Distribution and Abundance of Long-Finned Pilot Whales in the North Atlantic, Estimated From NASS-87 and NASS-89 Data

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ABSTRACT

During the summers of 1987 and 1989, large scale transect surveys were conducted throughout the North Atlantic by several national agencies in Denmark (off Greenland), Faroe Islands, Iceland, Norway and Spain (North Atlantic Sightings Surveys, NASS-87 and NASS-89). This paper analyses the pilot whale (*Globicephala melas*) survey data collected by three Icelandic and one Faroese survey vessel in 1987, and four Icelandic, one Faroese and one Spanish vessel in 1989. Norwegian survey vessels operated north and east of this area in both years, but only five groups (three primary sightings) were observed in 1989 and none in 1987. Furthermore, no sightings were made in the area north and northeast of Iceland, thus indicating that the joint surveys covered the northernmost areas of pilot whale distribution east of 42°W. The area further to the west was not covered in either survey. The coastal European waters between 42–52°N were covered by the Spanish vessel in 1989. Sightings made in 1989 by the Icelandic vessels tended to be at the southernmost boundaries of the survey area.

The present data were examined with respect to several potential stratification factors, namely geographic block, Beaufort (i.e. wind speed), vessel and school size, but sample size precluded stratification by all these factors simultaneously. The encounter rate was generally lower in the 1987 survey than in 1989, but the difference was not statistically significant. The total estimate for the 1989 survey, covering a wider area and further to the south than in 1987, was 778,000 (CV=0.295). This is regarded as the best available estimate of the total stock of long-finned pilot whales in the northeastern North Atlantic Ocean, although small numbers occur outside the NASS survey areas. The paper discusses potential biases in the abundance estimates, and the problems of estimating pilot whale abundance from sightings data.

KEYWORDS: PILOT WHALES–LONG-FINNED; NORTH ATLANTIC; ASSESSMENT; DISTRIBUTION; SURVEY.

INTRODUCTION

Distribution of pilot whales

Mitchell (1975b) reviewed the status and distribution of the long-finned pilot whale (*Globicephala melas*) in the North Atlantic. It is common from Northwest Africa (and the Mediterranean) to Cape Hatteras and north to Greenland, Iceland and the Barents Sea. Its close relative, the short-finned pilot whale (*G. macrorhynchus*) has a more southerly distribution and is rarely seen north of Cape Hatteras in the west and north of Madeira, off Northwest Africa, in the east. Brown's (1961) summary of observations made from ocean weather ships, merchant vessels and other ships, provides information on the oceanic range of this species as far south as 45°N in the central area of the North Atlantic,

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suggesting their occurrence throughout the year in oceanic waters between 45° and 50°N and probably in all longitudes from the Bay of Biscay to Newfoundland.

In the European part of the Northeast Atlantic, sightings reveal a distribution from the western basin of the Mediterranean east of Gibraltar to Corsica (Müller, 1882; McBrearty *et al.*, 1986) to Greenland (Kapel, 1975), with an inshore occurrence especially in late summer and autumn months (Joensen and Zachariassen, 1982; Desportes, 1983; Bloch *et al.*, 1989a). Strandings have frequently occurred on the coasts of Ireland and Great Britain (de Kock, 1956; Fraser, 1974; O'Riordan, 1975; Martin *et al.*, 1987) with an increasing number in this century (Sheldrick, 1976). Concentrations have been recorded in the Bay of Biscay, the southwestern coasts of Britain and Ireland, and in the more northern areas near the Hebrides, Shetland and the Faroe Islands (Evans, 1980; 1987; McBrearty *et al.*, 1986).

Abundance and status

Joensen and Zachariassen (1982) and Hoydal (1986; 1987) reviewed information on the distribution and abundance of North Atlantic pilot whales with reference to the well documented catch history from the Faroe Islands. Although the data did not permit estimation of stock size, Hoydal concluded that there were no signs of overexploitation in the stock exploited from the Faroes, despite average catches in the range 800–2,000 p.a. over three centuries. In contrast, the industrial pilot whale drive-fishery off Newfoundland after the Second World War appeared to cause drastic changes in local abundance before it ceased in the late 1970s (Mercer, 1975).

