicate sightings, mark-recapture distance sampling methods were used to estimate detection probability and subsequently abundance. There was no compelling evidence of movement in response to the ship in any species (see Appendix A1), so the partial independence model of detection probability was used in all cases. For sperm whale and beaked whales, 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.

Table 18 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. Plots of the detection functions are given in Appendix A1.

Table 19 gives the detection probabilities estimated using the models described in Table 18. Table 20 gives the group size correction factors for each species or species grouping.

Table 18. 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; 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 & covariates	Conditional detection function & covariates
Bottlenose dolphin	1,500	pi	HR: Beaufort (continuous)	Perpendicular distance
Common + striped dolphin	1,000	pi	HR: Sightability (2-level factor)	Perpendicular distance, Sightability (2-level factor)
Beaked whales (all species)	2,000	so	HR: Beaufort (2-level factor)	
Sperm whale	4,473 (max)	so	HR: null	
Fin whale	1,500	pi	HR: Sightability (2-level factor)	Perpendicular distance, Sightability (2-level factor)

Table 19. Estimated detection probabilities within the truncation distance (see Table 18) for each species or species grouping in the ship survey. ESW is the estimated effective strip half-width, which incorporates the effect of g(0) on detection probability, if estimated. 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)
Bottlenose dolphin	0.049 (0.641)	0.814 (0.148)	0.040 (0.658)	60
Common + striped dolphin	0.247 (0.234)	0.580 (0.248)	0.143 (0.372)	143
Beaked whales (all species)	0.392 (0.189)	-	0.392 (0.189)	785
Sperm whale	0.417 (0.415)	-	0.417 (0.415)	1,856
Fin whale	0.590 (0.488)	0.650 (0.104)	0.383 (0.116)	575

Table 20. Group size correction factors (CV in parentheses) for each species or species grouping used to correct Primary group sizes in the analysis. If a correction factor was less than one, group size was not corrected.

Species / species grouping	Group size correction	Sample size
Bottlenose dolphin	0.684 (0.638) = 1	11
Common dolphin	0.594 (0.487) = 1	11
Striped dolphin	0.898 (0.443) = 1	9
Unidentified common or striped	1.232 (0.290)	15
Fin whale	1.024 (0.110)	71

Tables 21-27 show estimates of abundance for each ship block for bottlenose dolphin, common dolphin, striped dolphin, unidentified common or striped dolphin, beaked whales (all species combined), sperm whale and fin whale.

Table 21. Bottlenose dolphin density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits. Blocks with no bottlenose dolphin sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0516	6.99	0.590	0.3613	0.815	24,701	5,541	110,114
BB2	0.0177	3.06	0.287	0.0543	1.051	6,899	1,078	44,169
BB3	0.0841	4.59	0.121	0.3867	0.909	29,175	5,969	142,593
All	**0.0448**	**5.10**	**0.248**	**0.225**	**0.706**	**60,775**	**16,709**	**221,051**

Table 22. Common dolphin density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits. Blocks with no common dolphin sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0407	19.78	0.103	0.805	0.582	55,077	16,352	185,510
BB2	0.0361	8.93	0.223	0.323	0.657	40,983	11,871	141,497
BB3	0.0905	7.78	0.458	0.705	0.745	53,182	13,752	205,658
All	**0.0524**	**10.50**	**0.246**	**0.551**	**0.449**	**149,242**	**63,639**	**349,993**

Table 23. Striped dolphin density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits. Blocks with no striped dolphin sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0171	38.03	0.367	0.651	1.018	44,487	7,296	271,246
BB2	0.0164	13.26	0.211	0.218	0.990	27,646	4,576	167,037
BB3	0.0196	2.87	0.280	0.056	0.613	4,253	1,267	14,282
All	**0.0175**	**16.14**	**0.438**	**0.282**	**0.766**	**76,386**	**19,171**	**304,342**

Table 24. Unidentified common or striped dolphin density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3) the estimated lower and upper 95% confidence limits. Blocks with no unidentified common or striped dolphin sightings are excluded.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0053	3.70	0.366	0.0197	0.590	1,354	509	3,599
BB2	0.0219	4.07	0.318	0.0924	0.700	11,311	3,171	40,338
BB3	0.0232	2.53	0.476	0.0591	0.614	4,445	2,020	9,782
All	**0.0181**	**3.49**	**0.343**	**0.0628**	**0.564**	**17,110**	**6,855**	**42,702**

Table 25. Beaked whale density (groups or animals/km^2) and abundance estimates (all species combined) from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0015	2.00	0.187	0.0031	0.665	211	54	816
BB2	0.0072	1.94	0.103	0.0140	0.357	1,779	848	3,731
BB3	0.0041	1.28	0.130	0.0052	0.550	396	131	1,198
All	**0.0049**	**1.80**	**0.090**	**0.0088**	**0.311**	**2,386**	**1,275**	**4,463**

Table 26. Sperm whale density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0004	1.00	0.000	0.0004	1.072	24	4	166
BB2	0.0014	1.00	0.000	0.0014	0.582	183	59	569
BB3	0.0006	1.67	0.398	0.0010	0.718	76	20	297
All	**0.0009**	**1.12**	**0.104**	**0.0010**	**0.524**	**284**	**102**	**787**

Table 27. Fin whale density (groups or animals/km^2) and abundance estimates from the ship survey (blocks BB1, BB2, BB3). CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits.

Block	Density (groups)	Mean group size	CV (mean group size)	Density (animals)	CV	Abundance	CL low	CL high
BB1	0.0208	1.23	0.119	0.0256	0.391	1,750	783	3,913
BB2	0.0301	1.11	0.118	0.0333	0.246	4,221	2,683	6,640
BB3	0.0466	1.30	0.125	0.0604	0.329	4,564	2,395	8,697
All	**0.0323**	**1.21**	**0.116**	**0.0389**	**0.224**	**10,535**	**7,178**	**15,460**

Table 28 gives the estimates of total abundance for all species over the whole survey area.

Table 28. Estimates of overall density (animals/km^2) and total abundance in the whole survey area. CV is the coefficient of variation of abundance and density of animals. CL low and CL high are the estimated lower and upper 95% confidence limits.

Species	Density	CV	Abundance	CL low	CL high
Harbour porpoise	0.279	0.17	409,244	298,194	578,505
Bottlenose dolphin	0.074	0.23	126,489	80,626	198,440
Risso's dolphin	0.0094	0.43	13,854	4,887	27,867
White-beaked dolphin	0.046	0.33	67,138	33,978	119,349
White-sided dolphin	0.0024	0.46	3,504	940	7,495
Common dolphin	0.259	0.18	439,212	309,153	623,987
Striped dolphin	0.110	0.36	186,825	94,244	370,355
Unidentified common or striped	0.086	0.22	145,567	95,486	221,917
Pilot whale	0.0023	0.43	3,314	1,456	7,541
Beaked whales (all species)	0.0028	0.21	4,809	3,178	7,278
Sperm whale	0.0010	0.52	148	102	786
Minke whale	0.0085	0.36	12,417	7,038	26,943
Fin whale	0.0075	0.19	12,764	8,875	18,357

Harbour porpoise Assessment Units

Estimates of harbour porpoise abundance for each Assessment Unit (AU) are given in Table 29. For the Belt Sea and for the North Sea AUs, the combined area of the aerial survey blocks used is identical to the area of the AUs. For the West Scotland & Ireland AU, offshore waters to the west of Scotland were not covered. Similarly, only a part of the Irish and Celtic Seas AU was covered by SCANS-IV, thus, the current estimate is not representative of the whole AU. Waters to the south and west of Ireland were covered by the ObSERVE2 project (see Discussion). The estimates for these two AUs will be updated as soon as the ObSERVE2 results become available. For the Iberian Peninsula, the aerial survey covered all continental shelf waters and parts off the shelf; the AU includes waters off the shelf, which are unlikely to include harbour porpoises (none were sighted in ship blocks BB1, BB2 and BB3 or in the offshore aerial survey blocks IC-B, IC-D, IC-E and IC-F).

Table 29. Estimates of harbour porpoise density (animals/km^2) and abundance in Assessment Units (AUs as defined in IMR/NAMMCO 2019) from SCANS-IV 2022. CV is the coefficient of variation of density and abundance. CL low and CL high are the estimated lower and upper 95% confidence limits of density and abundance, respectively. All estimates are from the aerial surveys. *Surveys in the Iberian AU were conducted in different time periods: Portuguese blocks (IC-B to IC-G) were surveyed in July; Spanish coastal blocks (IC-A, IC-H and IC-I) were surveyed between mid-September and October.

Assessment Unit	Density	CL low	CL high	CV	Abundance	CL low	CL high
Irish and Celtic Seas (partial coverage only)	0.090	0.06	0.14	0.22	26,870	17,745	41,536
West Scotland & Ireland (partial coverage only)	0.16	0.09	0.25	0.24	24,699	14,626	38,996
North Sea	0.55	0.40	0.77	0.17	338,918	243,063	476,203
Belt Sea	0.34	0.23	0.52	0.21	14,403	9,555	21,769
Iberian Peninsula*	0.015	0.01	0.03	0.35	4,043	1,842	7,309

Distribution of estimated density over the survey area

Spatial modelling of the collected data from 2022 to investigate fine scale distribution and habitat use is considered in a separate project report. For those species with sufficient data, how abundance was distributed over the survey area at a coarse scale can be seen from maps of estimated density by survey block. Maps for harbour porpoise; bottlenose, common and striped dolphin; minke and fin whale and white beaked dolphin are shown in Figure 6.

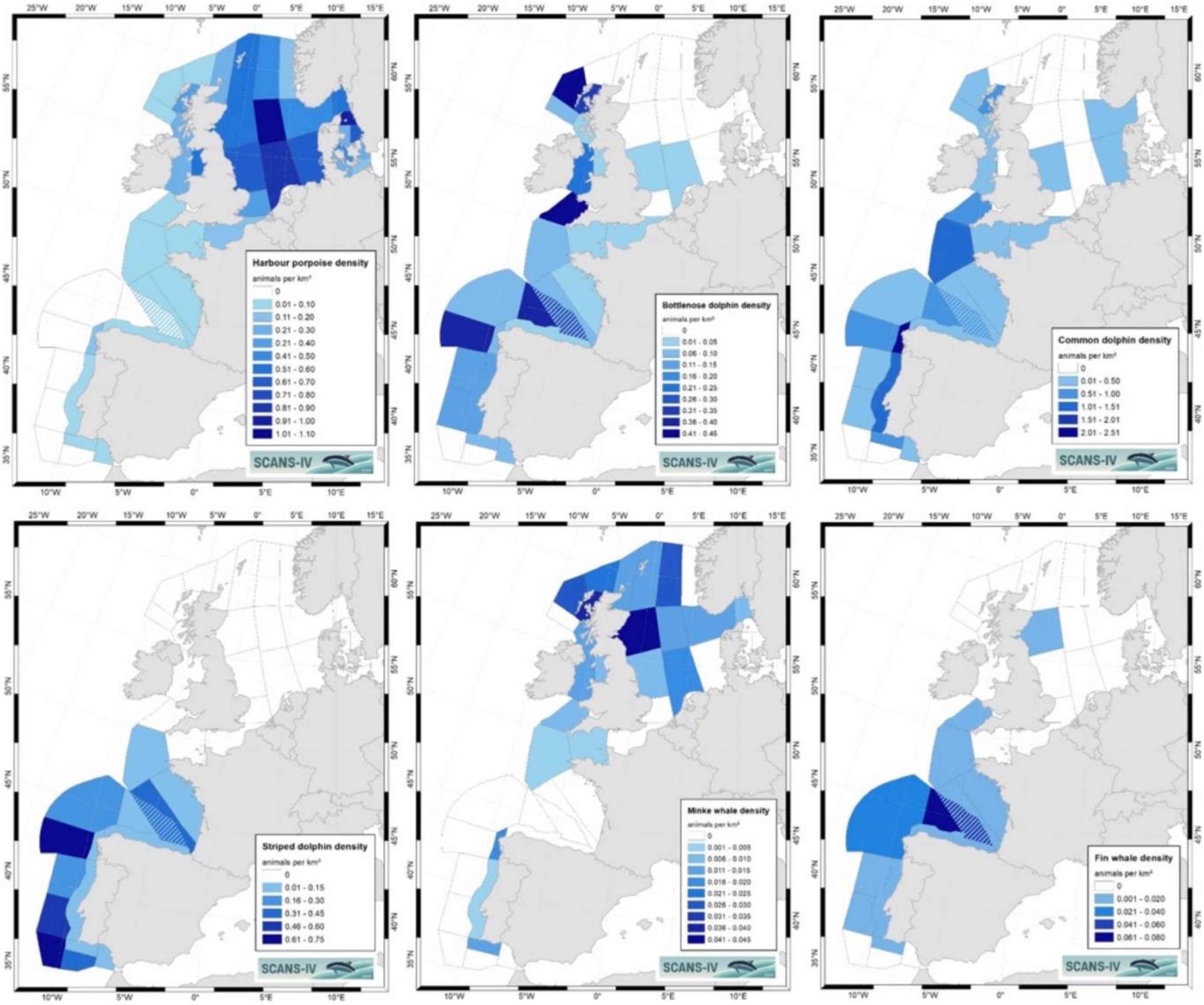

Figure 6. Estimated density in each survey block for harbour porpoise (top left), bottlenose dolphin (top middle), common dolphin (top right), striped dolphin (bottom left), minke whale (bottom middle) and fin whale (bottom right).

Trends in abundance

Following the successful completion of the SCANS-IV survey in 2022, there are now four estimates of abundance for harbour porpoise, white-beaked dolphin and minke whale in the North Sea from SCANS, SCANS-II, SCANS-III and SCANS-IV. For minke whale in the North Sea, there are six additional estimates from the Norwegian Independent Line Transect Surveys (NILS) (Schweder et al. 1997, Skaug et al. 2004, Bøthun etal. 2009, Solvang et al. 2015, Solvang et al. 2021). 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 asmaller area between 56°N and 61°N. The Norwegian minke whale estimates for 2009 and 2018 include waters south to 53°N.

Although not covering exactly the same area, there are also four estimates of abundance for harbour porpoise in the eastern Skagerrak, Kattegat and Belt Seas area in 1994, 2005, 2016 and 2022, and two estimates for the smaller area of the Belt Sea AU namely in 2012 (MiniSCANS, Viquerat et al. 2014) and 2020 (MiniSCANS-II, Unger et al. 2021). Figure 6 shows the areas covered in these six surveys compared to the AU for the harbour porpoise Belt Sea population, which has been showed to differ in both genetics, morphology, and distribution from the neighbouring North Sea population (Sveegaard et al. 2015). SCANS 1994 did not cover the full AU (about 30% in the east not surveyed) and SCANS-II 2005 covered the AU and adjacent waters in one large block, whereas the other surveys had blocks that fully corresponded to this AU (Figure 7).

