A short review of the distribution of short-beaked common dolphins (*Delphinus delphis*) in the central and eastern North Atlantic with an abundance estimate for part of this area

Ana Cañadas[1], Greg P.Donovan[2], Geneviève Desportes[3,4] and David L. Borchers[5]

[1] *Alnitak. Nalón 16, E 28240 Hoyo de Manzanares, Madrid, Spain*
[2] *International Whaling Commission, The Red House, Station Road, Impington, Cambridge CB4 9NP, United Kingdom*
[3] *GDnatur, Stejlestræde 9, DK 5300 Kerteminde, Denmark*
[4] *Faroese Museum of Natural History, Fútalág 40, FO-100 Tórshavn, Faroe Islands*
[5] *RUWPA, The Observatory, University of St Andrews, Fife, KY16 9LZ, United Kingdom*

ABSTRACT

This paper uses data from 3 programmes: (1) the North Atlantic Sightings Surveys (NASS) surveys undertaken throughout much of the central and eastern North Atlantic north of about 40° N in 1987, 1989, 1995 and 2001; (2) the MICA-93 programme; and (3) the north eastern Atlantic segment of the Small Cetacean Abundance in the North Sea (SCANS) survey in 1994. The data from all surveys were used to examine the distribution of common dolphins in the NE Atlantic. No sightings were made north of 57° N. An initial attempt to examine distribution against 4 potential non biological explanatory variables was made. A simple interpretation of the preliminary analyses presented here is that the primary areas for groups of common dolphins were in waters over 15° C and depths of 400-1,000 m (there does appear a link with shelf features), between around 49°-55° N especially between 20°-30°W. An illustrative example of spatial modelling is presented. Only for 1 year (and part of the total survey area) were there sufficient data to attempt to estimate abundance: 1995. The estimated abundance in the W Block of the NASS-95 Faroese survey was 273,159 (cv=0.26; 95% CI=153,392-435,104) short-beaked common dolphins. This estimate is corrected for animals missed on the trackline ($g(0)$) and for responsive movement.

Cañadas, A., Donovan, G.P., Desportes, G. and Borchers, D.L. 2009. A short review of the distribution of short-beaked common dolphins (*Delphinus delphis*) in the central and eastern North Atlantic with an abundance estimate for part of this area. *NAMMCO Sci. Publ.* 7:201-220.

INTRODUCTION

Although short-beaked common dolphins (*Delphinus delphis*) are known to occur in many areas of the North Atlantic (*e.g.* Perrin 2002), there have been few large scale systematic dedicated cetacean surveys to allow ocean basin estimates of their abundance to be obtained or even to allow their distribution to be described fully. In the north eastern Atlantic, the available information suggests that they are frequently encountered, most typically appearing in oceanic and shelf edge waters (Forcada *et al.* 1990, Goujon *et al.* (MS) 1993, Hammond *et al.* 2002, Harwood and Wilson 2001, Lopez 2003, Silva and Sequeira 2003). However, the overall distribution of the species and the biological and non biological factors affecting this, have been little studied. Abundance has been reported for only a few discontinuous areas (*e.g.* Goujon *et al.* (MS) 1993; Hammond *et al.* 2002, O'Cadhla *et al.* 2004), representing a patchy and sparse coverage of the distribution range. Stock structure is poorly understood. Since the beginning

of the 1990s, concerns over the conservation status of the species in the area have been raised as a result of documented by catches, mainly in trawl and driftnet fisheries (Goujon *et al.* (MS) 1993, Lopez *et al.* 2003, Morizur *et al.* 1999, Silva and Sequeira 2003, Tregenza and Collet 1998). Without better information on abundance, stock structure and total removals it is difficult to assess the impact of by catches at the population level (e.g. see Hall and Donovan 2002). Better information on the distribution of short-beaked common dolphins and the distribution of fishing effort may serve to identify potential 'hot spots' for by catches and enable a more focussed examination of the issue.

This paper examines the available data on short-beaked common dolphins from the NASS (North Atlantic Sightings Surveys) multi year, multi national survey programme that covered a large part of the north-eastern and central North Atlantic over several years (Víkingsson *et al.* 2009), supplemented with data from 2 other survey programmes of lesser geographical scope, the MICA-93 (Goujon *et al.* (MS) 1993) and the SCANS-94 (Hammond *et al.* 2002) surveys. Most of the effort of the SCANS-94 programme was in the North Sea. It uses these to (1) review and expand upon what is known about the distribution of common dolphins in the central and north eastern Atlantic, (2) present a preliminary examination of the non biological factors that may influence that distribution and (3) provide an abundance estimate of common dolphins from the Faroese vessel operating as part of the NASS-95 programme, following on from the work of Cañadas *et al.* (2004).

MATERIALS AND METHODS

Survey design and data collection

As noted above, this paper uses data from 3 programmes: (1) the NASS surveys undertaken throughout much of the central and eastern North Atlantic north of about 40° N in 1987, 1989, 1995 and 2001 (Víkingsson *et al.* 2009); (2) the MICA-93 programme (Goujon *et al.* (MS) 1993); and (3) the SCANS survey in 1994 (Hammond *et al.* 2002). The areas covered are shown in Fig.1.

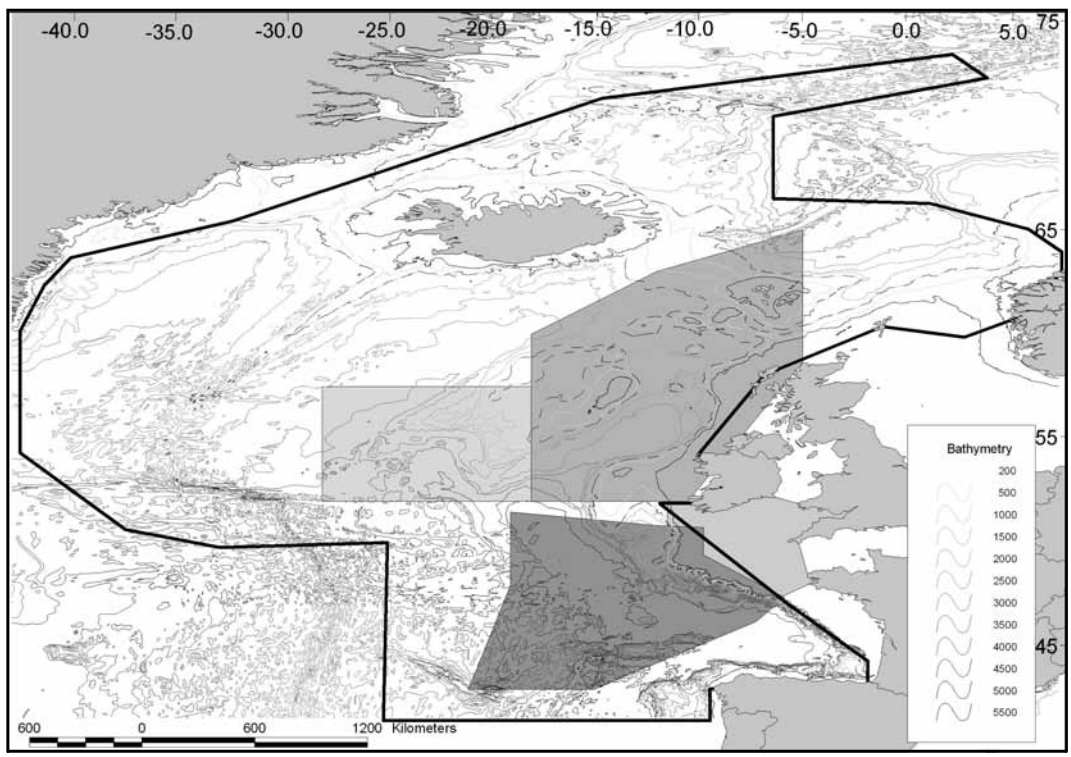


Fig.1. *Boundaries of the study area for the NASS surveys and bathymetry. A dark line has been plotted over the 200 m depth contour, and a dark dashes line over the 1000 m depth contour. The blocks E and W of NASS-95 and the blocks for MICA-93 and SCANS are also shown.*

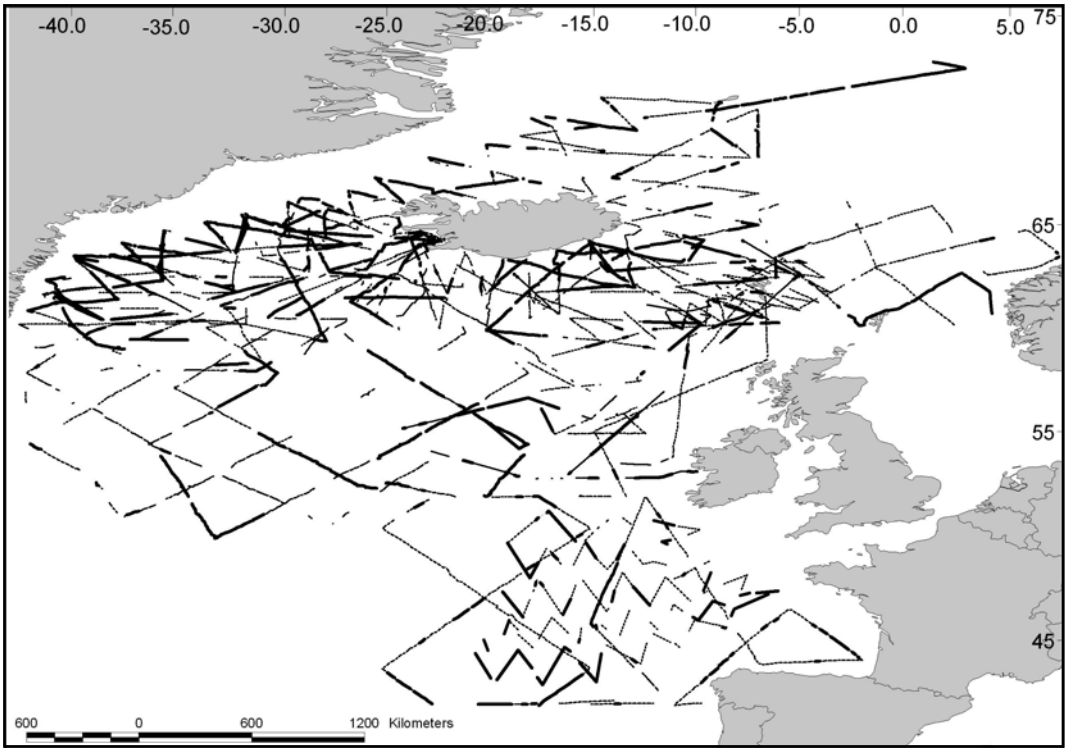


Fig. 2. *Cruise tracks for all surveys considered in this paper. Thick line corresponds to effort carried out with BSS 0 to 2. Thin dashed line corresponds to BSS 3 to 5.*

Details of the survey procedures can be found in the relevant papers. The important points to notice are that all of the surveys were dedicated cetacean line transect surveys following a random cruise track design and that they all collected standard line transect sightings, weather and effort data. A summary of the vessels used and other pertinent information is provided in Table 1.