Mitchell (1975a) suggested that since both these fisheries operated concurrently, but only the Newfoundland fishery collapsed, this suggested some separation of stocks. However, Sergeant (1986) noted that in the period 1948 to 1971 the catches at Newfoundland somewhat resembled the catches at the Faroe Islands, and that catches off the Faroes subsequently continued at a low level until 1976, after which they increased steadily. He considered that this, along with a simultaneous increase in the frequency of mass strandings in recent years in the western North Atlantic, indicated a trans-Atlantic connection of this species. Evans (1987) gives data on a substantial increase in both strandings and sightings of pilot whales in British and Irish waters since the 1950s, which concurs with Hoydal's (1986) observations of apparent increase in abundance reflected in higher catches in recent years.

Surveys

Before 1987, the only systematic vessel surveys for cetaceans in the northeastern Atlantic were carried out in limited areas and were of relatively short duration (Iceland, e.g. Sigurjónsson, 1983; 1985; Martin *et al.*, 1984; Norway, e.g. Øien and Christensen, 1985; Spain, e.g. Aguilar *et al.*, 1983; Sanpera *et al.*, 1984; 1985; Sanpera and Jover, 1986). Similarly, systematic aerial surveys covered only limited coastal areas (Iceland, e.g. Hiby *et al.*, 1984; Gunnlaugsson *et al.*, 1988; West Greenland, e.g. Larsen, 1984; 1985; 1986). In the Northwest Atlantic (the Newfoundland-Labrador area), a line-transect aerial survey directed towards humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*) and long-finned pilot whales was conducted in 1980 (Hay, 1982), and during 1978–82 cetacean aerial surveys were conducted on the shelf waters of the northeastern United States and shipboard surveys during 1980–88 (CeTAP, 1982; Payne *et al.*, 1993). Many of these surveys were not specifically designed to yield estimates of stock size and have suffered from their sporadic nature both in time and space, covering only a fraction of the species' summer ranges at a time.

In 1987, several interested national laboratories met to organise a joint North Atlantic Sightings Survey (NASS-87) to be implemented in June-August 1987 in the area bounded by Spitzbergen and the Barents Sea in the north and the Spanish coast in the south, and between West Greenland in the west and the Norwegian coast in the east (Anonymous, 1987a; b). A further survey (NASS-89) took place in the summer of 1989 (Anonymous, 1988; 1989a; b). This paper analyses the pilot whale data from both surveys collected by the Icelandic and Faroese vessels, and that from the NASS-89 survey collected by the Spanish vessel.

Although not included in the analyses of this paper, 11 pilot whale groups, comprising in total 123 animals, were detected during the Spanish cruise for NASS-87. These occurred between 44°N and 52°N, and between 11°W and 18°W, and were spread through most of the survey area (Lens *et al.*, 1989). No pilot whales were detected during Norwegian cruises for NASS-87 (Øritsland *et al.*, 1989) and only five groups were observed in 1989 (Øien, pers. comm.). The Norwegian data are also not included in the analysis here.

The pilot whale sightings data from the Icelandic and Faroese cruises in 1987 were first analysed by Bloch *et al.* (1989b). The analyses of NASS-87 data presented here are more extensive, are carried out using more conventional methods and yield revised abundance estimates.

METHODS

Vessels and ship methodology

During June and July 1987, three Icelandic vessels surveyed Icelandic and adjacent waters (Fig. 1). They were *Arni Friðriksson* (referred to here as *AF*), *Skírnir* (*Sk*) and *Keflvikingur* (*Ke*). The Faroese vessel *Hvítaklettur* surveyed Faroese and adjacent waters (Fig. 1) from June to August. In 1989, four Icelandic vessels surveyed Icelandic and adjacent waters (Fig. 2) during July and August: *Arni Friðriksson* (*AF*), *Bardinn*, which was the same vessel as *Skírnir* in 1987, so will be referred to as *Sk* here, *Hvalur 8* (*Hv8*) and *Hvalur 9* (*Hv9*). A Faroese vessel, the *Olavur Halgi*, surveyed Faroese and adjacent waters (Fig. 2) and a Spanish vessel surveyed part of the Bay of Biscay and waters to the west (see Fig. 3).