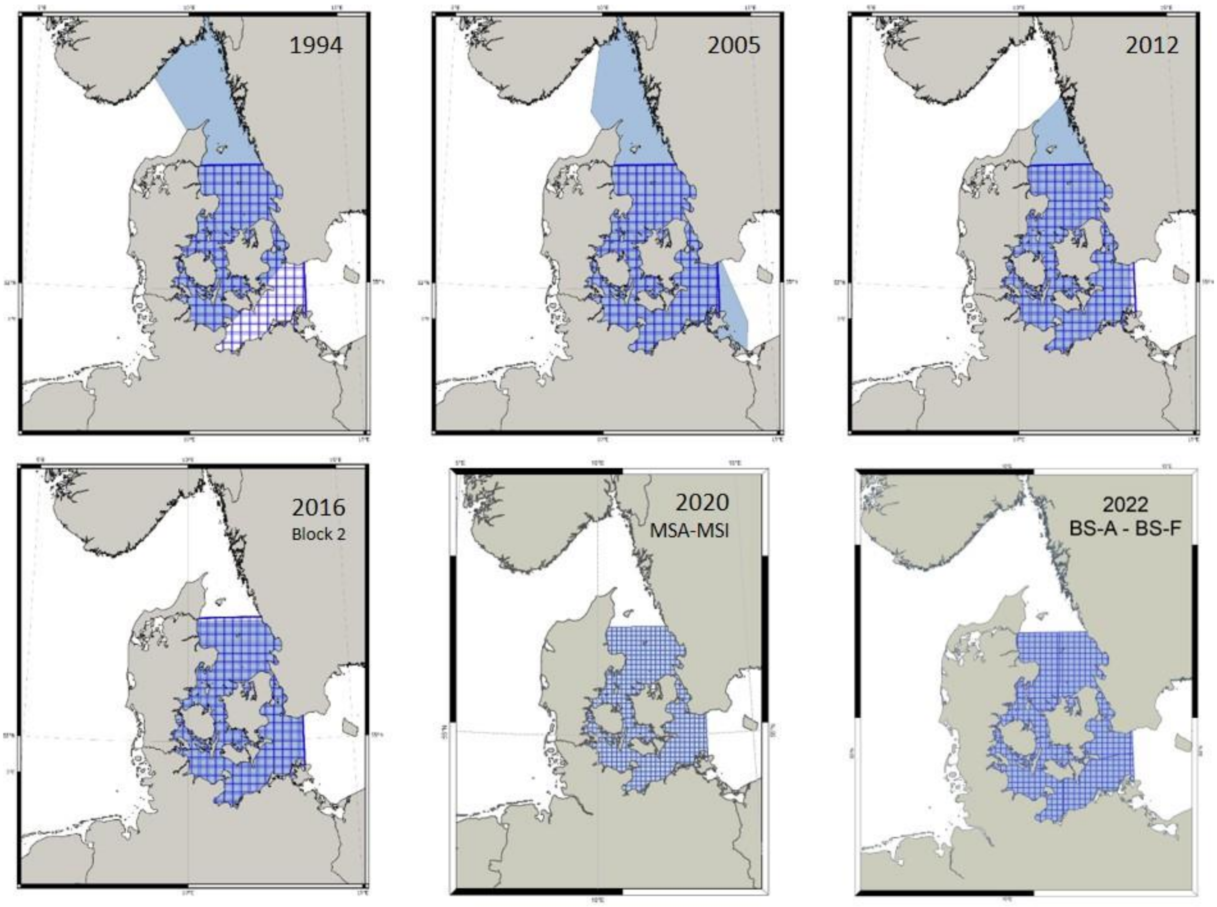

Figure 7. Areas covered during the four SCANS surveys and the two MiniSCANS surveys in 2012 and 2020 (Viquerat et al. 2014, Unger et al. 2022) in the extended Skagerrak/Kattegat/Belt Seas (coloured light blue) compared with the area representing the Belt Sea AU (Sveegaard et al. 2015) (cross-hatched dark blue). The map on the bottom-right represents the SCANS-IV survey area in this region.

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 (ignoring additional variance from variation in the number of animals present in the area at the time of the survey) were conducted to determine the annual rate of decline that could be detected with high (80%) power from the available estimates of abundance, using the simplified inequality:

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

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 p=0.05), Z_{β} = the value of a standardised random normal variable for the probability of making a Type II error, β, where power is 1-β (set to p=0.80) (Gerrodette 1987).

Figure 8 shows the abundance estimates and trend lines fitted to three species in regions with four or more comparable estimates of abundance. Although the poor precision of the estimated trends means that there is no statistical support for a change in abundance over the period covered by the surveys for any species/region, these results must be interpreted in the context of the power analysis, which indicates the minimum level of decline that can be detected from the data (see below). Thus, there could still be a true change in abundance, which is not detected in the present trend analysis due to a lack of statistical power. The rather simple linear regression used here, with intercept but without any regularisation (i.e., priors), could be supplemented or replaced by a more sophisticated Bayesian trend analysis recently applied to harbour porpoise estimates from the German North Sea (Nachtsheim et al. 2021). This approach is more efficient in detecting trends by using all the available information, including the uncertainty associated with each estimate.

Table 30 gives the results of the power calculations. The annual rates of decline that can be detected with 80% power from the four estimates in the North Sea are 0.88% for harbour porpoise and 1.9% for white-beaked dolphin. For minke whale, the ten estimates for the North Sea have 80% power to detect a 0.27% annual rate of decline. The annual rate of decline that can be detected with 80% power from the four estimates in the Belt Sea Assessment Unit is 4.4%.

For North Sea harbour porpoise, white-beaked dolphin and minke whale, the simple annual trends estimated from the data are positive but with poor precision and, thus, not significantly different from no trend (Figure 8b-d). Although there is no direct evidence of declines, these results should not be interpreted as providing evidence that there have been no declines. The power analysis shows that the data could only detect declines of 0.88%, 1.9% and 0.27%, respectively (Table 30), so any smaller annual declines would not be able to be detected.

For harbour porpoise in the Belt Sea Assessment Unit (AU), the estimated trend in the data is negative (-1.52% per year), but also with poor precision and, thus, not significantly different from no trend (Figure 8a). The shorter period (i.e., 2012-2022), for which abundance estimates from a comparable area are available, results in poorer power to detect a change in abundance, and a decline would need to be at least 4.4% per year to be detected by this method. Also, the large confidence intervals of the earlier surveys have an impact on the precision. Recent work applying a Bayesian trend analysis approach on harbour porpoise abundance estimates in the Belt Sea AU between 2005 and 2020 showed no clear trend but a moderate probability (69%) for a decline of 1.17% per year (Gilles et al. 2022; Owen et al. In Review), which is similar to the estimated decline of 1.52% found here. A re-run of this Bayesian approach including the SCANS-IV as well as the SCANS 1994 estimates would shed more light on the status of harbour porpoise from the Belt Sea population and is planned in 2023. Before this approach can be pursued, density surface modelling combined with a gap analysis is needed to predict density in the eastern portion of the AU, which was not surveyed in 1994, and the estimate from 2005 needs to be post-stratified.

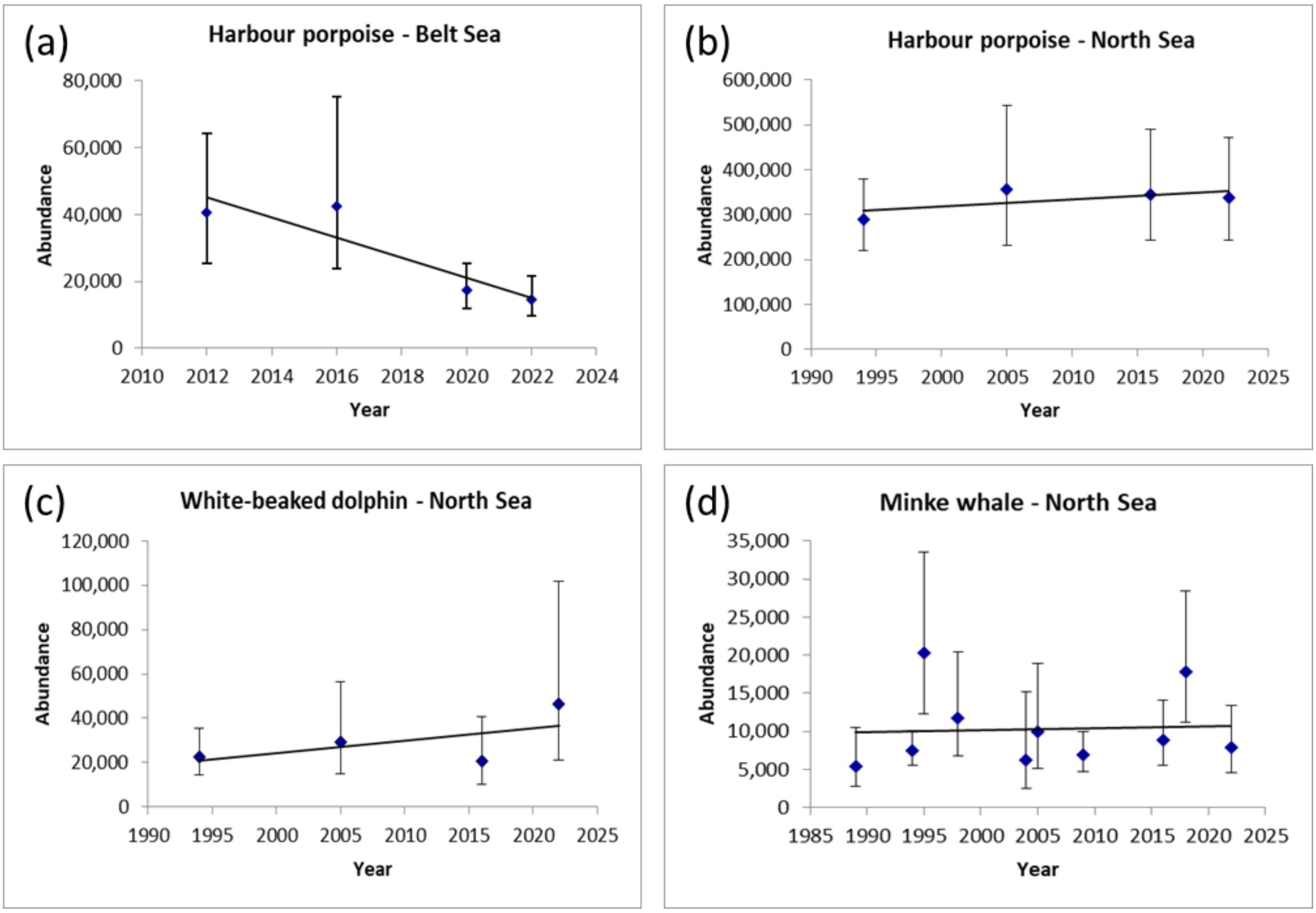

Figure 8. Trend lines fitted to time series of four or more abundance estimates. (a) harbour porpoise in the Belt Sea Assessment Unit: estimated rate of annual change = -1.52% (95%CI: -26.5; 31.9%), p = 0.84. (b) harbour porpoise in the North Sea: estimated rate of annual change = 0.51% (95%CI: -1.14; 2.20%), p = 0.32. (c) white-beaked dolphin in the North Sea: estimated rate of annual change = 1.63% (95%CI: -5.72; 9.55%), p = 0.45. (d) minke whale in the North Sea: estimated rate of annual change = 0.52% (95%CI: -2.60; 3.73%), p = 0.72. Error bars are log-normal 95% confidence intervals.

Table 30. Results of power calculations to determine the annual rate of decline that could be detected by the available data with 80% power. n is the number of abundance estimates. CV = average CV of abundance for the available estimates.

Species	**Region or Assessment unit (AU)**	**n**	**CV**	**Annual rate of decline detectable at 80% power**
Harbour porpoise	Belt Sea AU	4	0.24	4.4%
Harbour porpoise	Greater North Sea AU	4	0.18	0.88%
White-beaked dolphin	North Sea	4	0.34	1.9%
Minke whale	North Sea	10	0.28	0.27%

DISCUSSION

Here we present results from the fourth survey in a long-term time series (1994, 2005/07, 2016, 2022) of large-scale multinational surveys of cetaceans in European Atlantic waters (Figure 9) allowing snapshot views of how distribution and abundance have varied over almost three decades. Except for Portuguese offshore waters, that were included in SCANS-IV for the first time, and waters to the south and west of Ireland, there are now three comprehensive and comparable summer datasets for European Atlantic waters between 62°N and the Straits of Gibraltar. Additionally, there are four such comparable datasets for the Greater North Sea and the Kattegat/Belt Seas.

For harbour porpoise in the North Sea our results show no evidence of a trend 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 Belt Sea Assessment Unit, despite the 2020 and 2022 estimates being much smaller than those for 2012 and 2016 in the latter area (Figure 8a).

Power to detect directional changes in abundance from large-scale sightings surveys is generally low (Taylor et al. 2007, Authier et al. 2020) but the time span covered by the four SCANS surveys and reasonable precision in the estimates mean that, in the North Sea, the data have high power to detect changes of 1-2% per year for harbour porpoise and white-beaked dolphin. For minke whales in the North Sea, where more estimates are available, there is high power to detect a 0.27% change in abundance per year.

It should also be noted that for most species for which we can estimate abundance from these large-scale surveys, European Atlantic waters are at the edge of a wider North Atlantic range. Spatial variation in prey availability as well as other factors linked to climate change, may lead to redistribution of animals and the distribution and abundance of these species in European waters may vary over time.