The completed 'on effort' cruise tracks are shown in Fig. 2, stratified by Beaufort Sea State (BSS) (0–2, 3+). However, it should be noted that the primary target species of the cruises varied (see Table 1) and this influenced *inter alia* choice of survey blocks, 'acceptable' search conditions and observer strategy (*e.g.* single versus double platform, naked eye versus binoculars, *etc*.). The implications of these differences for the results obtained in this paper are considered in the Discussion.

Distribution and relative abundance

Only data for sightings of confirmed species identity were considered. In examining distribution and relative density, the following data, where available, were used: position of sighting, group size, BSS at the time of sighting. In addition, account was taken of the overall levels of effort by sea state where this was available. Sea state is known to be an important factor that affects the ability of observers to detect cetaceans, including common dolphins (*e.g.* see Cañadas *et al.* 2004). In the simplest instance, plots of sightings against completed survey track were made to examine distribution (see Fig. 5).

As an initial attempt to begin to try to explain the observed distribution patterns, 2 crude indices of abundance were calculated: (1) encounter rate expressed as number of groups per nm; and (2) encounter rate expressed as number of animals per nm. These indices of abundance were examined against 4 of the many potential non-biological explanatory variables that may influence distribution: position (latitude and longitude); depth; and sea surface temperature.

Table 1. Vessel characteristics, primary target species, survey dates and effort by BSS for the surveys considered in this paper (where available).

Vessel	Length of vessel (m)	No. sighting platforms	Platform height or heights (m)	Primary target species	Survey period	Effort: sea state 0-2 (nm)	Effort: sea state 3+ (nm)
1987 NASS-87							
Hvitaklettur	34.7	1	6.0	Large whales	24 June-28 July	1,455	1,885
Arni Fridriksson	40.4	1	7.3	Large whales	17 June-12 August	1,014	3,952
Skirnir	37.8	1	7.5	Large whales	24 June-27 July	1,896	1,160
Keflvikingur	33.9	1	7.0	Large whales	24 June-27 July	1,504	2,126
1989 NASS-89							
Arni Fridriksson RE100	40.4	1	7.3	Large whales	10 July-14 August	793	2,531
Bardinn (Skirnir)	37.8	1	7.5	Large whales	12 July-13 August	1,041	1,421
Hvalur 8	48.2	1	10.5	Large whales	27 July-12 August	822	939
Hvalur 9	51.2	1	10.5	Large whales	27 July-10 August	669	987
Olavur Halgi	55.0	1	8.2	Large whales	23 July-15 August	329	1,210
Investigador	43.5	1	6.0	Large whales	7 July-9 August	970	3,146
1993 MICA-93							
Croix Morand	38	1	6.2	Small cetaceans	July August	1,709	2,027
1994 SCANS							
Dana	68.9	2	Not available	Small cetaceans	July	Not available	Not available
1995 NASS-95							
Miðvingur	36.0	2	9.4 / 11.5	Pilot whales	8 July-6 August	606	1,029
2001 NASS-01							
Arni Fridriksson RE200	42.2	1	9 / 13.8	Large whales	22 June-2 July	348	419
Bjarni Sæmundsson	56.0	1	10.3 / 16.3	Large whales	20 June-2 July	153	682
West Freezer	42.0	1	11 / 13.8	Large whales	30 June-2 July	112	162
Arni Fridriksson RE100	69.9	1	15.3 / 18.6	Large whales	25 June-2 July	621	209

These were chosen because (a) there were some data available and (b) they have been implicated as being important factors in the distribution of other cetacean species (*e.g.* Cañadas *et al.* 2005, IWC 2006). The total area bounded by 42°–57° N (there were no sightings north of 57° N) and 1°–43° W was divided into 0.5°×0.5° squares and the average depth, latitude and longitude of the midpoint, and (for those cells for which it was available *i.e.* only north of 52° N) average sea surface temperature for July (1995 and 2001) were calculated (see Figs 3 and 4).

The variables listed above were stratified into suitable bins and encounter rates were then calculated as the average encounter rate for the grid cells included in each category (see Table 2). Choice of bin was chosen by inspection of the data and available information on common dolphin distribution from other sources; sensitivity to the choice of bins was examined but the results are not presented here as they were not found to be significant. Interested readers can contact one of us (Cañadas) if they wish to receive more information. Average group sizes were calculated also for each category of the 4 variables; the sample sizes are slightly smaller than shown in Table 2 as 16 sightings had no group sizes recorded. Only grid cells with more than 10 nm sailed on effort were used in the analysis this value represented a compromise between having sufficient effort to consider it representative and to maintain adequate sample size. The use of this criterion resulted in

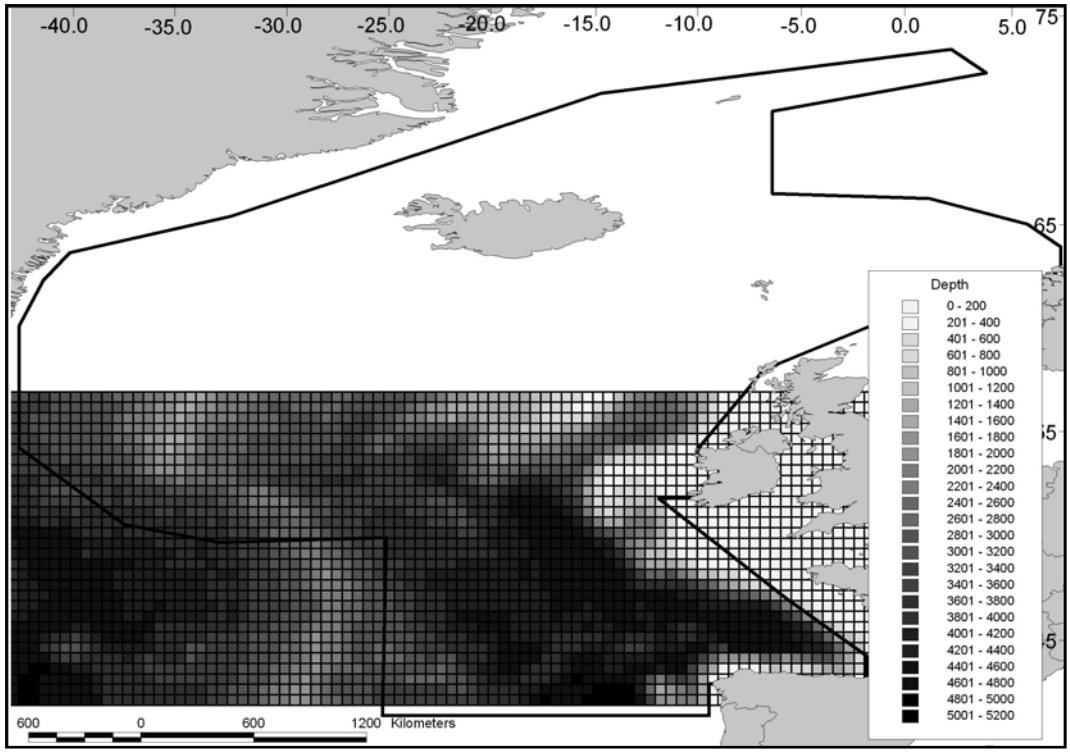


Fig. 3. *Grid cells and mean depth*

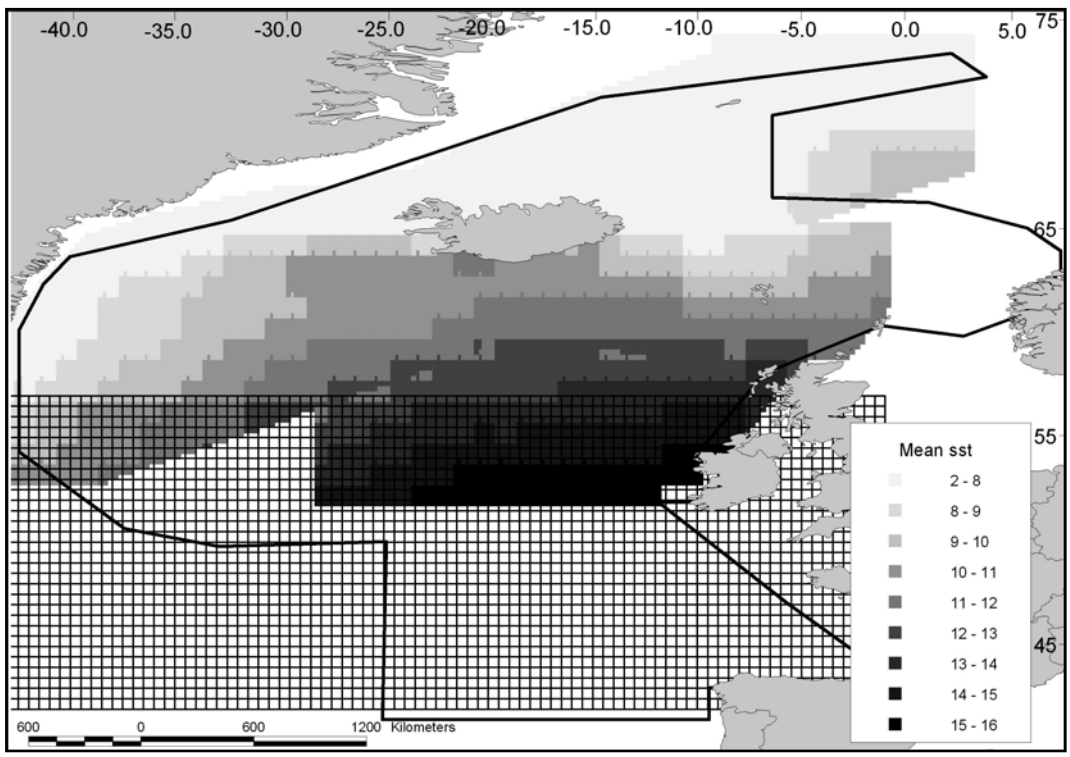


Fig. 4. *Grid cells and mean Sea Surface Temperature from data for 1995 and 2001*

Table 2. A summary of the data available for examining the encounter rates and explanatory variables by bin size. Sightings refers to sightings of groups. The total number of cells under 'All Effort' is usually greater than the sum of those for BSS 0-2 and 3+ since not all of the datasets included information on sea state. The number of potential cells for the temperature analysis is lower because data are only available north of 52° N.