The design and conduct of these surveys have been described in detail (Sigurjónsson *et al.*, 1989; 1991; Joyce *et al.*, 1990 and Lens, 1991). It is not repeated here.

Data and analyses

Only primary sightings[1] of pilot whales were analysed. The recorded sighting angles and distances to pilot whale schools were smeared and transformed to perpendicular distance intervals using smearing method (2) of Buckland and Anganuzzi (1988). The hazard-rate model (Buckland, 1985; 1987) was fitted to the smeared perpendicular distances, truncated at 0.65 n.miles.

School size

Where available, analyses were carried out using the 'best' estimates of school size. For all vessels in 1987, high, low and best estimates of school size were usually recorded. For these data, if a best estimate was not recorded, the mean of the low and high estimate was used. If there was no best or high estimate, the low estimate was used. In 1989, the Faroese

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[1] Sightings made when a vessel is searching 'on effort', i.e. when searching is the primary activity. Sightings made while other activities are being carried out (e.g. sailing towards a sighting to confirm its species identity or school size) are termed 'secondary' sightings.

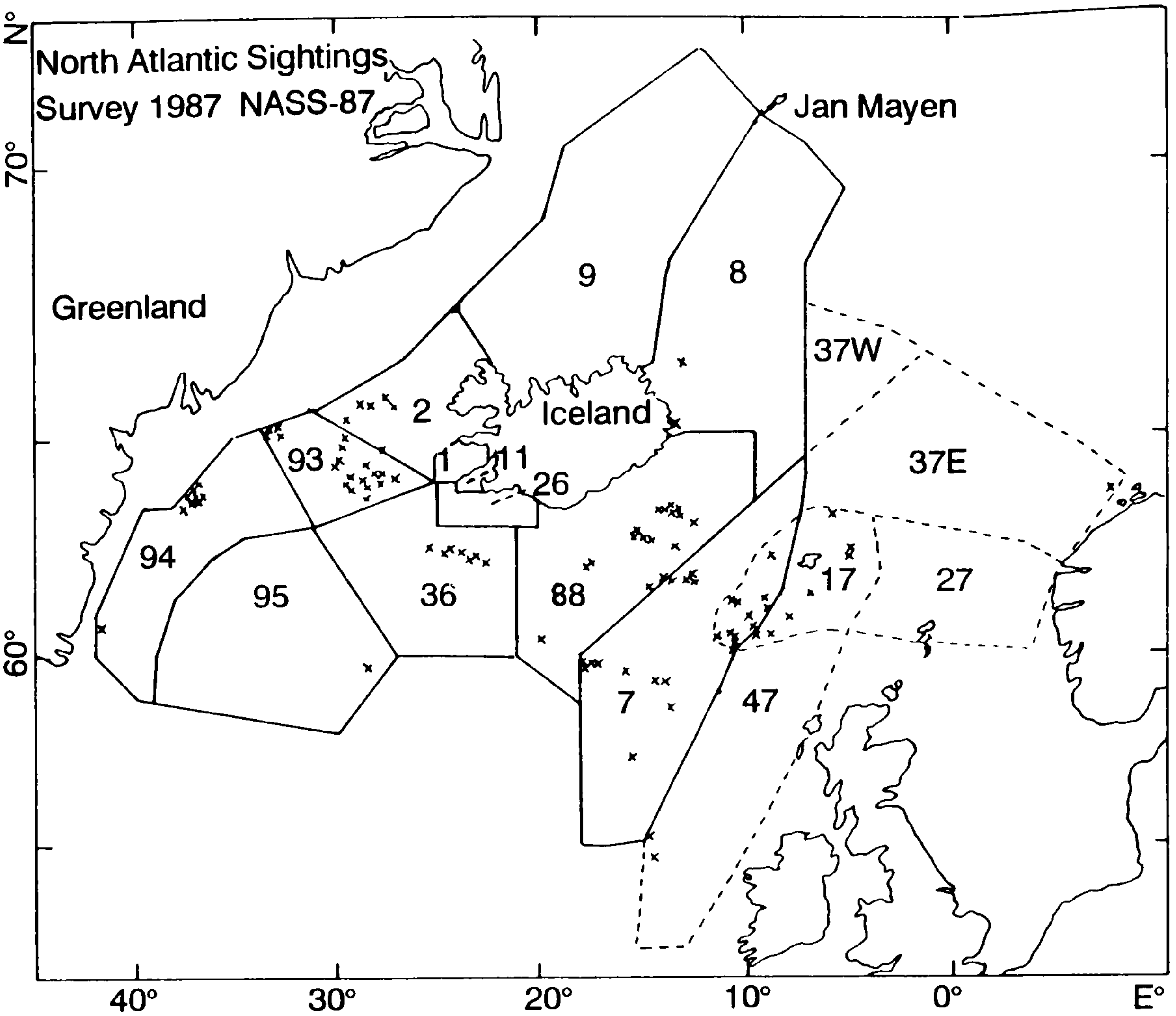

Fig. 1. Blocks in which there was Icelandic and/or Faroese effort in 1987. Faroese blocks are delineated by broken lines. Icelandic block 7 overlapped slightly with Faroese block 17. Sightings of pilot whales are indicated by crosses.

vessel again recorded high, low and best estimates. However, the Icelandic vessels recorded either a best estimate or a low and a high estimate. In this case, the best estimate was used if available; otherwise the low estimate was used. Analyses were also carried out after replacing the low estimate by the mean of the low and high estimates, to assess the impact on the final abundance estimate. For the Spanish data, the best estimate for each school was analysed.

Stratification

Data from the Icelandic NASS-89 cruises were analysed to determine an appropriate methodology for estimating pilot whale abundance. Sample sizes were too small for the NASS-87 survey and for the Faroese and Spanish NASS-89 cruises to allow adequate assessment of different stratification options from those data alone.

Several potential stratification factors were identified: geographic block, Beaufort (i.e. wind speed), vessel and school size. Ideally stratification should be by all of these factors, but sample size considerations preclude this, so stratification was initially carried out for each candidate factor in turn. To assess the effect of Beaufort, the average school size, encounter rate and effective search half-widths were estimated for each Beaufort (0–6) in turn, ignoring other possible stratification factors. Given the small sample sizes, this was