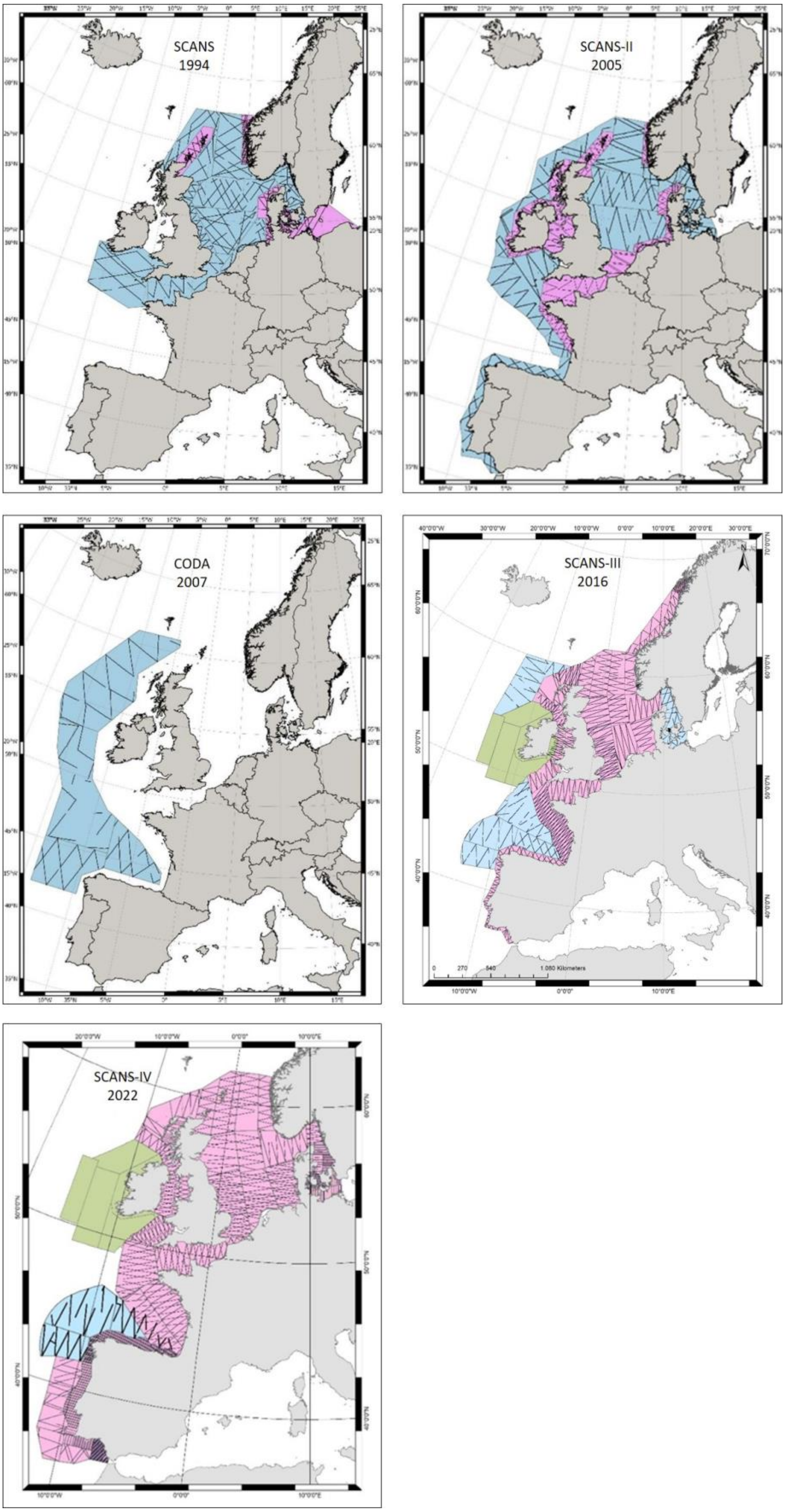

Figure 9. Areas surveyed, with covered on effort transect lines in aerial (pink) and ship (blue) survey blocks, by SCANS in 1994 (top left), SCANS-II in 2005 (top right), CODA in 2007 (middle left), SCANS-III in 2016 (middle right) and SCANS-IV in 2022 (bottom left). Blocks coloured green to the south and west of Ireland in 2016 and 2022 were surveyed by the Irish ObSERVE project.

New information on distribution and abundance

Small toothed cetaceans

Harbour porpoise

The observed distribution of harbour porpoises from SCANS-IV in summer 2022 (Figure 4a) was similar to that observed from SCANS-III in summer 2016 (Hammond et al. 2021). One feature of the results, from the series of now four SCANS surveys, is that the number of sightings made in the English Channel has steadily increased. In 1994, no sightings were made in the Channel or the southern North Sea (Hammond et al. 2002). In 2005, there were a few sightings at the far western end of the Channel (Hammond et al. 2013). In the SAMM ("S*uivi Aérien de la Mégafaune Marine*" [aerial survey for marine megafauna]) survey in 2012 and in the SCANS-III survey in 2016 there were sightings in both the western and eastern parts, but not the central part (Laran et al. 2017, Hammond et al. 2021). In winter 2021, during the SAMM-II survey several sightings of porpoises were recorded in the eastern part of the English Channel and southern part of the North Sea (Blanchard et al. 2021). Compared to the winter 2011-2012, more sightings were made in the western English Channel, in the waters around Devon, Cornwall and Brittany in winter 2021 (Laran et al. 2022). In SCANS-IV, there were harbour porpoise sightings throughout the Channel. The progressive increase of sightings into the Channel from these surveys over the past three decades indicates that harbour porpoise distribution continues to change and currently encompasses the entire Channel, at least in summer. Further data collection outside of summer SCANS surveys would support our understanding of this changing distribution and how management may need to be adapted as a result.

Abundance estimates in waters to the south and west of Ireland from the ObSERVE2 survey in summer 2022 are not yet available but will be added to the estimates from SCANS-IV to provide a total estimate for 2022 comparable to the SCANS-II estimate for 2005 and the SCANS-III + ObSERVE estimate for 2016 (Rogan et al. 2018, Hammond et al. 2021).

For the Assessment Units (AUs, see Figure 2), it is currently only possible to comment on the North Sea, Belt Sea and the Iberian Peninsula AUs, because the southern part of the West Scotland AU and the north-western part of the Celtic and Irish Seas AU were covered by the ObSERVE2 survey. This report will be updated in due time to include results from ObSERVE2.

In the North Sea, the estimate for 2022 (339,000, CV = 0.17) is very similar to the estimates for 2016 (345,000, CV = 0.18) and 2005 (355,000, CV = 0.22), compared with a slightly smaller estimate from 1994 (289,000, CV = 0.14). Thus, notwithstanding that the data only have sufficient power to detect a decline of around 1% per year, there is no evidence for a change in harbour porpoise abundance in the North Sea.

In the Belt Sea AU, the estimate for 2022 of 14,403 (CV = 0.21) is considerably lower than the estimates for 2016 of 42,324 (CV = 0.30, SCANS-III) and for 2012 of 40,475 (CV = 0.24) (MiniSCANS, Viquerat et al., 2014), but in line with the more recent MiniSCANS-II survey from 2020 (estimate: 17,301, CV = 0.20; Unger et al. 2021). The estimated annual decline from 2012 to 2022 is 1.5% per year but the power analysis showed that these data would only be able to detect a significant decline of 4.4% per year, or greater. Thus, the lack of a significant trend in the estimates from 2012 to 2022 cannot be interpreted as no decline in abundance. Further analysis using a Bayesian approach (Nachtsheim et al. 2021) will shed more light on the status of harbour porpoise from the Belt Sea population and is planned in 2023.

In the Iberian Peninsula AU, the 2022 estimate (4,040, CV = 0.35) is slightly larger than those from 2016 and 2005 (2,898, CV = 0.32 and 2,880, CV = 0.72, respectively) but the survey blocks in 2022 extended further offshore, which could contribute for this difference. Moreover, the SCANS-IV survey was conducted in different time periods in the Iberian Peninsula AU; specifically, the Portuguese blocks (IC-B to IC-G) were surveyed in July, whereas the Spanish coastal blocks were surveyed between mid-September and October 2022. Future surveys conducted during more similar periods in both countries, as planned for September 2023 and further in 2024 and 2025, will be helpful to understand porpoise abundance estimates in this AU. The significance of the different mean group sizes in both Iberian areas (between 1 and 1.27 in Portugal and between 3.37 and 8.00 in Spain) needs further investigation.

Bottlenose dolphin

The observed distribution of bottlenose dolphins in SCANS-IV was similar to SCANS-III in the southern areas but different in the northwest, with more sightings in the northern Celtic Sea, Irish Sea and the Hebrides in 2022.

The estimate of abundance in 2022 of 126,489 (CV = 0.23) includes offshore Portuguese waters, which have not previously been covered in a SCANS survey. Estimated abundance in these waters (blocks IC-B, IC-D, IC-E and IC-F) contributed around 10% to the overall estimate. In 2016, SCANS-III estimated 33,123 (CV = 0.24) bottlenose dolphins but the combined estimate from SCANS-III and ObSERVE for 2016 totalled 120,500 (CV = 0.17). These estimates for 2016 and 2022 are both considerably greater than that from 2005/07 of 56,077 (CV = 0.27) (unpublished combined analysis of SCANS-II and CODA data; Geelhoed et al. 2022).

The bottlenose dolphin is a species for which European Atlantic waters are at the edge of a wider North Atlantic range. There is no information on abundance in the central North Atlantic but the differences in distribution and abundance estimates between 2005/07, 2016 and 2022 may reflect bottlenose dolphins responding to interannual spatial variation in prey availability across the wider range. Data from the 2022 ObSERVE2 survey, when available, will add to understanding of the variation in distribution and abundance of bottlenose dolphin in European Atlantic waters seen between SCANS-IV and previous surveys.

Coastal bottlenose dolphins were assessed in eleven species' AUs in the recent OSPAR QSR 2023. Of those, the Sado Estuary population in the Coastal Portugal AU was assessed as in decline. Estimates from the wider Cardigan Bay in the Irish Sea and Coastal Wales AU, the populations in the Coastal Ireland AU, the Coastal Normandy and Brittany AU and the East Coast Scotland AU indicate broadly stable populations. The population in the East Coast Scotland AU is showing signs of increase and range expansion in recent years (Geelhoed et al. 2022).

White-beaked dolphin

The observed distribution of white-beaked dolphins in 2022 is similar to that observed in SCANS-III in 2016 (Hammond et al. 2021), SCANS-II in 2005 (Hammond et al. 2013) and in SCANS in 1994 (Hammond et al. 2002). In 2022, the highest densities were estimated around the Shetland Islands, northern North Sea (NS-E, NS-F) and in northwest Scotland (CS-G and CS-I) and in 17 sightings large groups of >10 individuals were observed.

The estimate of abundance in 2022 of 67,138 (CV = 0.33) is higher than all previous estimates from SCANS-III of 36,287 (CV = 0.29), SCANS-II of 37,689 (CV = 0.36) and from SCANS in 1994 of 23,716 (CV = 0.30) (revised in Hammond et al. 2021). In 2016, the combined estimate from SCANS-III + ObSERVE totalled 39,535 (CV = 0.27).

The trend analysis of estimates in the North Sea shows no significant change in abundance since 1994 (Figure 7) but the data only have sufficient power to detect an annual decline of a minimum of 2% per year (Table 30).

The only other large-scale estimate of abundance for this species is an estimated 159,000 (CV = 0.63) white-beaked dolphins in the central North Atlantic from the North Atlantic Sightings Survey (NASS) 2015 (Pike et al. 2019a).

White-sided dolphin

White-sided dolphins were sighted only in the north of the study area and west of Scotland, which fits the general observations of distribution for this species although they are also recorded further south in the North Sea.

In 2022, the SCANS-IV survey generated a total abundance estimate of 3,504 (CV = 0.46) white-sided dolphins which is lower than the estimate from SCANS-III (15,510, CV = 0.72) and from the SCANS-III + ObSERVE estimate of 17,431 (CV = 0.64). However, the SCANS-III estimate in 2016 for the offshore block 8 west of Scotland alone, that was not surveyed in SCANS-IV, was 13,322 (CV = 0.82) and the abundance in all other survey blocks in 2016 was 2,187 (CV = 0.70) (Hammond et al. 2021), suggesting that a high-density area for this species was not covered in 2022.

Estimates from surveys in these areas in previous years are not available. However, Pike et al. (2019a) estimated 131,022 (CV = 0.73) white-sided dolphins in the central North Atlantic from NASS 2015, 86,052 (CV = 0.83) of which were in block FW immediately to the west of the 2016 SCANS-III and ObSERVE survey areas.

Common and striped dolphins

The distribution of common and striped dolphins as well as the combined grouping of unidentified common/striped dolphins from SCANS-IV in summer 2022 (Figures 4 e, f, g) was overall consistent with SCANS-III in summer 2016 (Hammond et al. 2021) and partly with SCANS-II and CODA in 2005/07 (CODA 2009, Hammond et al. 2013). However, the extension of the survey area in 2022 to include offshore waters along the Portuguese coast, highlighted a more extended distribution of striped dolphin than could be seen from SCANS-III. Common dolphin occurrence has increased in the Celtic Sea, as well as southwest of UK and in the western part of the English Channel, suggesting that the population range may be expanding further north (see also Macleod et al. 2008, Williamson et al. 2022). A few sightings of common dolphin were also encountered in the Irish Sea, the Hebrides and in the North Sea, overall in more northerly areas compared to SCANS-III.

The distribution of common dolphins appears to be strongly concentrated in shelf waters. A substantial number of unidentified sightings of the category “either common or striped dolphin” were also made in offshore waters, but analysis from the digital system STORMM in SCANS-IV revealed that common dolphin only represented 19% of the unidentified individuals collected in BB-A (offshore Bay of Biscay) while representing 100% in CS-B (Southern Celtic Sea) and 93% on the shelf of the Bay of Biscay (BB-B; see Figures 1 & 5). Striped dolphins appeared to be concentrated in offshore waters, which could be confirmed by the image analysis showing that striped dolphin accounted for 81% of individuals in the offshore block (BB-A) while this species was not identified in the shelf waters of the Bay of Biscay (BB-B). This may indicate a preference for deeper waters for striped dolphin, and shallower waters for common dolphin as also shown in Lacey et al. (2022) where for SCANS-III the spatial model for common dolphin estimates a negative relationship with increasing depth and the model for striped dolphin a positive relationship with increasing depth. In areas where the two species are co-occurring, preferences are less clear. This is likely driven by prey preferences although diet composition shows significant variation in relation to season and sex/maturity status (Meynier et al. 2008). Pusineri et al. (2007) suggested that common dolphin forage in both habitats, oceanic and neritic, but with a more stable prey preference and foraging strategy than striped dolphin.

In Iberian waters, common dolphins were mostly sighted in the inshore blocks whereas striped dolphins were sighted in inshore and offshore blocks with a higher prevalence in deeper waters. Within Iberia, the area of the IC-C and IC-G blocks was systematically covered by aerial surveys between 2010 and 2015 in late summer/early autumn (September or October), with an annual average abundance estimate of 45,179 (CV = 0.25) common dolphins and 19,473 (CV = 0.44) striped dolphins (Vingada & Eira 2018). These autumn abundance estimates are lower than the SCANS-IV summer estimates (around 58,000 animals for IC-C and IC-G blocks combined) in the case of common dolphin and higher in the case of striped dolphins (around 6,500 animals for IC-C and IC-G blocks combined). These differences can be related to species seasonality, thus, enhancing the necessity of conducting seasonal surveys to better understand the species changing distribution and abundance.

European Atlantic waters are at the edge of larger North Atlantic ranges for common and striped dolphins. Common dolphin abundance has previously (1995) been estimated to be 273,000 (CV = 0.26) in a 370,000 km^2 survey block west of Ireland and south of Iceland (Cañadas et al. 2009). Within these wider ranges, interannual spatial variation in prey availability may influence dolphin distribution and the number of animals present in waters surveyed by SCANS, CODA and ObSERVE may also vary from year to year.

Common dolphin abundance estimates in the wider area of the European Atlantic did not vary much among the three sets of surveys: SCANS-II/CODA, SCANS-III/ObSERVE and SCANS-IV. Estimates were 468,356 (CV = 0.33) in 2005/07 (unpublished combined analysis of SCANS-II and CODA data; Geelhoed et al. 2022), 487,094 (CV = 0.26) in 2016 (Hammond et al. 2021, Rogan et al. 2018), and 439,212 (CV = 0.18) in 2022.

A similar comparison of striped dolphin abundance estimates shows more variation: 234,209 (CV = 0.80) in 2005/07 (unpublished combined analysis of SCANS-II and CODA data; Geelhoed et al. 2022), 441,455 (CV = 0.31) in 2016 (Hammond et al. 2021), and 186,825 (CV = 0.36) in 2022.