Range	Effort (BSS 0-2)	Effort (BSS 3+)	All effort	Range	Effort (BSS 0-2)	Effort (BSS 3+)	All effort
Latitude (° N)				**Depth (m)**			
Cells				Cells			
42.0-45.5	46	64	103	0-400	22	20	70
45.5-49.0	44	97	133	401-1000	10	21	28
49.0-51.0	29	40	83	1001-2000	30	44	71
51.0-53.0	31	49	87	2001-3000	24	86	110
53.0-55.0	29	39	74	3001-5200	118	173	280
55.0-57.0	25	55	79				
Total	**204**	**344**	**559**	**Total**	**204**	**344**	**559**
Sightings				Sightings			
42.0-45.5	4	6	12	0-400	12	5	22
45.5-49.0	23	14	42	401-1000	22	15	37
49.0-51.0	43	14	65	1001-2000	36	22	65
51.0-53.0	30	24	59	2001-3000	21	32	58
53.0-55.0	11	27	46	3001-5200	42	37	91
55.0-57.0	22	26	49				
Total	**133**	**111**	**273**	**Total**	**133**	**111**	**273**
Longitude (° W)				**SST (°C)**			
Cells				Cells			
30-40	13	46	53	8-12	3	29	34
20-30	58	64	101	12-14	22	14	37
10-20	152	262	342	14-15	20	33	50
2-10	34	57	75	15-16	12	25	39
Total	**257**	**429**	**571**	**Total**	**57**	**101**	**160**
Sightings				Sightings			
30-40	8	1	10	8-12	0	0	1
20-30	26	26	64	12-14	22	3	26
10-20	64	73	144	14-15	0	36	41
2-10	35	11	55	15-16	22	30	56
Total	**133**	**111**	**273**	**Total**	**44**	**69**	**124**

a reduction of accepted sightings from 298 to 273. The results were examined for effort in all sea states and separately for BSS 0-2 and 3+. In this paper, the results are presented for all sea states combined only. However, if there is a changing pattern by sea state, this is mentioned in the Results section. Again, interested readers can contact one of us (Cañadas) if they wish to receive more information. Given the preliminary nature of the analysis and the limitations of the data, we did not believe a complex statistical analysis was appropriate and thus restricted ourselves to a largely qualitative examination of graphical data. However, in order to provide an example as to how a more sophisticated analysis could be undertaken given more data, a simple spatial analysis (*e.g.* see discussion in IWC, 2006) is included as Appendix 1.

Abundance estimate

The only data suitable for obtaining an absolute abundance estimate that have not been previously analysed were those from the Faroese vessel *Miðvingur* that took part in the 1995 NASS survey and used a double platform methodology; details of that survey including the important methodological details of the approach used to estimate density taking into account animals missed on the trackline and the movement of the dolphins towards the ship before detection are given in Cañadas *et al.* (2004). It is not appropriate to repeat those details here. Several transects were defined within each block: 2 for block W and 10 for block E, and effort was calculated for each transect. The extent of each block is shown in Fig.1. Each transect was divided into segments of approximately 20 nautical miles (nm) each for bootstrapping purposes (non parametric bootstrap with replacement).

The estimated total number of animals in the survey area, N, is obtained by taking the estimated density D from Cañadas *et al.* (2004) and A, the surface area of the survey area:

(1)

$$\hat{N} = A \times \hat{D}$$

The cv of the abundance estimate was obtained using a non parametric bootstrap procedure, in which segments were the sampling units, with 1,000 resamples (Cañadas *et al.* 2004).

RESULTS

A total of 27,160 nm (50,300 km) were surveyed on effort (of which 33.6% were carried out in BSS) 0 to 2, 57.8% in BSS 3 to 5, and 2.8% in BSS 6 to 7) during the 6 years of survey considered in this paper (1987, 1989, 1993, 1994, 1995 and 2001). A total of 14,607 (27,052 km) were carried out within the grid cells analysed here. A total of 298 sightings of confirmed common dolphin groups were recorded with an average group size of 15 animals per group (±2.2, range 1–239). There were 77 sightings classified as 'maybe common dolphin' or 'unidentified dolphin'; these were excluded from the analysis. All confirmed sightings are plotted in Fig. 5.

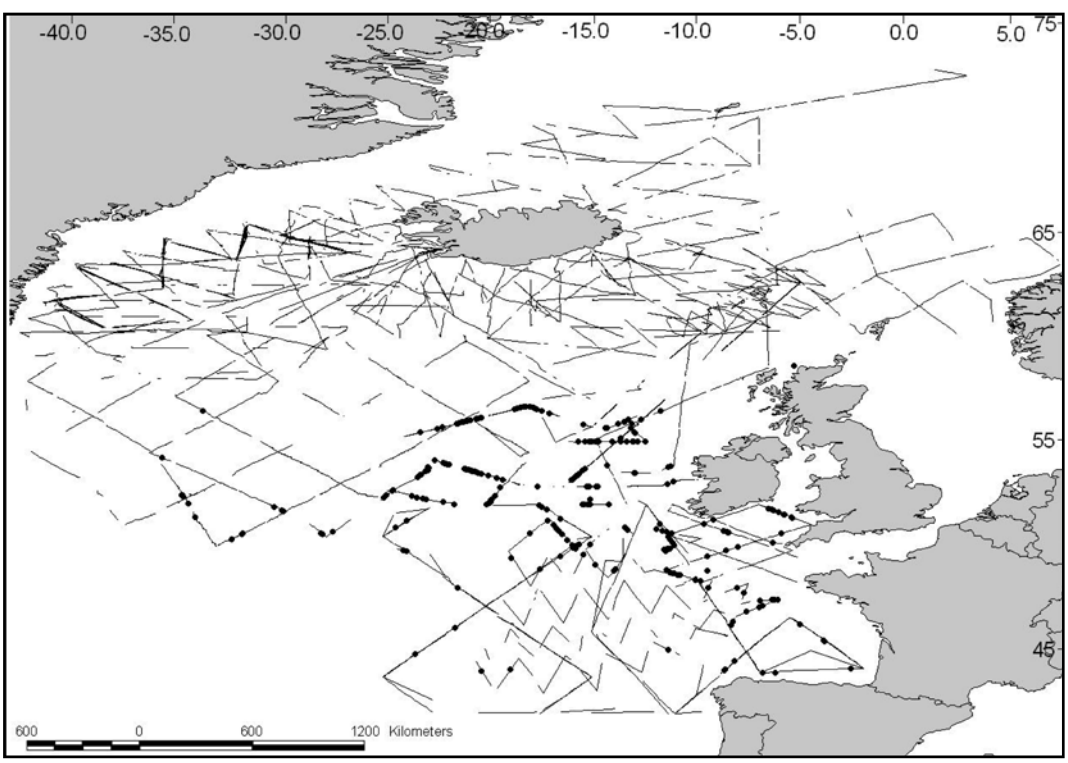


Fig. 5. *Cruise tracks and sightings of all surveys considered in this paper*

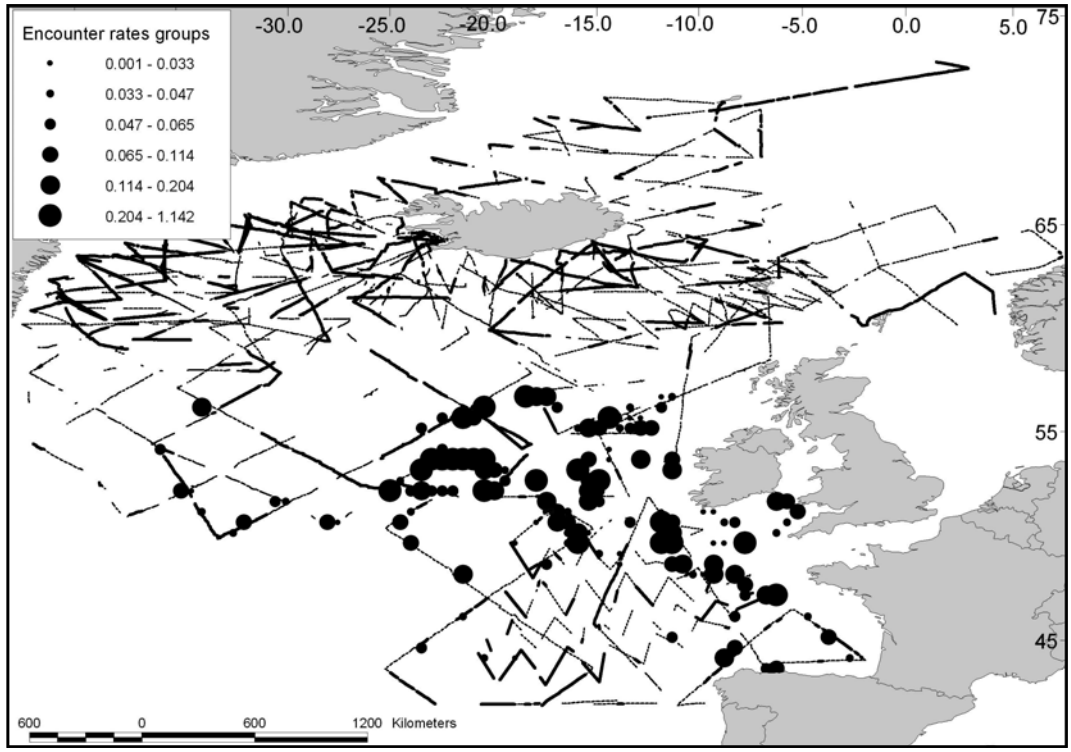


Fig. 6. *Schematic plot of encounter rate of groups by 0.5° square. Solid lines indicate effort with BSS 0 to 2. Dashed lines indicate effort with sea states of 3 or more.*