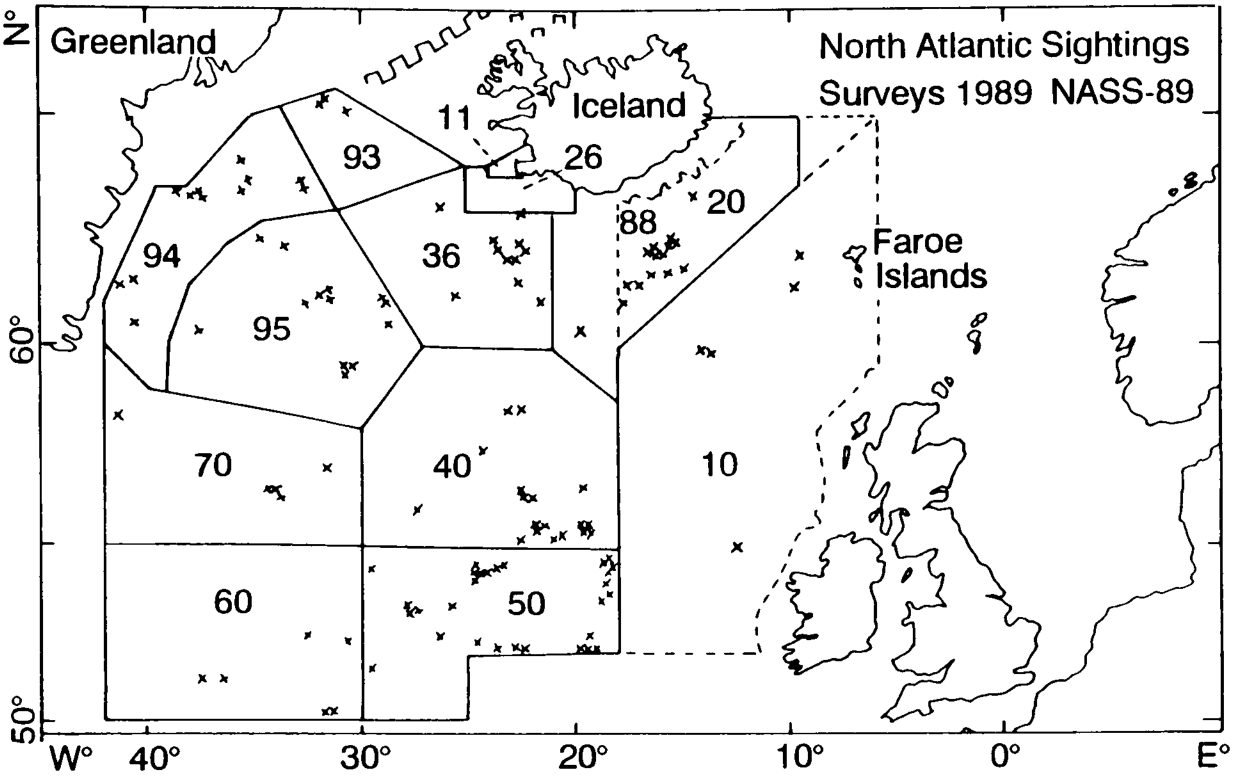

Fig. 2. Blocks in which there was Icelandic and/or Faroese effort in 1989. Faroese blocks are delineated by broken lines. Icelandic block 88 overlapped with Faroese block 20. Sightings of pilot whales are indicated by crosses.