Estimates of unidentified common or striped dolphin abundance also varied: 61,920 (CV = 0.35) in 2005/07 (unpublished combined analysis of SCANS-II and CODA data), 183,559 (CV = 0.20) in 2016 (Hammond et al. 2021), and 145,567 (CV = 0.22) in 2022.

Estimates of combined striped and common dolphin abundance (including unidentified) varied from around 760,000 in 2005/07, to 1,100,000 in 2016, to 770,000 in 2022; the larger combined estimate in 2016 being mostly a result of the larger estimate of striped dolphin abundance in that year.

Note that the 2022 estimates do not include offshore waters off western Scotland, which were surveyed in 2007 and 2016 but not in 2022, nor do they include waters to the south and west of Ireland, which were surveyed by ObSERVE2. Estimates from ObSERVE2 will need to be added once they are available to give a fuller picture of variation in abundance for these species.

Seasonal variation in distribution and abundance has also been found. In the Bay of Biscay, both species are encountered in winter (Laran et al. 2017) but in lower abundance compared to summer (Laran et al. 2022), whereas around Ireland the ObSERVE survey (2015/2016) reported higher abundances of common dolphin in winter than in summer (Rogan et al. 2018).

Baleen whales

Minke whale

Between 1994 and 2005 there was some evidence to suggest that minke whale distribution in the North Sea had shifted south (Hammond et al. 2013). However, in 2016, the observed distribution was similar to that in 2005 in the North Sea, and similar overall to that in 2005/07 (Hammond et al. 2011, Hammond et al. 2013). Frequent sightings were made in Irish waters in 2007, and this was also the case in summer 2016 during the ObSERVE survey (Rogan et al. 2018). The observed distribution in 2022 from SCANS-IV includes many sightings further south in the North Sea than previously seen, suggesting an extension of range in summer.

The new estimate of abundance from SCANS-IV of 12,417 (CV = 0.36) is lower than from SCANS-III with 14,759 (CV = 0.32) minke whales. However, SCANS-III included offshore waters of west Scotland not covered in SCANS-IV, and abundance in the offshore block 8 from SCANS-III was 1,657 (CV = 0.55) minke whales.

The estimate of abundance from SCANS-III plus the estimate from ObSERVE in summer 2016 totalled 21,157 (CV = 0.27) minke whales, which is very similar to the revised estimate for 2005/07 from SCANS-II/CODA of 22,000 (CV = 0.37) (Hammond et al. 2021). The addition of the ObSERVE2 estimate from summer 2022 when available, will give a more complete picture of minke whale abundance to compare over the time series.

The estimate for 2022 in the North Sea was 7,856 (CV = 0.28), which is within the range of previous estimates from SCANS, SCANS-II and SCANS-III but lower than the most recent Norwegian survey (17,792 (CV = 0.24) in 2018; Solvang et al. 2021). The result of the trend analysis using the available 10 estimates in the North Sea over the period 1989-2022 shows no support for a change in abundance since 1989. A total of 42,515 (CV = 0.31) minke whales were estimated from NASS 2015 (Pike et al. 2019a), including 12,926 (CV = 0.64) in block FC and 5,072 (CV = 0.43) in block FW adjacent to the SCANS-III and ObSERVE survey areas.

Fin whale

In 2022, the observed distribution of fin whales was similar to that observed in SCANS-III in 2016 and the offshore CODA survey in 2007 (CODA 2009, Hammond et al. 2011, Hammond et al. 2021), which is consistent with current knowledge on fin whale distribution in the SCANS area where the highest densities are found in the Bay of Biscay. During SCANS-IV, fin whales were also encountered in Portuguese offshore waters and close to the coast of Galicia/Spain. In SCANS-IV, besides the fin whale known areas of Bay of Biscay and west Scotland, there were a couple of sightings in the Celtic Sea, an area where fin whales in the last decades are sighted more regularly (Fariñas-Bermejo et al. 2023).

The abundance estimate from SCANS-IV totals 12,764 (CV = 0.19) fin whales which is lower than the SCANS-III 2016 estimate of 27,293 (CV = 0.38) and the estimate from CODA 2007 of 29,500 (CV = 0.21) that included a proportion of unidentified large whales (Hammond et al. 2011). Offshore waters west of Scotland were not covered in SCANS-IV but this area only contributed 820 (CV = 0.49) to the estimate from SCANS-III in 2016 (Hammond et al. 2021). Addition of the ObSERVE2 estimates, when available, will give a more complete picture of fin whale abundance to compare, although the ObSERVE survey estimated only 95 (CV = 0.73) fin whales in summer 2016 (Rogan et al. 2018).

Pike et al. (2019a) estimated 36,773 (CV = 0.17) fin whales in the central North Atlantic from NASS 2015, including 9,943 (CV = 0.39) and 5,014 (CV = 0.75) in blocks FW and FC, respectively. In addition, 3,729 (CV = 0.44) fin whales were estimated in the Norwegian Sea and around Jan Mayen in 2015 (Leonard & Øien 2020). A more updated comparison will be possible after the next NASS survey planned in 2024 when new series of abundance estimates will be available to compare with the SCANS surveys.

Deep-diving cetacean species

Deep offshore waters are the main habitat of deep-diving cetacean species, which remains to be a poorly understood group (Geelhoed et al. 2022, OSPAR 2023). It is challenging to quantify the distribution and abundance of this group of cryptic and highly mobile species and, as suggested by Rogan et al. (2017) a combination of visual and acoustic methods may help to refine our knowledge about them. When interpreting the results in the SCANS area, especially for the deep-divers, it must be borne in mind that the area offshore to the west of Scotland was not covered in SCANS-IV but it was in SCANS-III 2016 and CODA 2007. On the other hand, the offshore waters of the Iberian Coast were not covered in these previous surveys.

The northern part of SCANS borders the NASS study area, and the north-western part borders ObSERVE, therefore, the results from survey programmes in adjacent areas will contribute to a better understanding of the abundance and distribution of these species. The estimates of ObSERVE2 in 2022, when available, and from the upcoming NASS survey in 2024 will allow an updated comparison of the abundance estimates of deep-diving species, following the study from Rogan et al. (2017) who provided the first abundance estimates for five deep-diving species (sperm whale, long-finned pilot whale, northern bottlenose whale, Cuvier's beaked whale and Sowerby's beaked whale).

Long-finned pilot whale

The distribution of pilot whale in SCANS-IV 2022 is similar to that observed in SCANS-III 2016 as well as in SCANS-II and CODA in 2005/07 (Hammond et al. 2021). The abundance estimate for 2022 of 3,314 (CV = 0.43) is considerably lower than from SCANS-III 2016 of 28,654 (CV = 0.34) and 7,413 (CV = 0.40) from ObSERVE (total SCANS-III + ObSERVE 2016: 36,067; CV = 0.28), which was already seen as a substantial decrease from 2005/07 of 123,700 (CV = 0.35) (Rogan et al. 2017, Hammond et al. 2021). The pilot whale has an extensive range across the North Atlantic and analyses of NASS data have shown that pilot whale distribution has varied across survey years (Pike et al. 2019b). Estimated abundance in summer 2015 was 344,148 (CV = 0.35) in the central North Atlantic, including 26,177 (CV = 0.56) and 24,427 (CV = 0.55) in blocks FW and FC, respectively (Pike et al. 2019b). As with other species with a wider North Atlantic range, the difference in abundance estimates between 2005/07, 2016 and 2022 may reflect pilot whales responding to spatial variation in prey availability across the range and in general moving north or offshore. However, the updated estimates from ObSERVE2 and upcoming NASS 2024 will help to understand if the changes are only in the distribution or also in abundance.

Risso's dolphin

In 2022, the observed distribution and abundance estimate of Risso's dolphin was similar to that observed in SCANS-III in 2016 (Hammond et al. 2021), most of them in deeper waters as also described in ObSERVE (Rogan et al. 2018). However, no sightings of Risso's dolphin were reported in CODA in 2007 (CODA 2009). In the 2016 and 2022 surveys, Risso's dolphin was found in a variety of habitats along the SCANS area except east of the Skagerrak and in the central and southern North Sea.

The estimate of abundance for Risso's dolphin in 2022 was 13,854 (CV = 0.43), very similar to the 2016 estimate of 13,584 (CV = 0.44) (Hammond et al. 2021). ObSERVE estimated further 2,629 (CV = 0.41; Rogan et al. 2018) in summer 2016. No estimates are available from the neighbouring NASS area, in the central North Atlantic, where Risso's dolphins are suggested to be occasional visitors (e.g., Syvertsen et al. 2010).

Beaked whales (all species)

The observed distribution of beaked whales from SCANS-IV in 2022 was similar to that observed in previous surveys including SCANS-III in 2016 (Hammond et al. 2021), CODA in 2007 (CODA 2009) and from opportunistic sightings (WGMME 2016). Sightings made during the ObSERVE survey in summer 2016 also reflected this distribution (Rogan et al. 2018). The observed species of beaked whales were similar to previous SCANS surveys; however, in 2022 no northern bottlenose whales were detected.

The abundance estimates for all beaked whale species combined were 4,809 (CV = 0.21) in SCANS-IV and 6,799 (CV = 0.43) in SCANS-III (Hammond et al. 2021). The total estimate of abundance in 2016, including 3,142 (CV = 0.51) from ObSERVE, was 9,941 (CV = 0.34), which is slightly lower than the estimate from SCANS-II and CODA in 2005/2007 of 12,900 (CV = 0.31) (Rogan et al. 2017). To the west and north of European waters, in the central North Atlantic, the abundance of northern bottlenose whales was estimated from NASS 2015 as 19,975 (CV = 0.60), the majority in waters adjacent to the SCANS-III and ObSERVE survey areas (Pike et al. 2019a).

Sperm whale

In 2022, sightings of sperm whales were limited to offshore areas of the Bay of Biscay and the Iberian Coast. In previous SCANS surveys, sperm whale sightings were also made west of Scotland, however, this block was not covered in SCANS-IV. In SCANS-III and ObSERVE 2016, the observed distribution of sperm whales in the Bay of Biscay, west Scotland and west of Ireland was similar to that observed in CODA in 2007 (Rogan et al. 2017, Rogan et al. 2018).

The estimate of abundance of sperm whales in 2022 of 148 (CV = 0.52) is much lower than the previous surveys but is only representative for the southern area; in 2016 the west Scotland block alone had an estimate of 9,599 (CV = 0.47). In 2016, the estimate of 17,268 (CV = 0.40) was 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 was included (Rogan et al. 2017). Sperm whale abundance was not estimated from the ObSERVE data, but 23,166 (CV = 0.59) sperm whales were estimated from NASS in 2015 (Pike et al. 2019a), the large majority in areas immediately to the west and north of the SCANS-III and ObSERVE areas in blocks FW 16,204 (CV = 0.71) and FC 4,992 (CV = 0.72). In addition, 3,891 (CV = 0.33) sperm whales were estimated in the Norwegian Sea and around Jan Mayen in 2015 (Leonard & Øien 2020). Pike et al. (2019a) summarized estimates from different subareas in the central and eastern North Atlantic including Iceland-Faroes, Norway, Ireland, and from SCANS and CODA, suggesting more than 30,000 sperm whales are present in this area during the summer. A new assessment could be done once the updated estimates from ObSERVE2 and NASS 2024 are available.

Concluding remarks - lessons learned from the history of SCANS

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 providing a strong basis for assessments of conservation status. The information now available forms a good foundation for a large-scale time series continuing in the coming decades.

Though SCANS-type surveys as stand-alone projects require considerable resources focussed over a very short timeframe of a few months, they are cost-effective to meeting the requirements of EU Directives reporting cycles of 6 years, as fulfilled with SCANS-IV for the first time. Since the SCANS-surveys are mainly conducted in summer, there is limited understanding of species distribution and abundance in other seasons. Further data collection in seasons other than summer would not only enhance our understanding of seasonal changes in distribution but could also inform the need to adapt management (e.g., management of threats and spatial/temporal protection measures).

Although there have been four successful SCANS projects, they do not form a comprehensive programme of surveys; each one has been developed independently by a team of dedicated scientists and funding sought through various funding streams, including national monitoring programmes. In many fora (e.g., ASCOBANS, OSPAR, HELCOM, ICES), European Atlantic range states emphasize the value of the information provided by SCANS as well as the need to establish a clear governance structure to create an ongoing programme of work driven by government agencies responsible for implementing national and European policy, including timely securing of funding to enable the full planned programme of work to be completed. Coordination of surveys across the whole European Atlantic facilitates implementation of consistent data collection, enables comprehensive data analysis, and facilitates timely reporting of results. Ongoing inclusion of SCANS data in the Joint Cetacean Data Programme (JCDP) will ensure that the data are readily accessible for further analysis.

The results presented to date will be integral to cetacean assessments undertaken for OSPAR's Quality Status Reports, HELCOM's Holistic Assessments (HOLAS) and for the EU's Marine Strategy Framework Directive (or equivalent) assessments of Good Environmental Status. The results enable the impact of bycatch and other anthropogenic pressures on cetacean populations to be assessed, fulfilling a suite of needs under the EU Habitats Directive (or equivalent) and the Agreement on the Conservation of Small Cetaceans in the Baltic, Northeast 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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APPENDIX

Appendix A1

A.1 Investigation of responsive movement

For unbiased estimation of abundance, line transect (distance) sampling assumes that target animals do not move in response to the approaching survey platform prior to detection by observers. This is not a problem for aerial survey because of survey speed but could happen on a ship survey. Such responsive movement can lead to error in recorded measurements of perpendicular distance, bias in estimates of detection probability and effective strip half-width (ESW), and therefore bias in estimated abundance. Responsive movement to avoid the ship can lead to negative bias in abundance; attraction can lead to positive bias.

Movement of cetacean groups in response to the survey ship was investigated in three ways.

A1.1 Comparison of perpendicular distances recorded by Tracker and Primary observers

Measurements of perpendicular distance for cetacean groups that were sighted by both Tracker and Primary teams (duplicates) can be compared graphically.

Figures A1.1-A1.3 show Primary perpendicular distance plotted against Tracker perpendicular distance for duplicate sightings for bottlenose dolphin, common and/or striped dolphin, and fin whale.