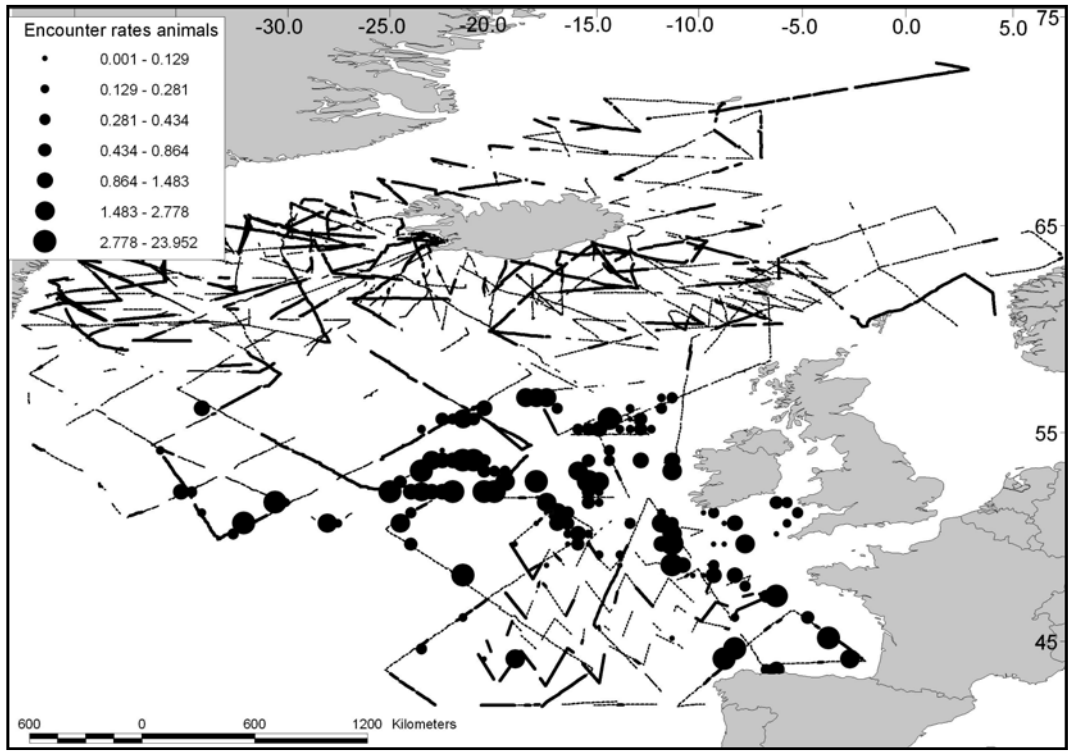


Fig. 7. *Schematic plot of encounter rate of animals by 0.5° square. Solid lines indicate effort with BSS 0 to 2. Dashed lines indicate effort with sea states of 3 or more.*

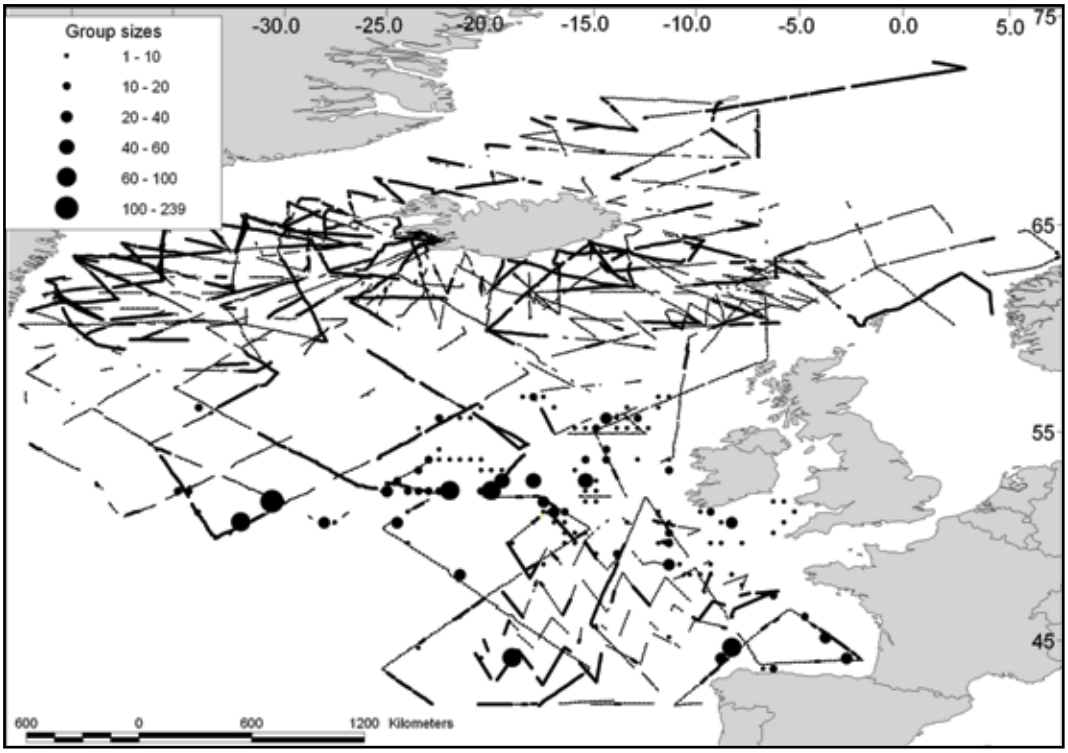


Fig. 8. *Schematic plot of group sizes by 0.5° square. Solid lines indicate effort with BSS 0 to 2. Dashed lines indicate effort with BSS of 3 or more.*

Distribution and group size

Figs 6–8 present schematic maps (based on 0.5° squares) encounter rates and group size, along with the completed cruise tracks.

Position

Despite considerable effort to the north (see Fig. 5), there were no sightings of short-beaked common dolphins north of around 57° N. The most northerly sighting in the surveys covered in this paper was at 56°45' N.

Fig. 9a shows the encounter rate of groups stratified into 6 latitudinal bins. South of around 49° N, encounter rates were lowest (around 0.01±0.001 groups nm^{-1}). However, they increased significantly (at the 5% level) after this before maintaining a relatively stable value of around 0.03 (±0.002) groups nm^{-1} between 49° N and 55° N and then declining to 0.023 (±0.003) north of 55° N. By contrast, encounter rates of *animals* (Fig. 9c) shows a pronounced and significant peak (of around 0.8±0.27 animals nm 1) between 51-53° N. This reflects the second significant peak in average group size (26.4±5.72 animals) between 51-53° N an earli-

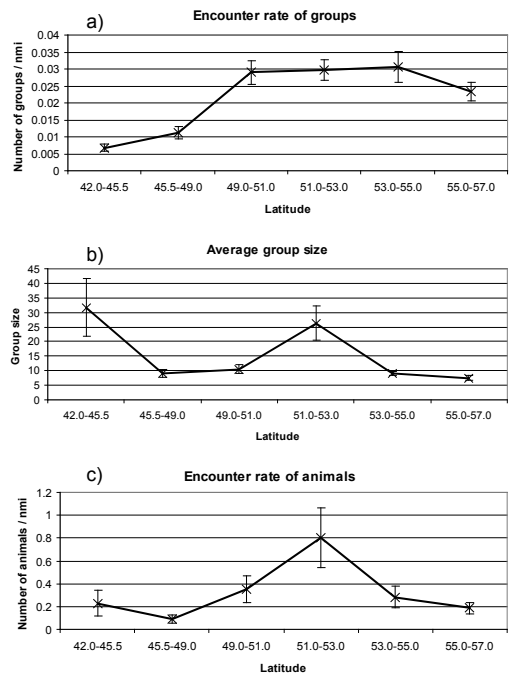


Fig. 9. *Encounter rates of groups (a) and animals (c) and average group sizes (b) of common dolphins for 6 bins of latitude. Vertical bars show standard errors.*

er peak, (31.7±9.86 animals) but with larger SE occurred in the most southerly bin (42-45.5° N). In other latitudes, the average group size (Fig. 9b) was relatively consistent at around 8-10 animals with small SEs (0.68-1.46).

Fig. 10a shows the encounter rate of *groups* stratified into 4 longitudinal bins. Encounter rates of groups were highest (0.03±0.003 groups nm^{-1}) between 20-30° W and lowest (0.005±0.0007 groups nm^{-1}) in the most easterly bin (at the 5% level). East of 20° W, the rates were reasonably constant at around 0.02±0.002 groups nm^{-1}. The pattern is somewhat different for encounter rates of *animals* (Fig. 10c) where the variation with longitude is much less pronounced, although there is a slight but insignificant peak at 20-30° W. This reflects, in particular, the much higher average *group size* (49.5±27.21 *animals*). East of 30° W, the average *group size* (Fig. 10b) was consistent at about 12–15 animals (SEs=1.24–2.79).