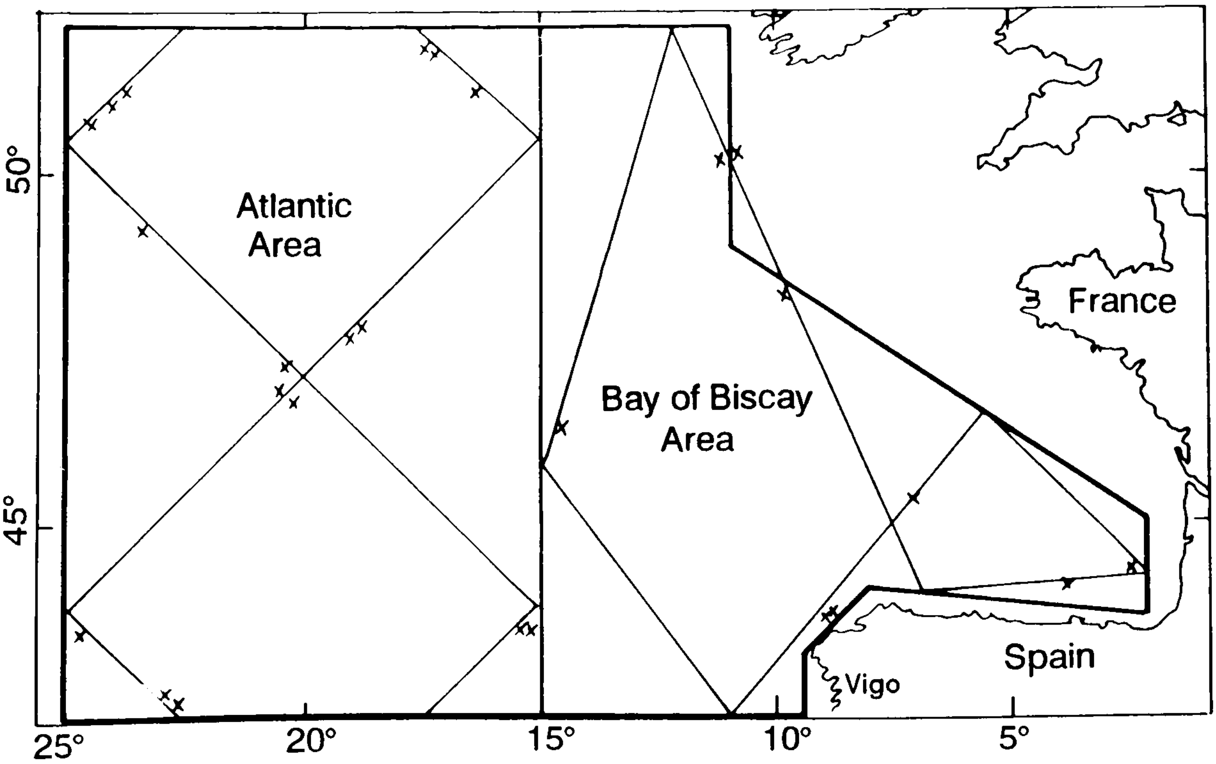

Fig. 3. Blocks in which there was Spanish effort in 1989. Block 21 is to the west of 15°W, and block 22 to the east. Sightings of pilot whales are indicated by crosses.