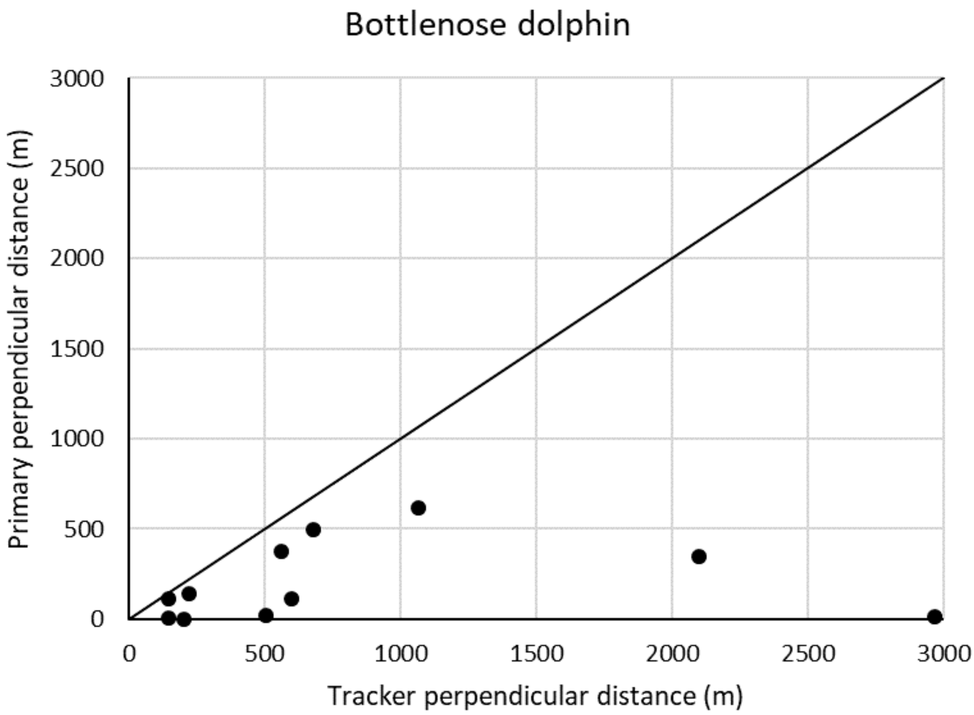
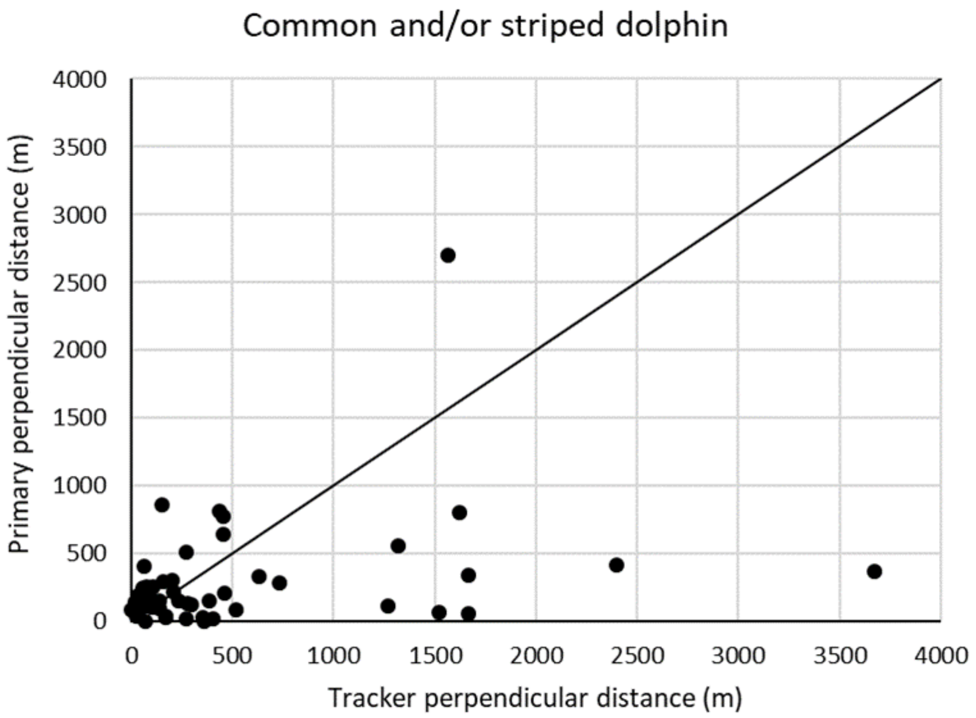


Figure A1.1. Perpendicular distance for Primary and Tracker for duplicate sightings of bottlenose dolphin groups. The solid line is a 1:1 relationship.



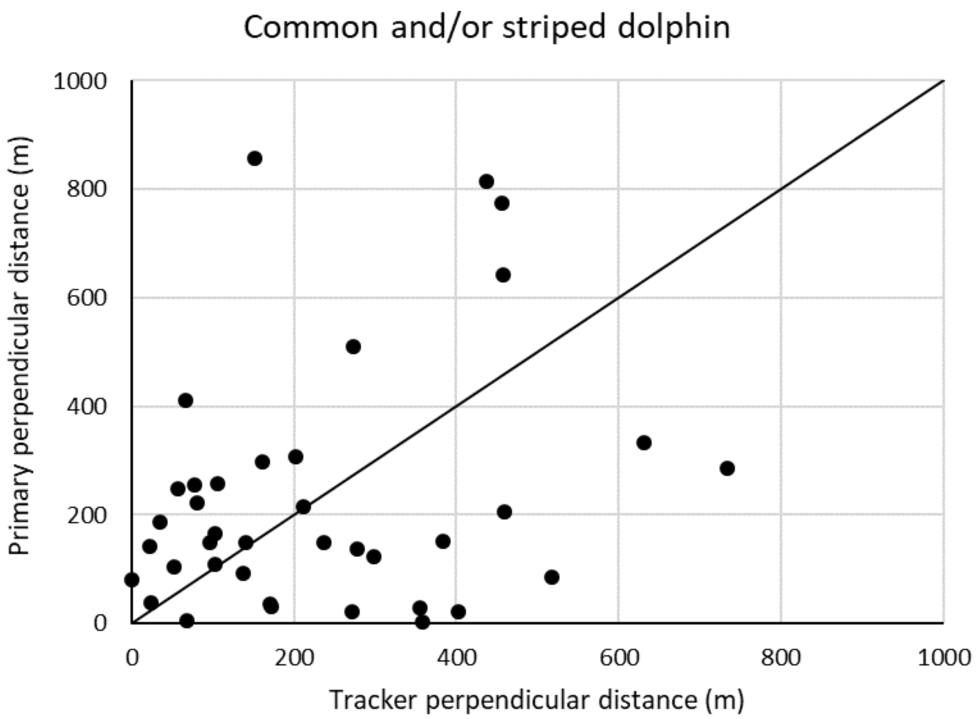
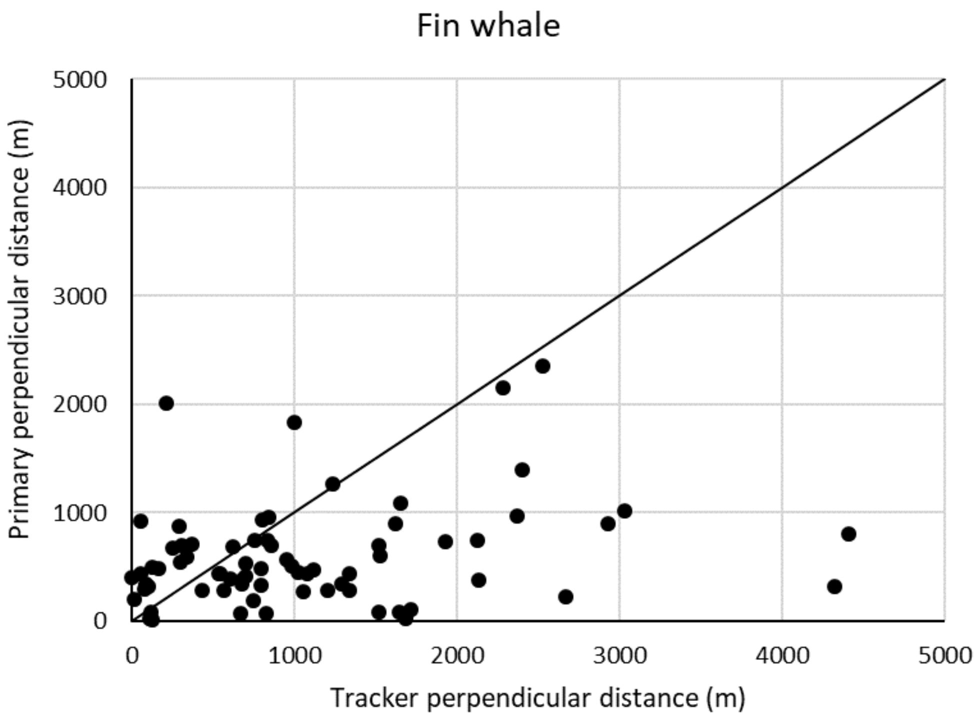


Figure A1.2. Perpendicular distance for Primary and Tracker for duplicate sightings of common and/or striped dolphin groups. The solid line is a 1:1 relationship. The lower plot is limited to sightings detected within 1,000 m perpendicular distance (truncation distance in analysis) to show the data closer to the transect line more clearly.



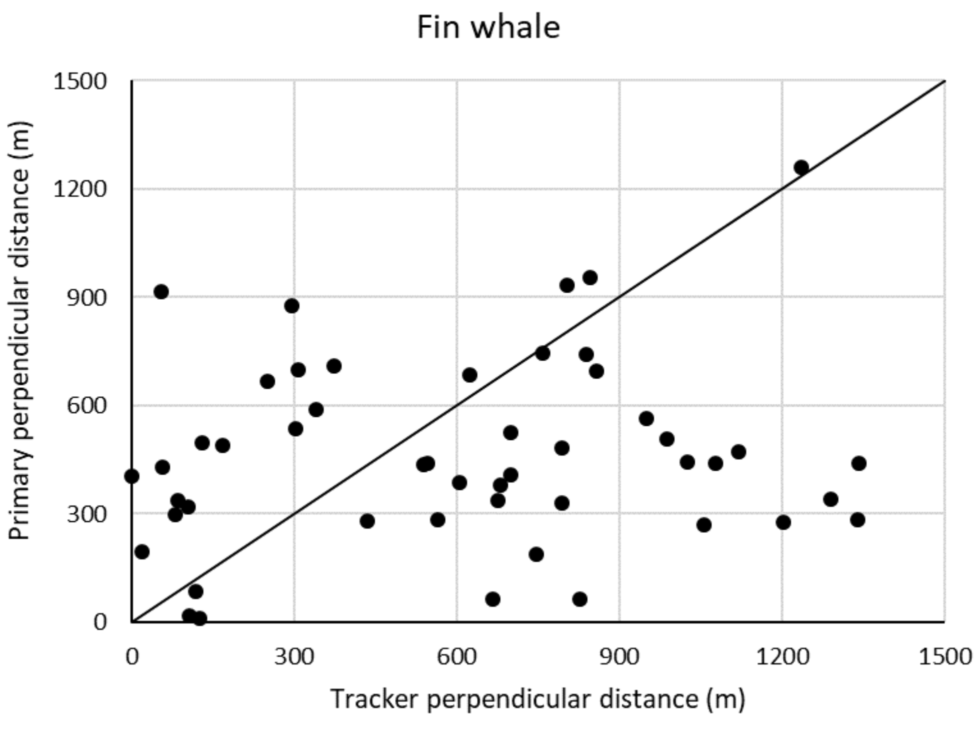


Figure A1.3. Perpendicular distance for Primary and Tracker for duplicate sightings of fin whale groups. The solid line is a 1:1 relationship. The lower plot is limited to sightings detected within 1,500 m perpendicular distance (truncation distance in analysis) to show the data closer to the transect line more clearly.

Caution is needed in interpretation of Figures A1.1-A1.3 because groups seen by Tracker that are moving towards the ship are more likely to be detected by Primary than groups that are moving away from the ship. Thus, other things notwithstanding, perpendicular distance recorded by Primary will on average be smaller than recorded by Tracker. The extent of the difference depends in part on the difference in time between detection by Primary and Tracker, influenced strongly by the radial distance of detection by Tracker.

For bottlenose dolphin (Fig A1.1), Primary perpendicular distances are smaller than Tracker distances for all duplicate sightings, indicating the possibility of attraction to the ship prior to detection. However, the sample of duplicate sightings is small (11 groups), the two sightings at large Tracker perpendicular distance (2,099 m and 2,965 m) were seen far from the ship (radial distance 4,330 m and 6,531 m, respectively). This, and the expectation that perpendicular distance will tend to be smaller for Primary than for Tracker, indicates that attraction cannot be inferred from these data.

The plots for common and/or striped dolphin and fin whale are similar but less extreme (Figs A1.2-A1.3). For common and/or striped dolphins, the 9 sightings with Tracker perpendicular distance greater than 1,000 m and mostly much smaller Primary perpendicular distances were all seen at large radial distances (mean = 4,153 m). The data within the truncation distance of 1,000 m show no obvious pattern. For fin whale, similarly, the 20 sightings with Tracker perpendicular distance greater than 1,500 m and smaller Primary perpendicular distances were all seen at large radial distances (mean = 4,928 m). The data within the truncation distance of 1,500 m still show a tendency for perpendicular distance to be smaller for Primary than for Tracker but, as above, this pattern is expected and is not indicative of attraction to the transect line.

Overall, therefore, for these species for which there are sufficient duplicates, the patterns provide no compelling evidence for responsive movement.

A1.2 Investigation of swimming direction data

The method of Palka & Hammond (2001) was used to investigate whether the data on swimming direction at first detection were indicative of responsive movement (avoidance or attraction) prior to detection. The method involves assigning detected groups of animals into quadrants of swimming direction (Q1=0-90°, Q2=90-180°, Q3=180-270°, Q4=270-360°) relative to the transect line. Data are standardized to refer to the port side of the ship. Palka & Hammond (2001) show that, taking into account the tendency for there to be a greater probability of detection for groups moving towards the transect line and for groups perpendicular to line-of-sight, evidence of responsive movement can be inferred from the ratio of the number of animals in Q3 (n3) to the number of animals in Q1 (n1). A ratio n3/n1 significantly greater than 1 is indicative of avoidance; a ratio n3/n1 significantly less than 1 is indicative of attraction.

In SCANS-IV, there were sufficient data to employ this method for fin whale, common and/or striped dolphin, bottlenose dolphin, and beaked whales (all species combined). The ratio n3/n1 was calculated for all sightings stratified by species group, Primary/Tracker platform, and radial distance from the ship (less than or greater than 500m).

The results are given in Table A1.1, which shows that most n3/n1 ratios are greater than one (possibly indicative of avoidance) but only for common and/or striped dolphins was the X2 test significant at the p=0.05 level (around 0.03) so, for these species, there is weak evidence responsive movement (avoidance).

Table A.1. Number of sightings with swimming direction in each quadrant (n1, n2, n3, n4, Total) for fin whale, common and/or striped dolphin (CD-SD-CS), bottlenose dolphin, and beaked whales (all species combined), seen from either the Primary (P) or Tracker (T) platform, at radial distance less than or greater than 500 m. For the ratio n3/n1, the Chi-squared test statistic (X^2) and its probability (p) are given.