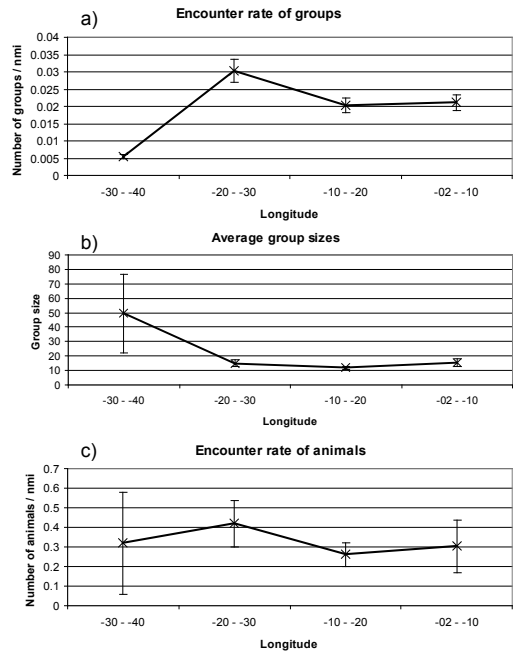


Fig. 10. *Encounter rates of groups (a) and animals (c) and average group sizes (b) of common dolphins for 4 bins of longitude. Vertical bars show standard errors.*

Depth

Fig. 11a shows the encounter rate of groups stratified into 5 depth range bins. The lowest encounter rates (<0.02±0.002 groups nm^{-1}) were found in shallow waters (0 400 m) and waters over 2,000 m (significant at the 5% level). Encounter rates were highest (0.057±0.011 groups nm^{-1}) between 400 and 1,000 m followed by 1,000 2,000 m (0.038±0.006 groups nm^{-1}). A similar pattern was found for encounter rates of animals (Fig. 11c). Average group sizes showed a significant increasing trend with depth, from 8.0±1.44 animals in waters <400 m up to 18.6±2.76 animals in waters >2,000 m (Fig. 8b).

Sea surface temperature(SST)

Fig 12a shows the encounter rate of *groups* stratified into 4 SST bins. As noted above, SST data were only available for some of the waters north of 52° N (Fig. 4). This has the effect of both limiting the sample size (see Table 2) and restricting the analysis to SSTs between 8° and 16° C. Only 1 group was seen in the coolest bin (8°-12°C) and that was a group of 3 *animals* in water of 11.6°C at 54°10' N, 35°26' W. Encounter rates of *groups* in waters between 12°-15° C were stable at around 0.03±0.005 *groups* nm^{-1} but increased sharply to 0.07±0.01 groups nm^{-1} for the warmest (15°-16° C) bin. A similar gener-

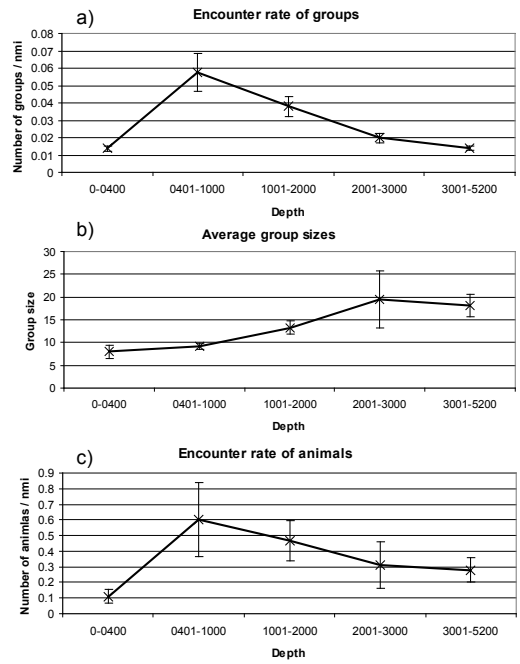


Fig. 11. *Encounter rates of groups (a) and animals (c) and average group sizes (b) of common dolphins for 5 bins of depth. Vertical bars show standard errors.*

al increasing trend with temperature was found for both encounter rate of *animals* (up to a peak of 1.28±0.41 *animals* nm^{-1}) in the warmest bin (Fig. 9c), and for group size (Fig. 9b) with around 8-10 (SEs=0.78−1.15) animals for waters <15° C increasing up to around 21.8±3.38 *animals* for waters of 15°-16° C (significant at the 5% level).

Abundance estimates

A total of 74 primary sightings of common dolphins were recorded, 25 in block E and 49 in block W (see Table 3 and Fig. 13). The results of the analysis including bootstrapping with 1,000 resamples are shown in Table 3 and the mean abundance estimates obtained from the bootstrapping are close to the point estimates (Cañadas *et al.* 2004). The limitations and implications of these estimates are discussed in the following section. For the reasons discussed there, we believe that only the abundance estimate for the western block can be considered reliable.

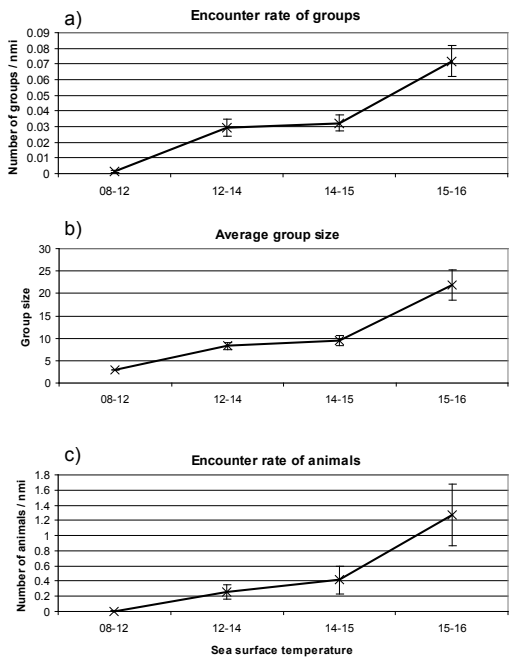


Fig. 12. *Encounter rates of groups (a) and animals (c) and average group sizes (b) of common dolphins for 4 bins of sea surface temperature. Vertical bars show standard errors.*

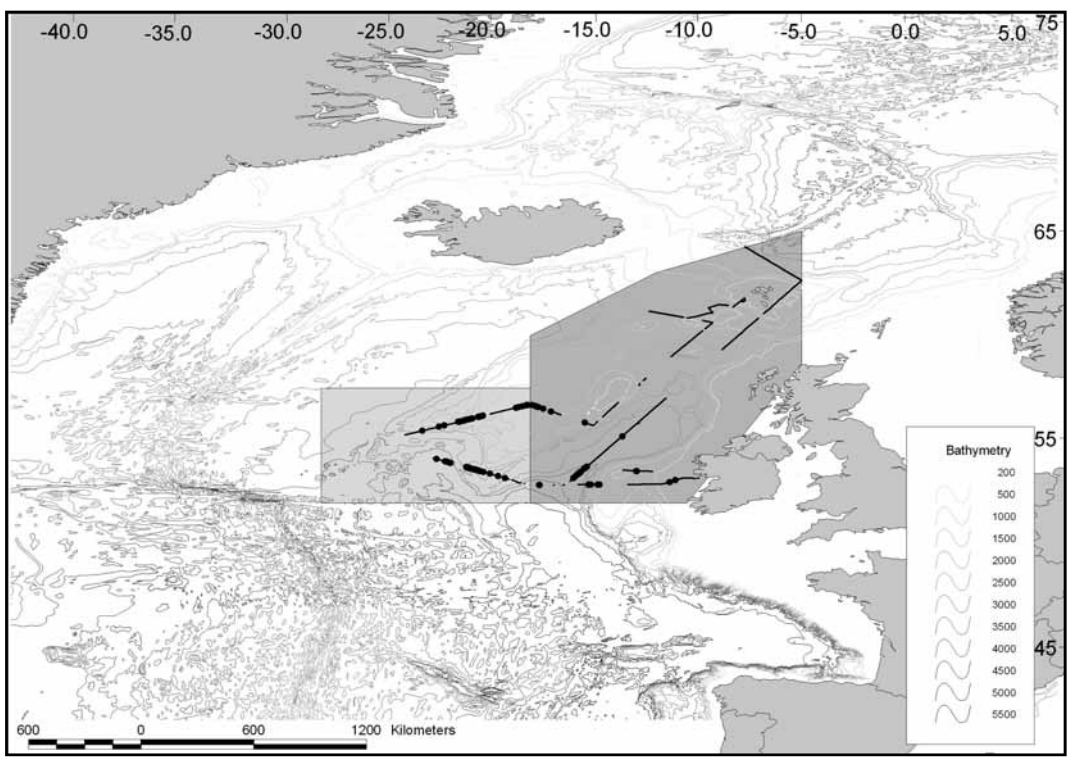


Fig. 13. *Tracks and sightings of common dolphins during the NASS-95 survey.*

Table 3. Estimates of the various parameters required to estimate abundance for the blocks, E, W and the combined area covered by *Miðvingur* in 1995. The density estimates, accounting for responsive movement and $g(0)$ are from Cañadas *et al.* (2004). Where appropriate, values of the mean ($Mean_{bs}$) and coefficients of variation (cv_{bs}) after bootstrapping are given, together with the 95% confidence intervals (CI) calculated using a simple percentile approach (Cañadas *et al.* 2004). The truncation distance was 0.3° nm. Note: for reasons given in the discussion, only the abundance estimate for Block W is considered satisfactory.