repeated, grouping together data from Beauforts 0–2 and 3–6. Standard errors (SE) were calculated for each estimate and z-tests carried out to assess whether there were significant differences in estimates at different Beauforts. The SE for mean school size was calculated as sample standard deviation (SD) divided by the square root of the sample size. For encounter rate, the rate per day was calculated, and the sample variance of these rates, weighted by daily effort was used following the empirical method described by Burnham *et al.* (1980). The SE for the effective search half-width was obtained using likelihood methods, via the information matrix. A similar analysis was carried out for each stratification factor. As these factors are confounded with each other and the above approach ignores interactions between them, analyses were supplemented by knowledge of likely effects of the different factors on the three components of estimation to determine an appropriate stratification (see below).

Abundance within strata

Within a stratum the abundance N was estimated by (Burnham *et al.*, 1980)

$$\hat{N} = \frac{n.\hat{f}(0).\bar{s}.A}{2L}, \tag{1}$$

with

$$\hat{\text{var}}(\hat{N}) = \hat{N}^2 . \left[\frac{\hat{\text{var}}(n)}{n^2} + \frac{\hat{\text{var}}\{\hat{f}(0)\}}{\{\hat{f}(0)\}^2} + \frac{\hat{\text{var}}(\bar{s})}{\bar{s}^2} \right], \tag{2}$$

where

n = number of sightings after truncation,
$\hat{f}(0)$ = estimated probability density of perpendicular distances, evaluated at zero,
$\bar{s}$ = mean group size,
L = distance covered by the vessel while on effort,
A = size of the area containing the population of N animals.

The encounter rate is then defined as n/L and the effective search half-width is $1/\hat{f}(0)$.

Where abundance estimates were combined across strata for which a common value of $\hat{f}(0)$ was assumed, the variance of the combined estimate was calculated allowing for the covariance between the individual estimates. If instead the individual abundance estimates were assumed to be independent, variances would be underestimated.

When the coefficient of variation (CV) of an abundance estimate $\hat{N}$ is large, a poor, possibly negative, lower confidence limit can be obtained if the estimate is assumed to be normally distributed. Here, $\hat{N}$ was assumed to have a log normal distribution and a 95% confidence interval was estimated using the method of Burnham *et al.* (1987, p.212):

$$(\hat{N}/C \, , \hat{N} \, . \, C) \tag{3}$$

where

$$C = \exp \, [1.96. \sqrt{\{\hat{\text{var}}(\log_e \hat{N})\}}] \tag{4}$$

and

$$\hat{\text{var}} \, (\log_e \hat{N}) = \log_e \left[1 + \frac{\hat{\text{var}}(\hat{N})}{\hat{N}^2} \right].$$

Treatment of aggregations

Pilot whales often occur in large, loose aggregations of subgroups. For all cruises but one, the whole aggregation was treated as a single sighting. In 1987, vessel *Ke* recorded data by subgroup, making it possible to estimate abundance treating aggregations two ways: first by taking subgroups as schools, and second by taking the aggregation as the school, located at the recorded position of the first subgroup detected. By taking the ratio of the estimate from the first method to that from the second, a correction factor was obtained. An SE and confidence interval for the correction factor were found by segregating the sightings and effort data by day, block, Beaufort and cloud cover category, bootstrapping from the resulting units, and applying the two estimation methods to each of 399 bootstrap replicates. This yields 399 estimates of the correction factor; their SD is an estimate of the SE of the correction factor, and the tenth smallest and tenth largest estimates provide a 95% 'percentile' confidence interval.

RESULTS

Distribution

The distribution of sightings is given in Figs 1–3.

Abundance

The effects of Beaufort on parameter estimates are summarised in Table 1. The effective search half-width did not vary significantly with Beaufort category. Indeed, the estimated width was greater at higher Beaufort, the reverse of what might be expected and thus it seems reasonable to assume that the effective search half-width is independent of sea state for these data. There was some evidence that encounter rate varied with Beaufort, but the results were inconsistent, with low encounter rates at Beauforts 0 and 5, and high encounter rates at Beauforts 2 and 3. This probably occurred because the geographic areas with high densities of pilot whales were predominantly surveyed during Beauforts 2 and 3 while Beauforts 0 and 5 were recorded mostly in areas of low density. There was no indication of variation in mean school size with Beaufort. Thus, data were pooled across Beaufort for all subsequent analyses.