Species	P/T	radial distance	n1	n2	n3	n4	Total	n3/n1	X^2	p
Fin whale	P	<=500	4	3	9	5	21	**2.25**	1.923	0.17
Fin whale	P	>500	8	0	0	31	39	**-**	-	-
Fin whale	**P**	**all**	**12**	**3**	**9**	**36**	**60**	**0.75**	**0.429**	**0.51**
Fin whale	T	<=500	2	0	0	1	3	**-**	-	-
Fin whale	T	>500	47	22	59	33	161	**1.26**	1.358	0.24
Fin whale	**T**	**all**	**49**	**22**	**59**	**34**	**164**	**1.20**	**0.926**	**0.34**
CD-SD-CS	P	<=500	6	35	16	6	63	**2.67**	4.545	0.033 *
CD-SD-CS	P	>500	7	11	5	11	34	**0.71**	0.333	0.56
CD-SD-CS	**P**	**all**	**13**	**46**	**21**	**17**	**97**	**1.62**	**1.882**	**0.17**
CD-SD-CS	T	<=500	4	2	6	2	14	**1.50**	0.400	0.53
CD-SD-CS	T	>500	27	21	45	16	109	**1.67**	4.500	0.034 *
CD-SD-CS	**T**	**all**	**31**	**23**	**51**	**18**	**123**	**1.65**	**4.878**	**0.027 ***
Bottlenose dolphin	P	<=500	2	7	4	0	13	**2.00**	0.667	0.41
Bottlenose dolphin	P	>500	3	0	3	2	8	**1.00**	0.000	1.00
Bottlenose dolphin	**P**	**all**	**5**	**7**	**7**	**2**	**21**	**1.40**	**0.333**	**0.57**
Bottlenose dolphin	T	<=500	0	1	1	1	3	**-**	-	-
Bottlenose dolphin	T	>500	4	7	8	3	22	**2.00**	1.333	0.25
Bottlenose dolphin	**T**	**all**	**4**	**8**	**9**	**4**	**25**	**2.25**	**1.923**	**0.17**
Beaked whales	P	<=500	2	2	5	2	11	**2.50**	1.286	0.26
Beaked whales	P	>500	0	0	3	0	3	**-**	-	-
Beaked whales	**P**	**all**	**2**	**2**	**8**	**2**	**14**	**4.00**	**3.600**	**0.058**
Beaked whales	T	<=500	0	0	1	1	2	**-**	-	-
Beaked whales	T	>500	8	3	7	3	21	**0.88**	0.067	0.80
Beaked whales	**T**	**all**	**8**	**3**	**8**	**4**	**23**	**1.00**	**0.000**	**1.00**

A1.3 Comparison of partial independence and full independence models of detection probability

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 (Laake & Borchers 2004, Borchers et al. 2006).

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 mrds model (Laake & Borchers 2004, Borchers et al. 2006).

To investigate if there was any support for using the full independence model instead of the partial independence mrds model, for each species or species group, some full independence models were run and compared with equivalent partial independent models using AIC.

The results confirmed that full independence models had no support compared with equivalent partial independence models.

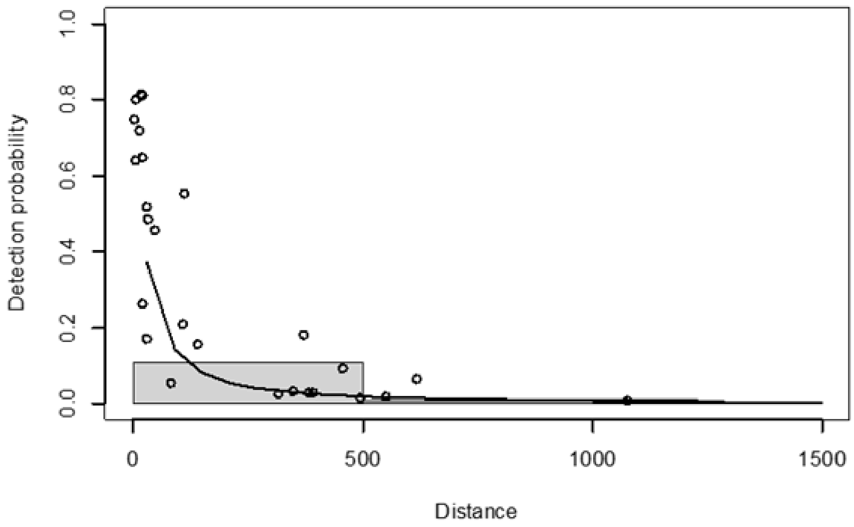
A.2 Ship survey detection functions

Detection functions (detection probability as a function of perpendicular distance in meters) estimated for bottlenose dolphin, common and striped dolphin, beaked whales, sperm whale and fin whale from the ship survey. The histograms represent the frequency of detections in intervals of perpendicular distance, the open circles represent the predicted value of each observation, and the solid line represents the estimated overall detection probability. The predicted values of each observation do not fall on the line for the overall estimated detection probability when the detection function incorporates covariates (see Table 18).

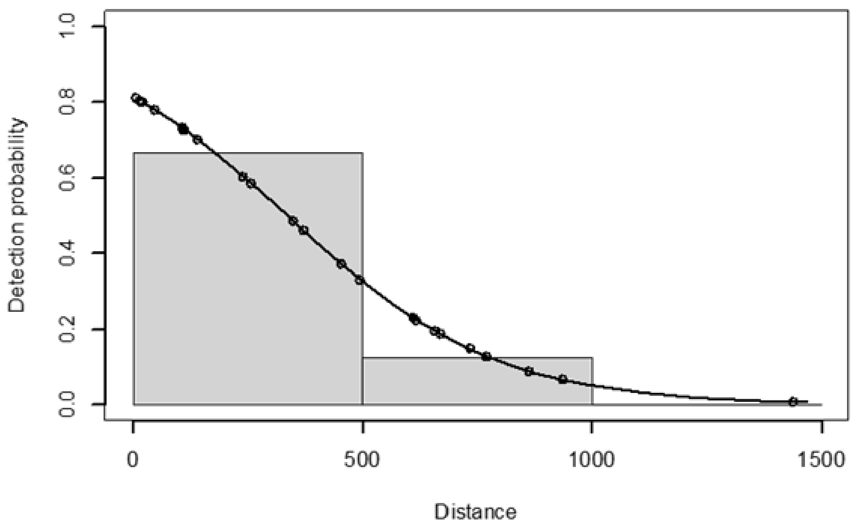
Bottlenose dolphin, common and striped dolphin, and fin whale data were analyzed using mark recapture distance sampling and thus have two detection functions: (a) detection probability for the Primary team and (b) detection probability for the Primary team conditional on first being detected by the Tracker team.

A2.1 Bottlenose dolphin

(a) Primary detection function

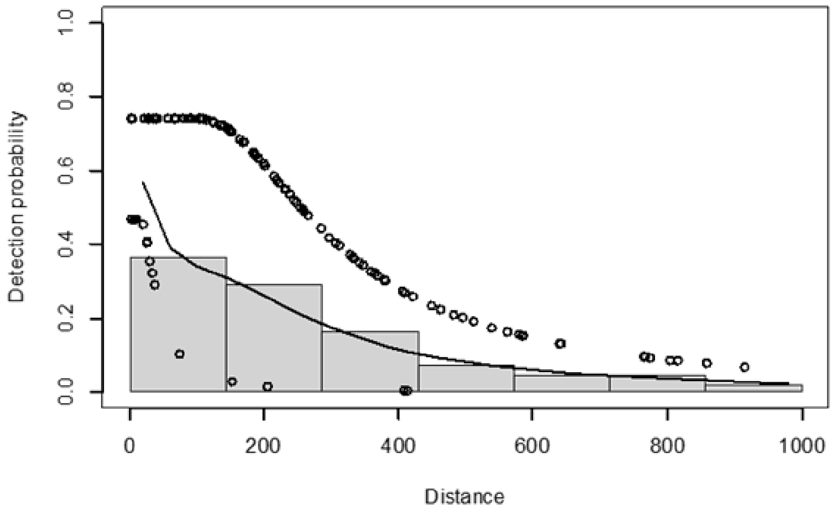


(b) Conditional detection function

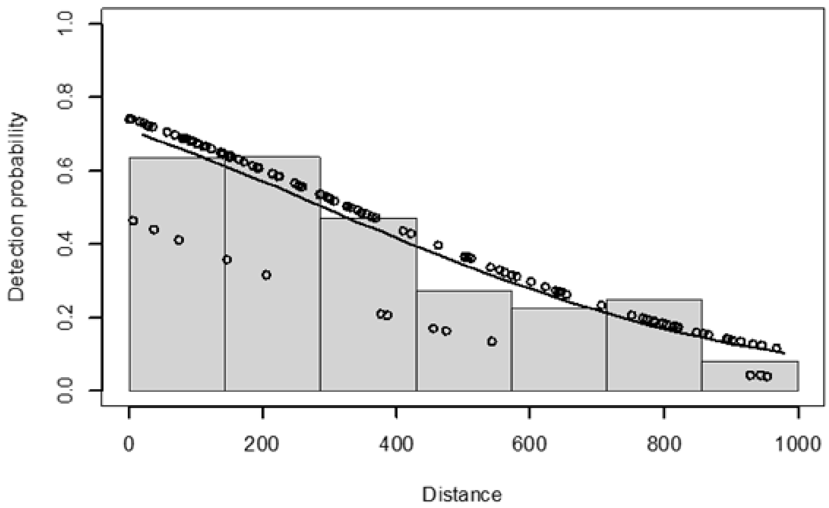


A2.2 Common and striped dolphin

(a) Primary detection function

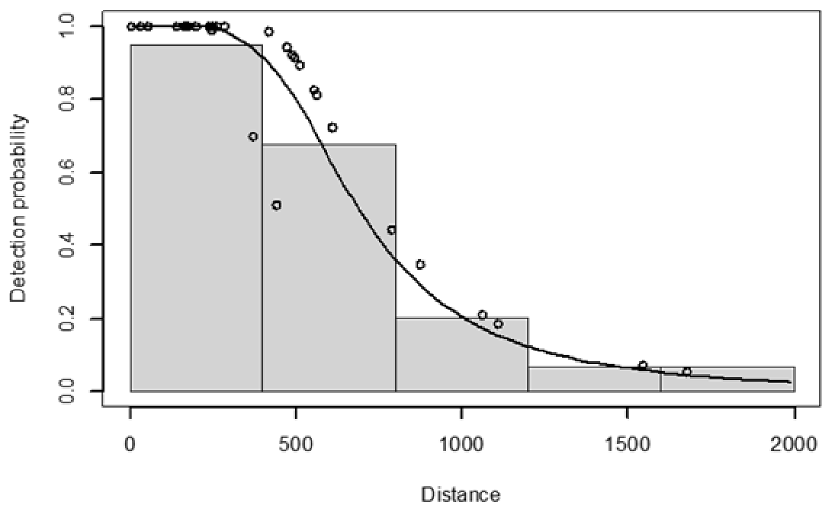


(b) Conditional detection function



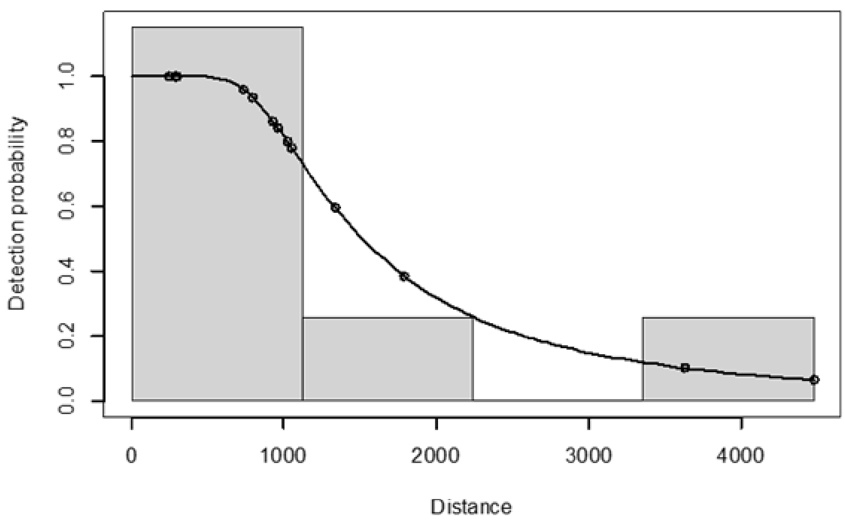
A2.3 Beaked whales

(a) Primary detection function



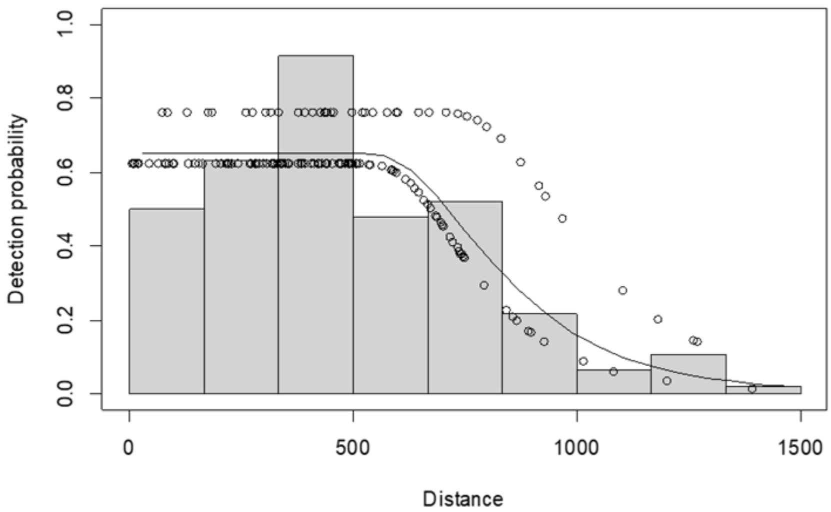
A2.4 Sperm whale

(a) Primary detection function

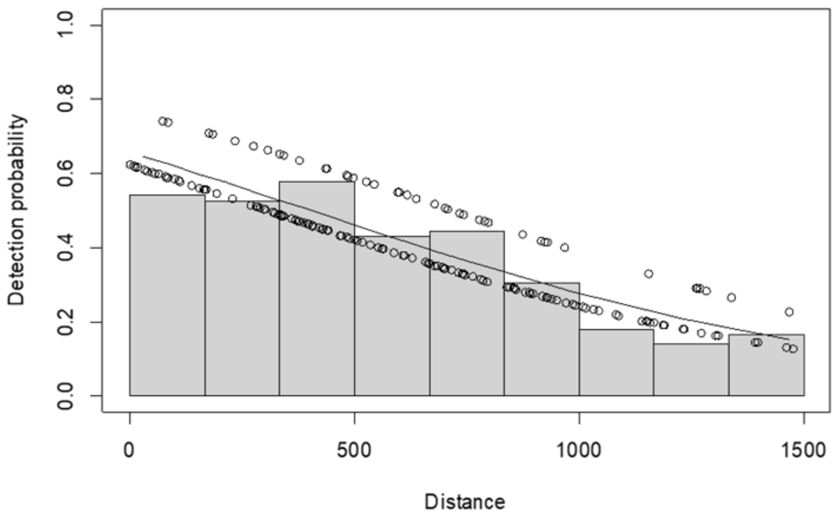


A2.5 Fin whale

(a) Primary detection function



(b) Conditional detection function



Appendix A2 – EXAMPLES OF DIGITAL PHOTOS

EXAMPLES OF DIGITAL PHOTOS (STORMM: "Système Télédétection Optique Recensement Mégafaune Marine", digital high-definition acquisition system for marine megafauna, Pelagis -HyTech)

Figure A2.1. Common dolphin (*Delphinus delphis*).