	L (track length in nm)	*N* (number of primary sightings)	*n/L*	Density of groups	Number of groups	Group size	Density of animals	Number of animals	*g*(0)
Total area (341,183 nm²)									
Estimate	1,672.77	74	0.044	0.124	42,289	8.29	1.028	350,696	0.796
$Mean_{bs}$				0.133	45,432	8.16	1.052	358,831	0.788
cv_{bs}				0.32	0.32	0.18	0.24	0.24	0.13
Lower 95% $_{bs}$				0.072	24,587	5.33	0.618	210,958	0.577
Upper 95% $_{bs}$				0.226	77,197	11.20	1.583	539,926	0.961
Block E (232,858 nm²)									
Estimate	1,321.77	25	0.019	0.040	9,351	8.29	0.333	77,547	0.807
$Mean_{bs}$				0.042	9,787	8.16	0.34	79,614	0.799
cv_{bs}				0.51	0.51	0.18	0.43	0.43	0.14
Lower 95%$_{bs}$				0.017	3,907	5.33	0.109	25,290	0.556
Upper 95% $_{bs}$				0.078	18,134	11.20	0.661	153,831	0.985
Block W (108,325 nm²)									
Estimate	351.01	49	0.140	0.304	32,938	8.29	2.522	273,159	0.791
$Mean_{bs}$				0.329	35,646	8.16	2.578	279,218	0.785
cv_{bs}				0.37	0.37	0.18	0.26	0.26	0.13
Lower 95% $_{bs}$				0.159	17,221	5.33	1.416	153,392	0.542
Upper 95% $_{bs}$				0.592	64,144	11.20	4.017	435,104	0.957

DISCUSSION

General limitations of the NASS datasets in the context of this study

The advantage of the datasets examined is that they were all dedicated cetacean surveys following recognised design principles for line transect surveys. However, it should be noted that, for most of the NASS surveys, the primary target species were large cetaceans (see Table 1). Whilst the instructions to observers would of course be to record all cetacean sightings, the different priorities have the potential to affect the obtained results for non target species such as the common dolphin in a number of ways *e.g.*

(1) survey areas and blocks may be non-optimal for common dolphins;
(2) surveys may continue in weather conditions that are sub optimal for common dolphins (possibly leading to an over-representation of larger and/or more visible groups);
(3) time may not be allocated to confirming species identity and/or group size, particularly where animals are not seen close to the vessel (possibly leading to bias in the perpendicular distances to confirmed schools);
(4) data reporting (*e.g.* of angle or distance to sighting) may be less reliable if observers are told or believe that small cetacean sightings are of low priority;
(5) in high density 'target species areas', non-target species may be overlooked or not recorded, in order to maximise high quality data for the target species.

The importance of consideration of these factors to any conclusions drawn will, of course, depend on the use to which the data are being put. A brief examination of the group size data

by sea state (see Table 4) did not suggest that (2) above will be particularly problematic for discussions of general distribution and group size considerations; over 90% of the sightings were made in BSS 4 or less with just over half being made at BSS 2 or less. With respect to item (3), some indication of this can be given by examining the numbers of unidentified dolphins reported: 77 sightings were classified as 'maybe common dolphin' or 'unidentified dolphin'; 298 confirmed sightings were made. Item (4) is clearly only of importance if abundance is being investigated (for example, a problem was encountered with the distance measurements in the 1989 dataset from the vessel *Investigador*, where the reticule readings were wrongly stored) but in general, it is difficult to assess how reliable are the data on angle and distance for non target species without data. Similarly, it is difficult to examine whether item (5) is indeed a problem and so this possibility should be borne in mind in the discussion below. Given *inter alia* the preliminary nature of the analyses regarding distribution, we believe that it was appropriate to use all of the data for this purpose.

After considering the potential for bias arising out of consideration of the above factors, we believe that only the Faroese NASS-95 double platform data are suitable for abundance estimation. The primary target species of that vessel was the pilot whale rather than large whales and thus the potential for bias arising from the above points is minimised. Any limitations of the data with respect to abundance estimation were also considered in Cañadas *et al.* (2004).

Table 4. Average group size by recorded BSS

Sea state	Number of groups	Average group size	Standard deviation
0	14	19.9	31.32
1	36	14.0	15.77
2	91	15.3	28.99
3	59	18.8	34.26
4	54	9.4	14.92
5	16	18.7	21.34
6	6	17.2	10.30
7	1	10.0	-
Not recorded	5	4.2	1.30
Total	**282**	**15.0**	**25.88**

Distribution

General distribution

One interesting aspect of the datasets analysed here is the lack of sightings north of around 57° N, despite the considerable effort there.

Víkingsson (*pers. comm.*) reported no reliable sighting or stranding records of common dolphins from Icelandic waters. There have been some reported sightings north of 57° N within the study area in the literature. McBrearty *et al.* (1986) examined several thousand reliable opportunistic records of cetacean sightings made between 1978 and 1982 in the north eastern Atlantic. The most northerly record they provide (and that we have been able to find in the literature) is of a group of 6 short-beaked common dolphins as far north as 73°34' N 11°04' E in August. The sea surface temperature was relatively high (10.7° C) for that latitude although at the lowest end of our observations (see Fig. 9); apart from this record, they reported only 2 more sightings above 60° N (*ibid.*, table 14-15). Stone (MS 2003) reported on sightings made by dedicated marine mammal observers on board seismic vessels between 1998 and 2000 in the north eastern Atlantic, with most effort to the south and east of roughly 64° N and 12° W. From her Fig. 33, most sightings were south of around 58° 30' N but there was a record of a large (50+) group at just below 62 °N (around 2 °W) and a small group off the coast of west Norway at around 63° N. A similar pattern was presented in Pollock *et al.* (2000) for surveys occurring in waters north and west of Scotland between 1979 and 1999, with only 3 sightings north of 60° N (1 at around 61° N and 2 at around 62° N). The available literature therefore, do not contradict the overall picture presented in this study that in summer, short-beaked common dolphins appear most common south of around 57° N the existing occasional records north of that region were generally to the northeast and either outside the area covered here or in areas of low density.

Despite the limitations of the available SST data (the reduced sample size of dolphins due to the large areas where no SST data were available also meant that a less than optimal averaging of the SST data for 2 different years was needed), the results (Fig. 12) suggest that temperature (presumably via its effect on prey species) may

be an important factor in at least determining the northerly limit of distribution. The absence of SST data for the more southerly (and presumably warmer) part of the area does not allow investigation of how far the trend of increasing encounter rates and average group size with temperature may continue. This would be a valuable exercise and inclusion of SST data would also strengthen any future spatial analyses (see below).

Inspection of Figs 6 and 7 shows that short-beaked common dolphins are found across the North Atlantic between about 50°-57°N at least as far as around 35° W. Effort west of 35° W was relatively low in the present study although some extended out to around 40° W. These data are not in accord with an apparent hiatus shown at 20° W by Perrin (2002). The apparent westerly limit or hiatus may be related in some way to temperature since the westernmost sightings were also in the coolest (*ca* 11° C) waters. The apparent 'gap' in distribution between around 53°-57° N and 25°-34° W may be a function of the relatively low effort. However the 'gap' between 42-48° N and 12°-18°W appears real given the high level of effort there. The reason for this gap is unclear but does not appear to be related to any obvious depth feature.

A simple interpretation of the preliminary analysis presented here is that the primary areas for groups of short-beaked common dolphins were in waters over 15° C and depths of 400-1,000 m (there does appear a link with shelf features), between around 49°-55° N especially between 20°-30° W. Group sizes interestingly showed a strong increase with depth (over 2,000 m) that may imply social strategies related to feeding or social behaviour.

Spatial analysis

Spatial analysis is an increasingly powerful and flexible method for examining density, distribution and abundance of cetaceans (*e.g.* Hedley *et al.* 1999, Marques 2001, Cañadas *et al.* 2005, Cañadas and Hammond, 2006) that can cope better with non-systematic survey data and 'filling in' gaps in effort; however, it is 'data' hungry and the simple analysis given in Appendix 1 suffers for that reason. At this stage, the limitations of the data preclude a full analysis that properly takes into account a wider variety of factors (*e.g.* a spatial trend in detectability with sea state, further examination of the mean group size surface and predictive relative group density surface). As noted above, it was presented for illustrative reasons as a possible future approach rather than as a serious study at this stage. Despite this, a comparison of the results of the simple analysis presented in the Appendix is interesting. In general, the predicted relative densities (Appendix Fig. 3) from the spatial modelling show similar patterns to the more 'traditional' plots (*e.g.* see Figs 6 and 7), with relatively high densities in similar areas between 50°-55° N. However, in particular it does not allocate as much weight to depth (see Appendix Figs 1-2) as one might have expected from Fig. 11. This is most noticeable along the shelf edge from the Bay of Biscay to the southwest of Ireland where encounter rates of both groups and animals were relatively large but are not incorporated into the predicted densities.

Abundance estimate(s)

The abundance estimates presented here are the first for this part of the North Atlantic that incorporate corrections for $g(0)$ and responsive movement; as shown by Cañadas *et al.* (2004), the latter is particularly important and failure to consider it can result in severe negative bias in some surveys. Although we have presented the results for block E, we do not believe that this can be considered a reliable abundance estimate for a number of reasons: (1) the fact that the realised transects lie in the middle of the stratum giving inadequate spatial coverage; (2) the large differences between the designed and the realised cruise tracks; and (3) the realised cruise tracks lay roughly parallel to the depth contours (Cañadas *et al.* 2004). In addition, there were relatively few sightings. Given that, we believe that it is only appropriate to present a final abundance estimate for the western block, where although the completed tracks were largely in the east of that block, they seemed representative of the block as a whole and the sample size was high. Thus the estimate of abundance of common dolphins in block W (52°-57.5° N, 18°-28° W) is 273,000 (cv 0.26, 95% CI 153,000-435,000).

There have been several other estimates of abundance from dedicated surveys in this area (Fig. 14). However, they are not strictly compa-

rable. Only the NASS-95 and SIAR (O'Cadhla *et al.* 2004) surveys corrected for $g(0)$ not allowing for this would lead to a negative bias. Only the NASS-95 estimate accounts for responsive movement; if similar movement occurred in the other surveys their estimates would be biased upwards. Both of these biases will be ship specific. During 2005, a new survey was carried out on the shelf waters of the north-eastern Atlantic, the SCANS II project (Hammond and MacLeod (MS) 2004). This survey accounts both for $g(0)$ and for responsive movement. Data from this survey are being now analysed and the results will be then comparable with the NASS-95 estimate.

CONCLUSIONS

This paper has extended our knowledge of the distribution of short-beaked common dolphins in an area previously poorly studied. It has also highlighted the need for more data both in terms of sightings data and appropriate explanatory variables if a more sophisticated spatial modelling analysis of distribution is to be carried out. It has also presented the first abundance estimate a previously unknown area based on NASS-95 data for the summer period. Valuable as this is, from a management perspective (*e.g.* see Hall and Donovan 2002), it is important that future work focuses on:

(1) obtaining a better understanding of stock structure;
(2) the undertaking of additional surveys that take advantage of the available information presented here and elsewhere with a more appropriate stratification and appropriately focused on small cetaceans;
(3) better estimates of anthropogenic removals.

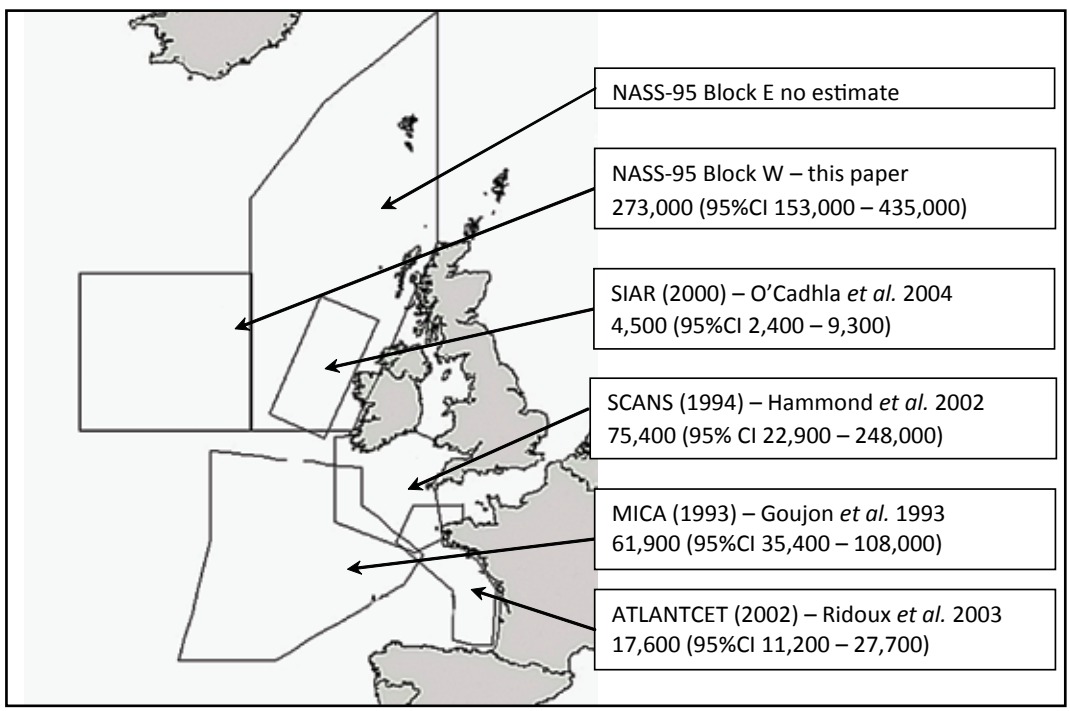


Fig. 14. *Estimates of abundance from dedicated surveys in the NE Atlantic.*

ACKNOWLEDGEMENTS

The primary funding for the NASS-95 survey was provided by the Government of the Faroe Islands and by the North Atlantic Marine Mammal Commission (NAMMCO). In addition, Føroya Sparikassi, Føroya Banki and Føroya Shell sponsored aspects of the study; Atlantic Airways provided the travel of the cruise leader. The EU project SCANS provided the sightings and effort data entry software used during the cruise. Various pieces of equipment were kindly lent by the Faroese Museum of Natural History, the Faroese Telephone Company, Danbiu APS (Copenhagen, Denmark), le Centre de Recherche sur les Mammifères Marins (La Rochelle, France), l'Institut Français de Recherche et d'Exploitation des Mers (IFREMER, Brest, France) and the Sea Mammal Research Unit (Cambridge, UK). Thanks are due to T. Johannesen, captain of the Miðvingur, and his crew for their cooperation in conducting the research, as well to all the observers onboard. Very special thanks are due to the Faroese Natural History Museum, and especially Dorete Bloch, for taking care of the survey logistics and financing, and for allowing the use of the data in the present study. Special thanks are due also to S. Buckland and S. Cumberworth for their advice and help in the design of the survey, S. Chalis for modifying the SCANS software, and L. Thomas and P. S. Hammond for their valuable comments and advice during data analysis.

We are also very grateful to Daniel Pike for providing the data for the NASS-87, NASS-89 and NASS-2001 surveys, to Phil Hammond for providing the data from SCANS, and to Michel Goujon for providing the data from the MICA-93 survey. Daniel Pike also requested the present study. Thanks are due to the organisers of all the NASS surveys and to all the skippers and observers on board the research vessels.

Many thanks to Sinead Murphy, Simon Northridge, Arne Bjørge, Gísli Víkingsson and 2 anonymous reviewers for providing very useful information and suggestions on earlier drafts of this manuscript.

REFERENCES

Cañadas, A., Desportes, G. and Borchers, D. 2004. The estimation of the detection function and *g*(0) for short-beaked common dolphins (*Delphinus delphis*), using double platform data collected during the NASS-95 Faroese survey. *J. Cetacean Res. Manage*. 6(2):191-98.

Cañadas, A. and Hammond, P.S. 2006. Model based abundance estimates for bottlenose dolphins off southern Spain: implications for conservation and management. *J. Cetacean Res. Manage.* 8(1):13-27.

Cañadas, A., Sagarminaga, R., De Stephanis, R., Urquiola, E. and Hammond, P.S. 2005. Habitat selection modelling as a conservation tool: proposals for marine protected areas for cetaceans in southern Spanish waters. *Aquat. Conserv.* 15:495-521.

Forcada, J., Aguilar, A., Evans, P.G.H. and Perrin, W.F. 1990. Distribution of common and striped dolphins in the temperate waters of the eastern North Atlantic. *European Research on Cetaceans.* 4:64-66.

Goujon, M., Antoine, L., Collet, A. and Fifas, S. (MS) 1993. Approche de l'impact écologique de la pêcherie thonnière au filet maillant dérivant en Atlantique nord est. Rapport interne de la Direction des Resources Vivantes de l'IFREMER, réf. RI.DRV 93.034: 47pp. [Also presented at the 24th Meeting of the Scientific and Technical Committee for Fisheries, Bruxelles, 15-17 November 1993, available at IFREMER, in French]

Hall, M.A. and Donovan, G.P. 2002. Environmentalists, fishermen, cetaceans and fish: is there a balance and can science find it? In: Evans, P.G. and Raga, J.A., *Marine Mammals: Biology and Conservation*. Kluwer Academic/Plenum Publishers, New York. pp.491-521.

Hammond, P.S., Berggren, P., Benke, H., Borchers, D.L., Collet, A., Heide-Jørgensen, M.P., Heimlich, S., Hiby, A.R., Leopold, M.F. and Øien, N. 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *J. Appl. Ecol.* 39(2):361-76.

Hammond, P.S. and MacLeod, K. (MS) 2004. Abundance, monitoring and conservation of European small cetaceans: the SCANS II project. Paper SC/56/SM4 presented to the IWC Scientific Committee, July 2004, Sorrento, Italy. 6pp. [Available at the IWC Secretariat]

Harwood, J. and Wilson, B. 2001. The implications of developments on the Atlantic Frontier for marine mammals. *Cont. Shelf Res.* 21:1073-93.

International Whaling Commission. 2006. Report of the IWC Scientific Committee Workshop on Habitat Degradation, 12 15 November 2004, Siena, Italy. *J. Cetacean Res. Manage.* (Suppl.) 8:313-35.

Lopez, A. 2003. *Estatus dos pequenos cetaceos da plataforma de Galicia.* Universidade de Santiago. 337pp.

Lopez, A., Pierce, G.J., Santos, M.B., Garcia, J. and Guerra, A. 2003. Fishery by catches of marine mammals in Galacian waters: results from on board observations and an interview survey of fishermen. *Biol. Conserv.* 111(1):25-40.

McBrearty, D.A. 1986. Observations on small cetaceans in the northeast Atlantic Ocean and the Mediterranean Sea: 1978 1982. *In*: Bryden, M.M. and Harrison, R., *Research on dolphins*. Clarendon Press, Oxford. pp.225-50.

Morizur, Y., Berrow, S.D., Tregenza, N.J.C., Couperus, A.S. and Pouvreau, S. 1999. Incidental catches of marine mammals in pelagic trawl fisheries of the northeast Atlantic. *Fish. Res*. 41:297-307.

O'Cadhla, O., Burt, M.L., Borchers, D.L. and Rogan, E. 2004. Distribution and abundance of cetaceans in western Irish waters and the Rockall Trench. *European Cetacean Society Conference Guide and Abstracts* 15:448.

Perrin, W. 2002. Common dolphins *Delphinus delphis*, D. capensis, and D. tropicalis. In: Perrin, W., Würsig, B. and Thewissen, J., *Encyclopedia of Marine Mammals*. p.245-248. Academic Press, San Diego, 414pp.

Pollock, C.M., Mavor, R., Weir, C.R., Reid, A., White, R.W., Tasker, M.L., Webb, A. and Reid, J.B. 2000. *The Distribution of Seabirds and Marine Mammals in the Atlantic Frontier, North and West of Scotland*. Joint Nature Conservation Committee, Aberdeen. 92pp.

Silva, M.A. and Sequeira, M. 2003. Patterns in the mortality of common dolphins (*Delphinus delphis*) on the Portuguese coast, using stranding records, 1975 1998. *Aquat. Mamm.* 29(1):88-98.

Stone, C.J. (MS) 2003. Marine mammal observations during seismic surveys in 2000. *JNCC Report* 322. 66pp. [Available from the Joint Nature Conservation Committee, Aberdeen]

Tregenza, N.J.C. and Collet, A. 1998. Common dolphin (*Delphinus delphis*) bycatch in pelagic trawl and other fisheries in the northeast Atlantic. *Rep. int. Whal. Commn* 48:453-459.

Víkingsson, G.A, Pike, D.G., Desportes, G., Øien, N., Gunnlaugsson, Th. and Bloch, D. 2009. Distribution and abundance of fin whales (*Balaenoptera physalus*) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987 29001. *NAMMCO Sci. Publ*. 7:49-72.

Wood, S. N. 2001. *mgcv: GAMs and Generalized Ridge Regression for R.* R News 1(2):20-25.