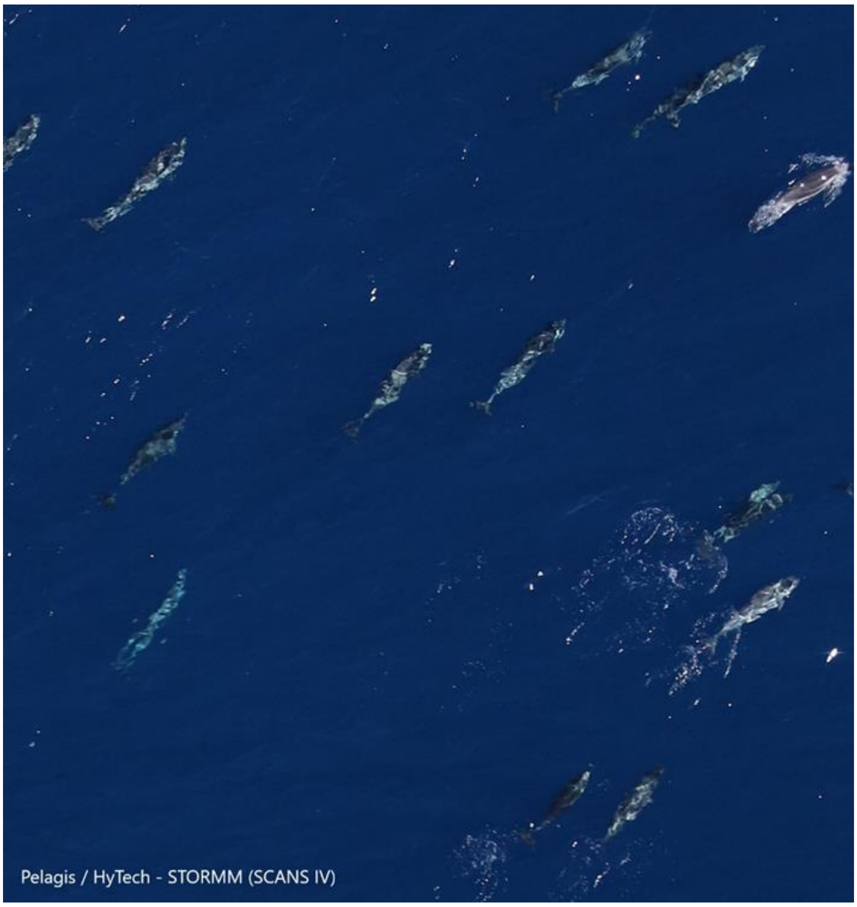


Figure A2.2. Striped dolphin (*Stenella coeruleoalba*).

Figure A2.3. Harbour porpoise (*Phocoena phocoena*).

Figure A2.4. Long-finned pilot whale (*Globicephala melas*).

Figure A2.5. Risso’s dolphin (*Grampus griseus*).

Appendix A3 - RACETRACK ANALYSIS

A3.1 Harbour porpoise

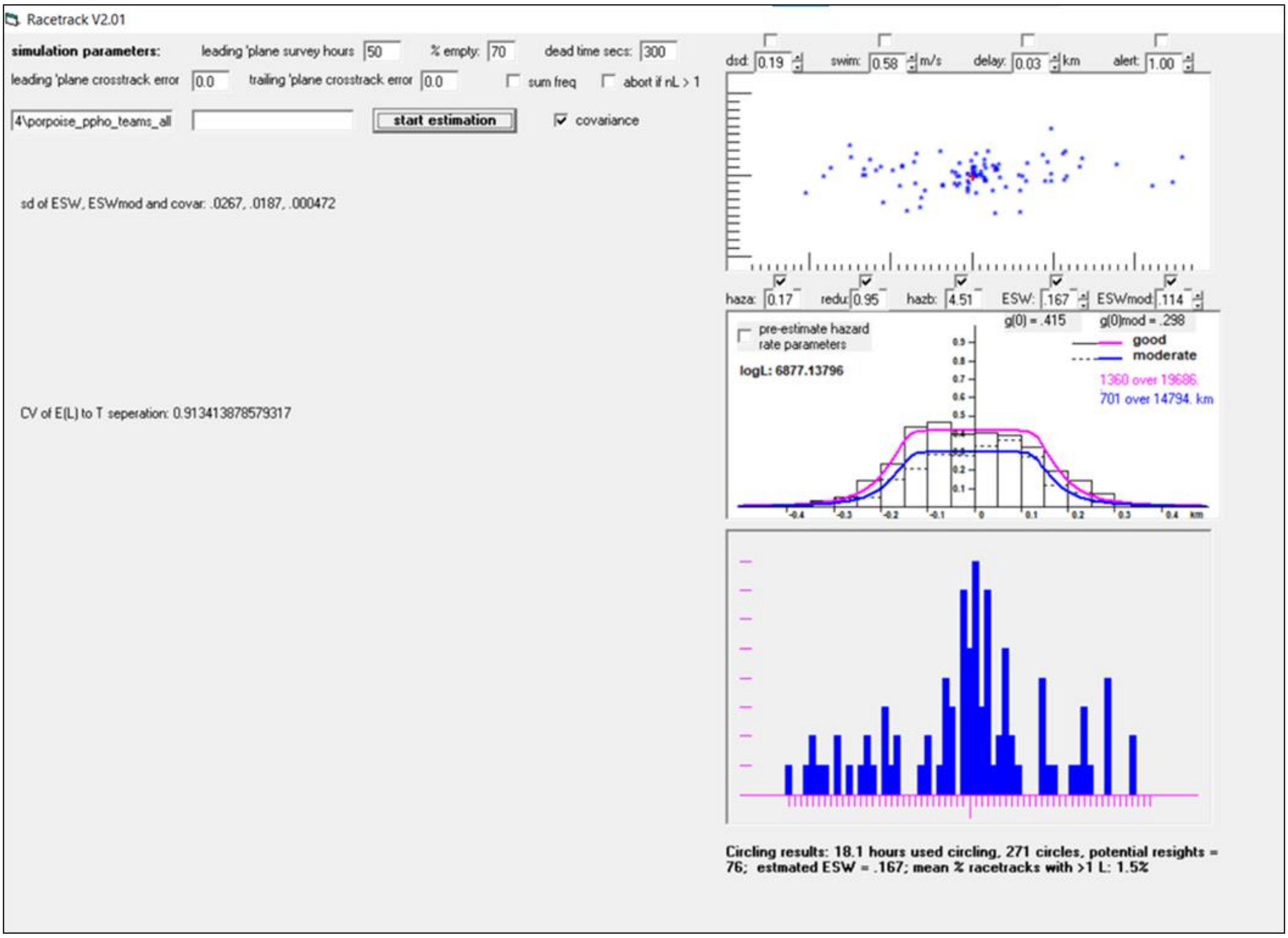


Figure A3.1. Racetracks for harbour porpoises, with a total of 176 leading sightings in SCANS-IV. The screenshot displays the results when the aerial survey data from all eight SCANS-IV teams were combined, resulting in a total of 76 potential resightings. Note that the displayed number of circles refers to all conducted racetracks, not only to those triggered by the sighting of a harbour porpoise.

The result shows that the effective strip width was estimated at 0.167 km and 0.114 km under good and moderate conditions, corresponding to g(0) of 0.415 and 0.298, respectively. The coefficient of variation (CV) for ESW under good conditions is 0.18 and for ESW under moderate conditions is 0.19. “Moderate” as compared to “good” conditions have little effect on the scale parameter of the hazard rate function, and thus the distance out to which porpoises are seen, but a clear effect on g(0).

A3.2. Dolphins

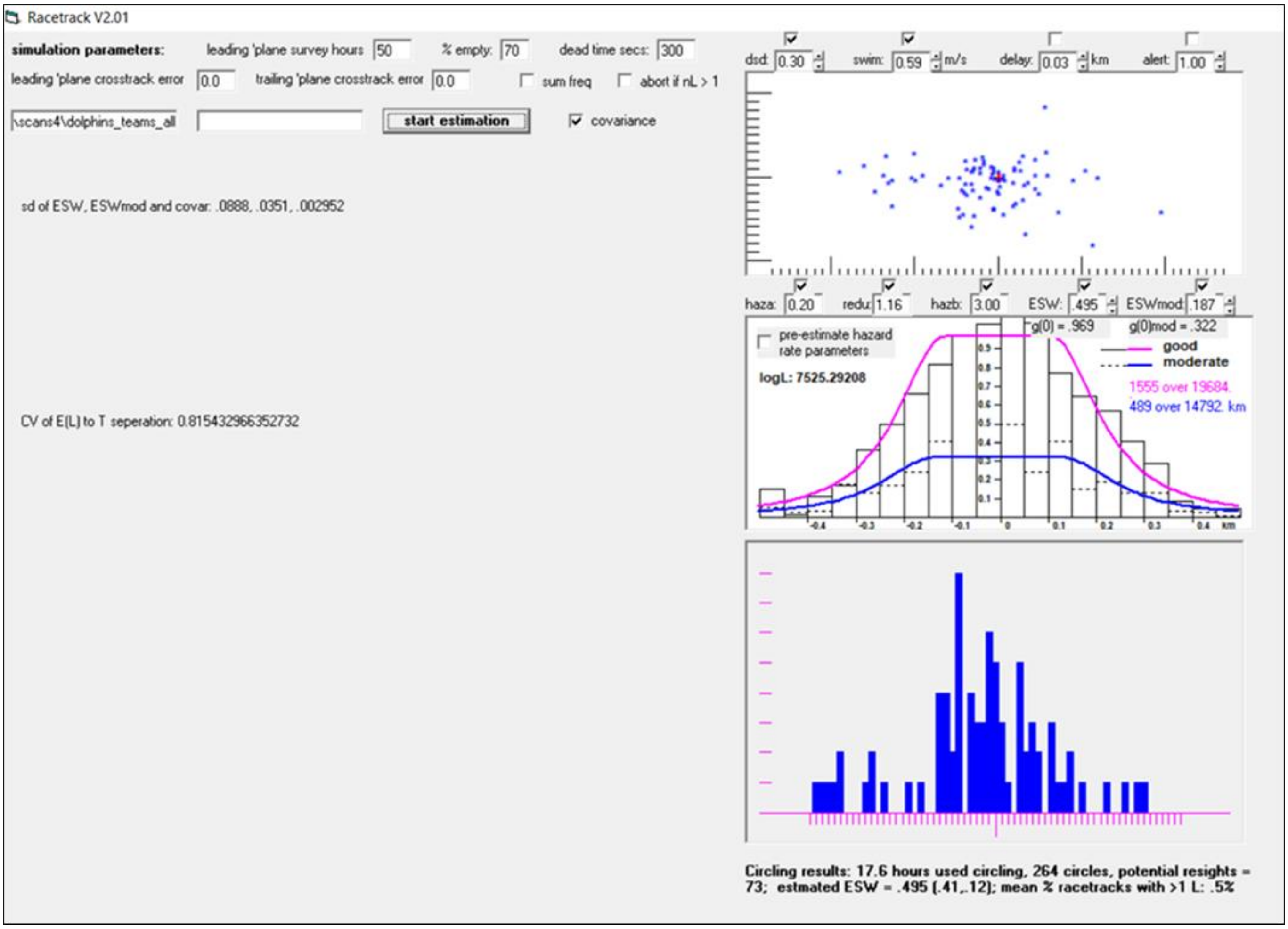


Figure A3.2. Racetracks for dolphins, here for common dolphin (n=34), striped dolphin (n=2), unid. common/striped (n=17), bottlenose dolphin (n=24), white-beaked dolphin (n=10), white-sided dolphin (n=1) and unid. delphinids (n=7). The screenshot displays the results when the aerial survey data from all eight SCANS-IV teams were combined, resulting in a total of 73 potential resightings. Note that the displayed number of circles refers to all conducted racetracks, not only to those triggered by the sighting of a dolphin species.

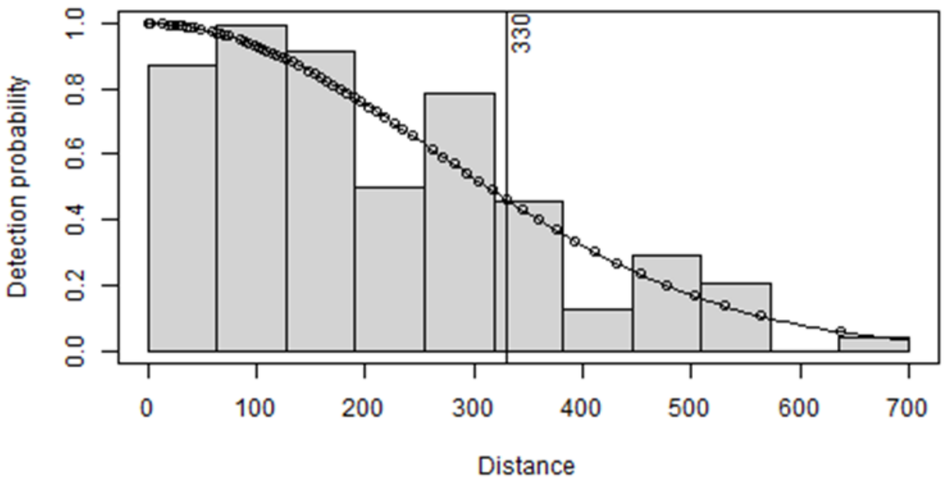
Out of the total of 95 leading sightings for this pooled dolphin category, the large majority were common or striped dolphin (or unid. common or striped). These new results are thus appropriate for these species and may also explain the increase in g(0) in good conditions compared to the value obtained in SCANS-III. However, this also means that the new results are probably not suitable for the other more northern dolphin species.

Given these results, the decision for now is to use the ESW and g(0) estimates from SCANS-IV for common and striped dolphins but to use g(0) from SCANS-III for the other dolphin species (i.e. white-beaked, white-sided, bottlenose and Risso's dolphin). Further analysis will follow. Pooling all racetracks conducted during SCANS-III and SCANS-IV will allow to evaluate whether a combined racetrack analysis would improve the estimates of g(0) for the different dolphin species.

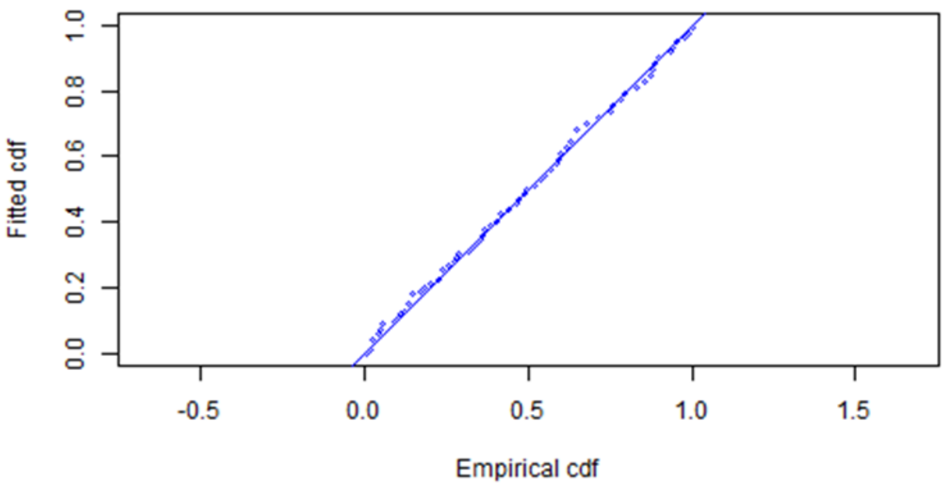
Appendix A4 - AERIAL SURVEY DETECTION FUNCTIONS FOR SPECIES WITHOUT g(0)

A4.1 Fin whale

The best fitting model was a half-normal detection function with no additional covariates and a truncation of 700 m. The average probability of detection, p, was estimated as 0.472 (CV = 0.073), with an effective strip half width of 330 m.