Appendix 1

Simple illustrative example of the type of spatial analysis that could be done given more and better data

Brief summary of the method

An illustrative example of a simple spatial analysis was performed using the available covariates for the grid cells: depth, latitude and longitude; SST could not be examined since the data were unavailable for much of the area, as noted above. As in Cañadas *et al.* (2005) and Cañadas and Hammond (2006), a two step approach was followed: first the density of groups and then the modelling of group size. The final prediction of relative density was obtained by multiplying the results from both models. For modelling the relative density of groups, the sampling unit used was each time a vessel passed over a grid cell. The response variable was the number of groups encountered during each of these sampling units. The amount of effort for each sampling unit (nm covered) was used as the weighting factor. The number of groups (n) was modelled using a Generalized Additive Model (GAM) with a logarithmic link function, weighted by effort. A quasi-Poisson family was used, with variance proportional to the mean. Interested readers should consult Cañadas *et al.* (2005) and Cañadas and Hammond (2006) for more details. Given the preliminary and illustrative nature of this exercise, a more detailed explanation is not appropriate for this paper. The general structure of the model was: (1)

$$N_i = \exp\left[\theta_0 + \sum_k f_k(z_{ik})\right]$$

where Θ_0 is the intercept, f_k are smoothed functions of the explanatory covariates and z_{ik} is the value of the k_{th} explanatory covariate in the i^{th} segment.

In this particular example, group size was also modelled using a GAM with a logarithmic link function; other approaches are possible. Here, the response variable was the number of animals counted in each group (s_j) and, given the large overdispersion due to the wide range of group sizes (1-239), a quasi Poisson error distribution was used, with the variance proportional to the mean. The general structure of the model was: (2)

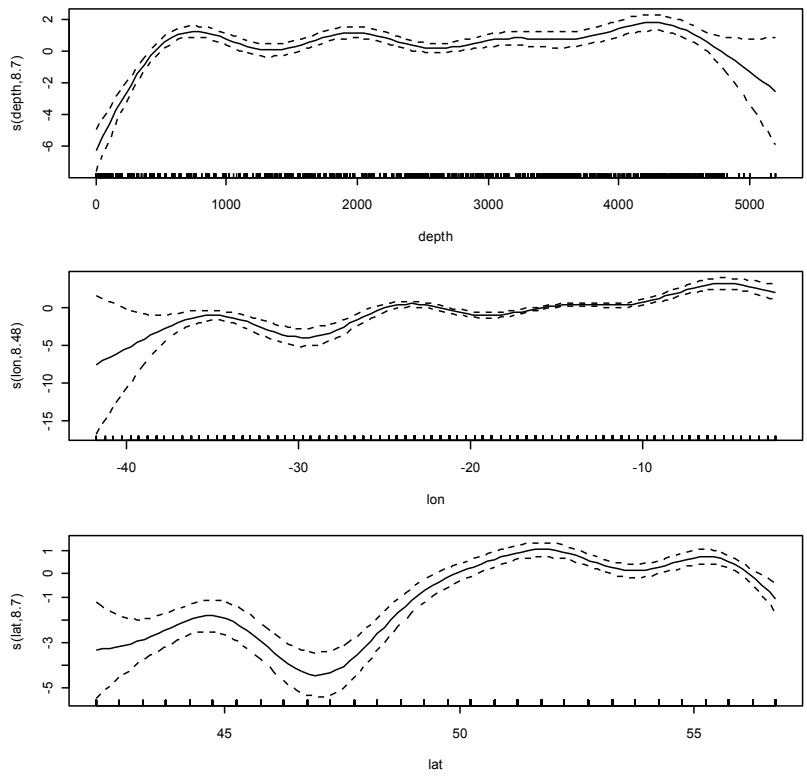
$$E(s_j) = \exp\left[\theta_0 + \sum_k f_k(z_{jk})\right]$$

where Θ_0 is the intercept, f_k are smoothed functions of the explanatory covariates, and z_{jk} is the value of the k^{th} explanatory covariate in the j^{th} group.

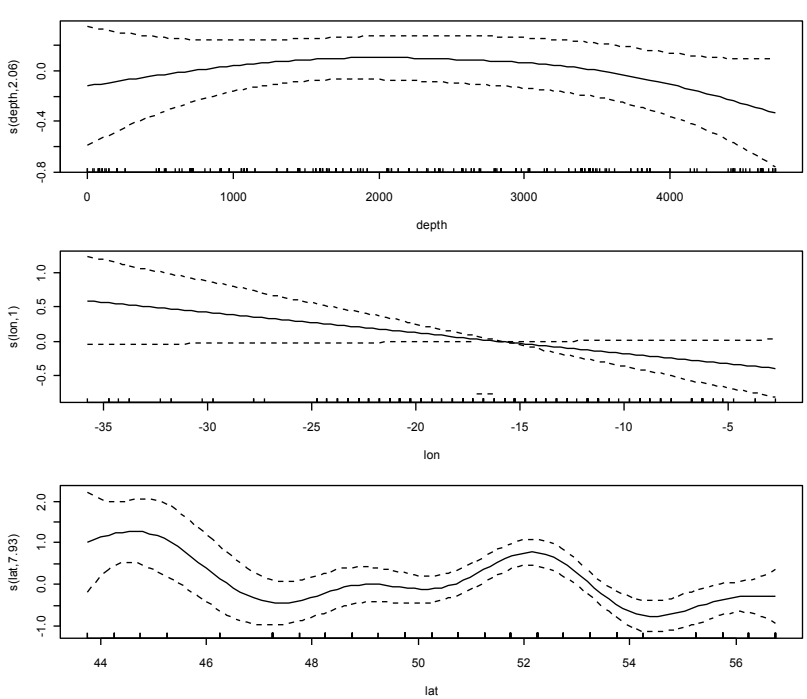
Models were fitted using package 'mgcv' version 1.0-5 for *R* (Wood, 2001). Automated model selection by a stepwise procedure was not available in the version of *R* used (2.0.1-http://cran.r-project.org).

Appendix Table 1. Variables used in the spatial analysis, both for the model of density of groups and for the model of group sizes, their estimated degrees of freedom and associated p values. The percentage of deviance explained by the models is also shown.

Variable	Estimated degrees of freedom	*p*-value	Deviance explained
Density of groups			26.0%
Depth	8.7	<0.00001	
Latitude	8.7	<0.00001	
Longitude	8.4	<0.00001	
Group size			24.9%
Depth	2.1	0.23	
Latitude	1	0.06	
Longitude	7.9	<0.00001	



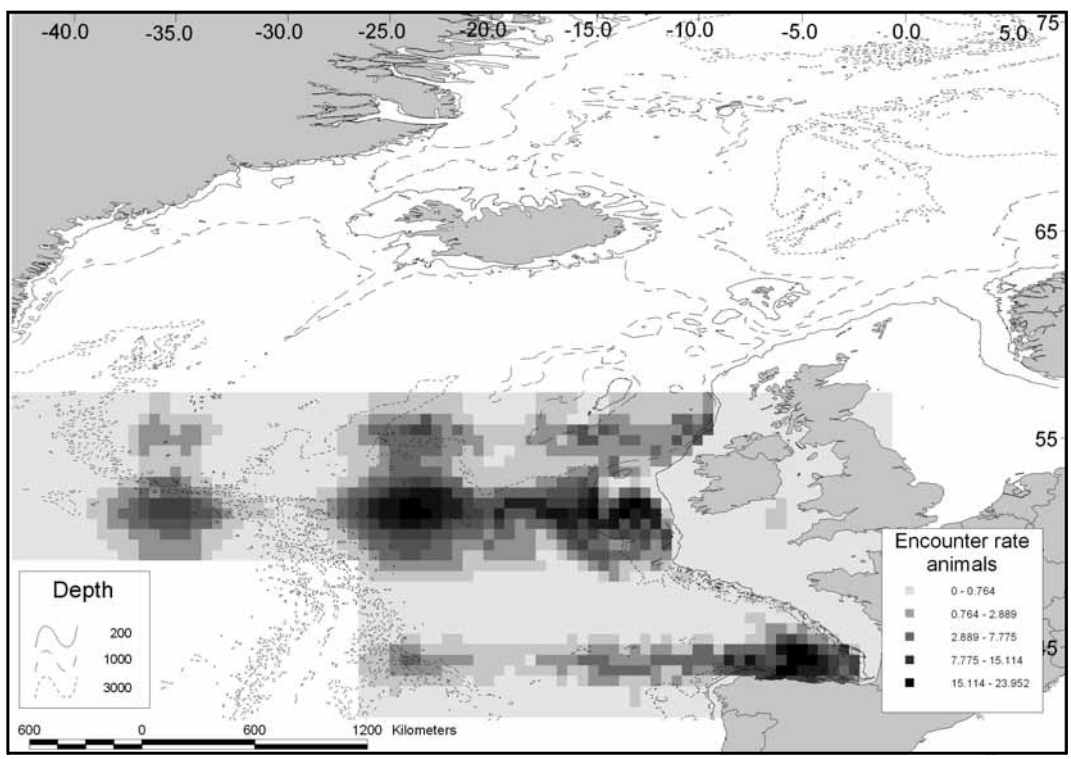
Appendix Fig.1. *Shapes of the functional forms for smoothed co-variables used in the model of density of groups. Zero on the vertical axis corresponds to no effect of the co-variables on the estimated response. The locations of the observations are plotted as small ticks along the horizontal axis.*



Appendix Fig.2. *Shapes of the functional forms for smoothed co-variables used in the model of group sizes. Zero on the vertical axis corresponds to no effect of the co variables on the estimated response. The locations of the observations are plotted as small ticks along the horizontal axis.*

RESULTS

In the simple illustrative analysis, the 3 available variables (depth, latitude and longitude) were retained by the models. The results are shown in Appendix Table 1. All 3 variables were highly significant in the model of density of groups. In the model of group sizes, while both depth and latitude had p values > 0.05, excluding these values reduced the deviance explained and increased the generalised cross validation (gcv) value; thus it was decided to retain them. The nonlinear forms of dependence of group density and group size on the co variables, given that the other co-variables are included in the model, are shown in Appendix Figs 1 and 2, respectively. The final surface map of predicted relative density of common dolphins, after combining the predictions of group density and group sizes, is shown in Fig. 3.



Appendix Fig. 3. *Surface map of predicted relative density of common dolphins, estimated using spatial analysis.*