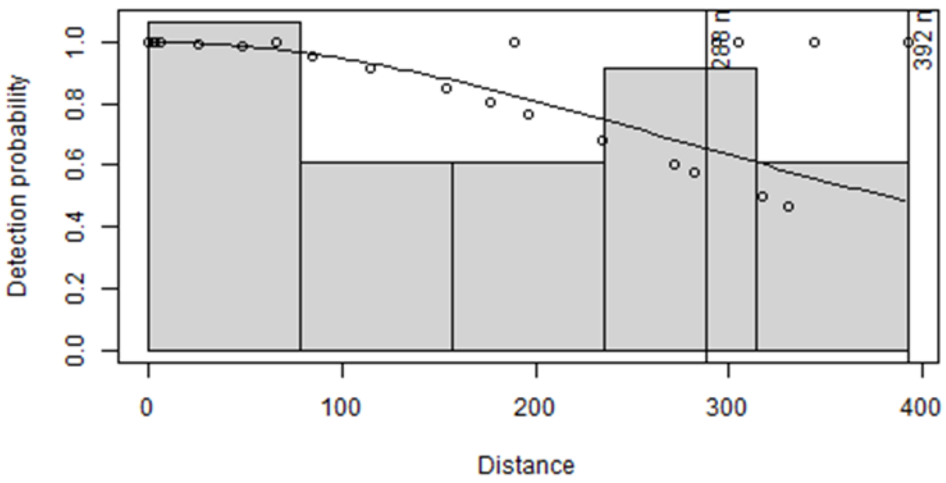


The goodness of fit tests showed a good fit (Cramer-von Mises test [unweighted] statistic = 0.038, p = 0.945). The Q-Q plot, in which the points are the fitted values of fin whale detection and the solid line represents the expected data distribution, shows a very good fit.

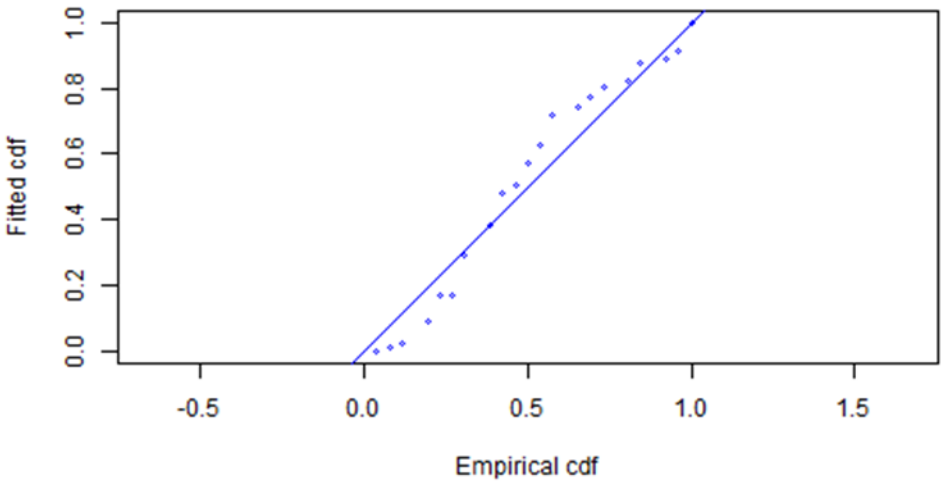


A4.2 Pilot whale

The best fitting model was a half-normal detection function with subjective conditions as an additional covariate and without truncation. The average probability of detection, p, was estimated as 0.790 (CV = 0.178), with effective strip half widths of 288 m and 392 m, for “moderate” and “good” conditions, respectively.

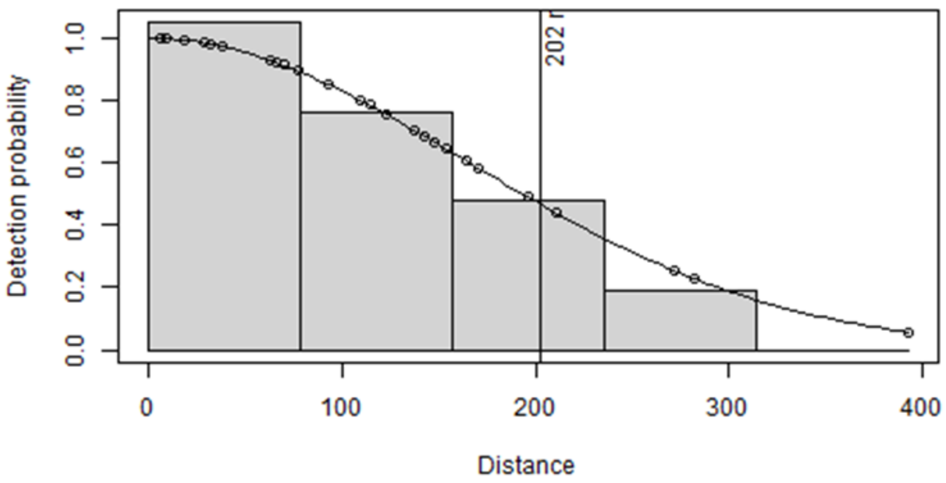


The goodness of fit tests showed a good fit (Cramer-von Mises test [unweighted] statistic = 0.155, p = 0.376). The Q-Q plot, in which the points are the fitted values of pilot whale detection and the solid line represents the expected data distribution, shows a reasonable fit.

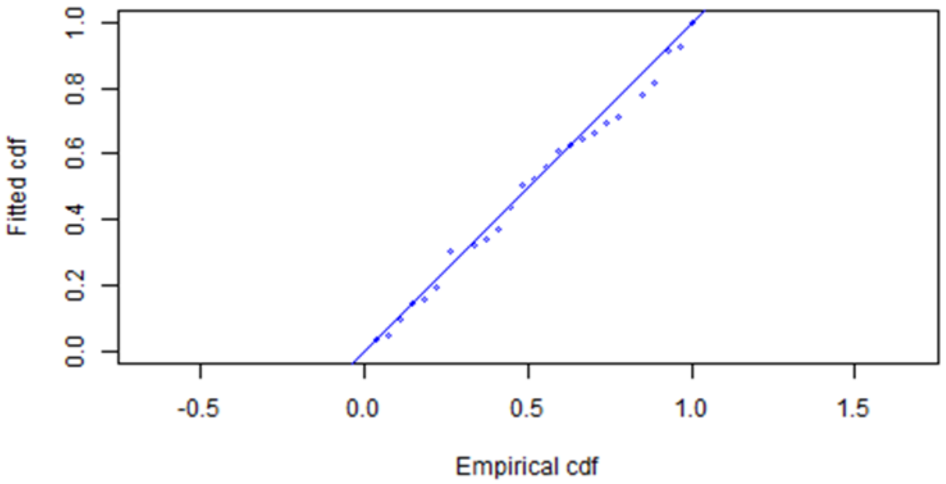


A4.3 Beaked whales

The best fitting model was a half-normal detection function with no additional covariates and without truncation. The average probability of detection p was estimated as 0.515 (CV = 0.140), with an effective strip half width of 202 m.



The goodness of fit tests showed a good fit (Cramer-von Mises test [unweighted] statistic = 0.025, p = 0.990). The Q-Q plot, in which the points are the fitted values of beaked whale detection and the solid line represents the expected data distribution, shows a good fit.



Appendix A5 - DISTRIBUTION OF BIRD WRECKS

In 2021-2022, the High Pathogenicity Avian Influenza (HPAI) A(H5N1) virus, or 'bird flu', spread through many European countries killing thousands of wild birds including seabirds, especially sandwich terns (*Thalasseus sandvicensis*, Rijks et al. 2022), great skuas (*Stercorarius skua,* Camphuysen et al. 2022) and northern gannets (*Morus bassanus*, Grémillet et al. 2023). Notably, bird researchers found high numbers of dead gannets in breeding colonies in the United Kingdom. For instance, on 30th June 2022 a total of 5,035 birds were identified as dead on Bass Rock in eastern Scotland, approximately 3.3% of the breeding population (ca. 150,518 breeding adults, Murray et al. 2015). However, many additional birds were expected to have died at sea (Lane et al. 2023). Therefore, a few days before the SCANS-IV survey started the decision was made to collect observations of dead birds during the surveys. These birds were registered following the same protocol as other sightings, but only an estimate of the concentration of floating wrecks (fdb and mdb; few and many dead birds) was recorded in a 300 m wide strip on each side of the plane. If possible, details on bird species and age were recorded on audio for later transcription. All teams were instructed to not lower their focus on the target species, however, given that dead birds are floating it was not assumed that the concentration of the observers would be impacted.

Here we present the raw data as recorded during SCANS-IV. An analysis to estimate densities of dead birds is foreseen in the future to inform on numbers and the geographical range of the mortality. In total, 793 observations of dead birds (fdb) were registered. The majority of these (89.4%) were northern gannets. The observed distribution of dead birds from SCANS-IV in summer 2022 therefore consists mainly of gannets and broadly reflects the foraging ranges of gannets from the breeding colonies along the east coast of the UK mainland. Though the effort was restricted in the block around Bass Rock, the biggest gannetry in the world, the highest numbers were seen in this area. In the North Sea, numbers were lower in the eastern part, especially in Danish waters, and in the northern part, despite the presence of big colonies on the Northern Isles. Observations of dead gannets were much lower in the Channel, and Irish Sea, and virtually absent in the Celtic Sea and Bay of Biscay. Ongoing work to understand the distribution of HPAI impacts will benefit from these opportunistic data, enabling correlations to be drawn in terms of what is being seen on land, versus what was recorded at sea. The lack of dead gannets in summer the Celtic Sea and the lower number in the Irish Sea fits the data from the ObSERVE2 survey in 2022, which detected a single dead bird in their summer survey and found large numbers of dead birds during their September survey (M. Jessopp, in lit).

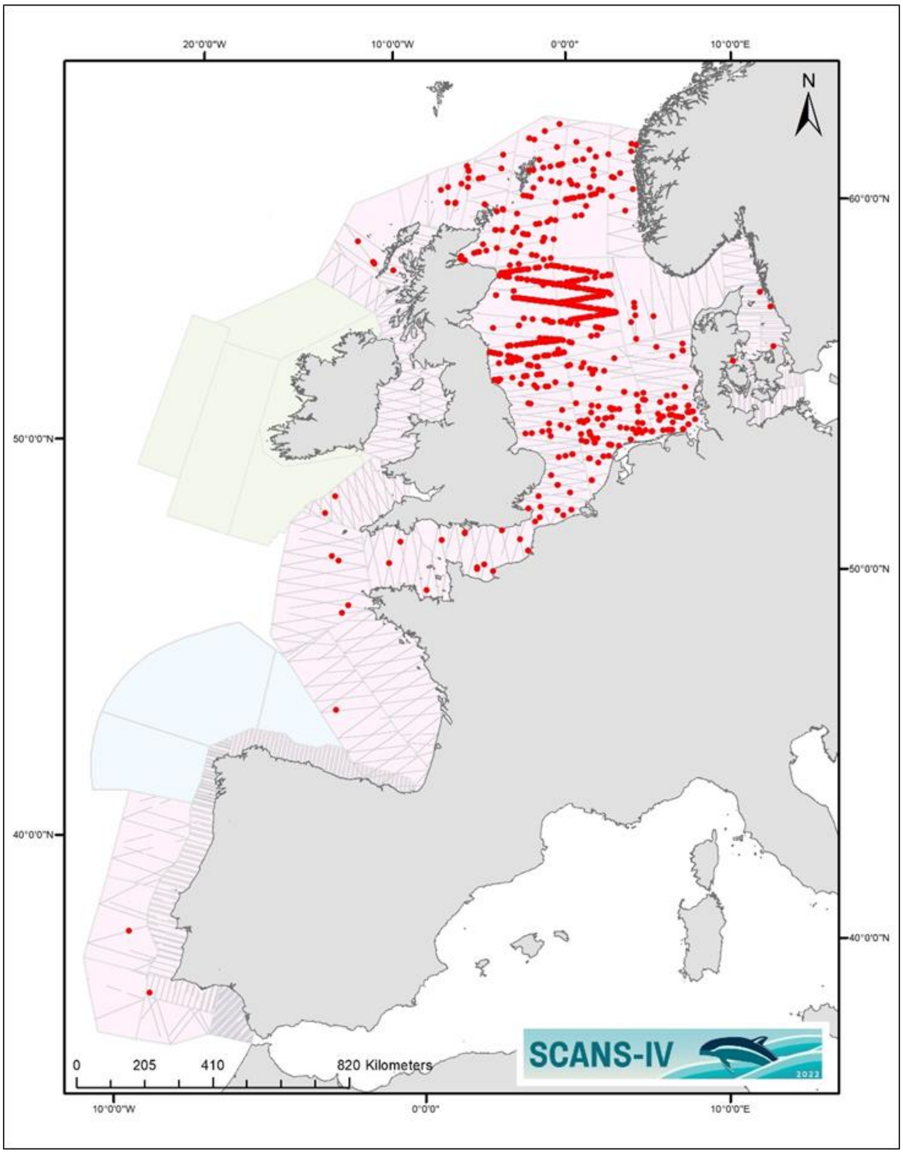


Figure A.5.1. Distribution of observed bird wrecks during the SCANS-IV aerial surveys in summer 2022. Ship survey blocks are coloured in blue. Blocks coloured green to the south and west of Ireland were surveyed by the Irish ObSERVE2 project.

Camphuysen CJ, Gear SC & Furness RW (2022). Avian influenza leads to mass mortality of adult Great Skuas in Foula in summer 2022. Scottish Birds 42: 312-323.

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Murray S, Harris MP & Wanless S (2015). The status of the gannet in Scotland in 2013- 14. Scottish Birds. 35: 3–18.

Rijks JM, Leopold MF, Kühn S, in 't Veld R, Schenk F, Brenninkmeijer A, Lilipaly SJ, Ballmann MZ, Kelder L, de Jong J, Courtens W, Slaterus R, Kleyheeg E, Vreman S, Kik MJL, Gröne A, Fouchier RAM, Engelsma M, de Jong MCM, Kuiken T, Beerens N (2022). Highly Pathogenic Avian Influenza A(H5N1) Virus causes mass mortality in Sandwich Terns during the breeding period, The Netherlands, 2022. Emerging Infectious Diseases 28, doi https://doi.org/10.3201/eid2812.221292