Parameter estimates are shown by block in Table 2. Sample sizes were too small to allow stratification of effective search half-width by block. There was strong evidence of differences in encounter rates among geographic blocks. Small sample size does not rule

Table 1

Number of sightings (after truncation but before smearing), effective search half-width, encounter rate and mean school size by sea state, Icelandic pilot whale data, NASS-89. Standard errors in parentheses. Values in the same column with different superscript letters differ significantly ($p<0.05$). Thus the encounter rates at Beauforts 2 and 3 were significantly higher than those at Beauforts 0 and 5, but no other differences in this table were significant.

Beaufort	Number of sightings, n	Effective search half-width (nm)	Encounter rate (schools/100nm)	Mean school size, $\overline{s}$
0	1	-	0.31 (0.39)^{a}	7.0 (-)$_{a}$
1	12	0.140 (0.114)^{a}	1.10 (0.71)^{ab}	24.3 (8.0)^{a}
2	34	0.113 (0.062)^{a}	1.95 (0.56)^{b}	29.4 (6.4)^{a}
3	28	0.207 (0.072)^{a}	1.59 (0.35)^{b}	19.9 (2.7)^{a}
4	10	0.268 (0.136)^{a}	0.72 (0.40)^{ab}	32.6 (9.9)^{a}
5	1	-	0.08 (0.13)^{a}	100.0 (-)$_{a}$
6	4	-	0.62 (0.46)^{ab}	24.0 (6.3)^{a}
0-2	47	0.113 (0.053)$^{\alpha}$	1.48 (0.36)$^{\alpha}$	27.7 (5.1)$^{\alpha}$
3-6	43	0.221 (0.063)$^{\alpha}$	0.84 (0.14)$^{\alpha}$	25.1 (3.5)$^{\alpha}$

Table 2

Number of sightings (after truncation but before smearing), encounter rate and mean school size by area, pilot whale data, NASS-89. Standard errors in parentheses. Values in the same column with different superscript letters differ significantly ($p<0.05$). Sample sizes were too small to calculate effective search half-width by block.

Nationality	Block	Number of sightings, n	Encounter rate (schools/100nm)	Mean school size, $\bar{s}$
Icelandic	36	16	1.50 (0.35)^{ab}	23.1 (3.9)^{a}
	40	10	1.32 (0.49)^{abc}	17.0 (3.8)^{a}
	50	25	2.24 (0.55)^{a}	31.8 (8.1)^{a}
	60	3	0.33 (0.20)^{c}	83.3 (32.8)
	70	7	0.81 (0.30)^{bcd}	19.0 (4.3)^{a}
	88	9	0.80 (0.40)^{bc}	21.7 (5.7)^{a}
	93	2	0.53 (0.28)^{c}	5.0 (0.0)
	94	9	1.18 (0.41)^{abc}	27.9 (10.2)^{a}
	95	9	0.76 (0.28)^{bc}	22.8 (6.6)^{a}
Faroese	10	11	0.70 (0.28)	13.5 (5.1)
Spanish	21	15	0.92 (0.28)$^{\alpha}$	17.7 (6.2)$^{\alpha}$
	22	4	0.22 (0.09)$^{\beta}$	10.0 (3.5)$^{\alpha}$

out valid estimation of encounter rate and mean school size by block and so we stratified by block for those two parameters. This yields more reliable abundance estimates by block than does an unstratified analysis in which the total abundance estimate is proportioned by block area, although precision may be poor for individual block estimates.

Stratification by block also effectively stratifies the data by vessel, because most blocks were surveyed largely or entirely by a single vessel. As the effective search half-width was not stratified by block, it was necessary to determine whether it should be stratified by vessel. Table 3 shows that there were no significant differences between Icelandic vessels, although the effective search half-width for vessel *Hv9* was just a quarter of that for vessel *Sk*. When the effective search half-width was stratified by vessel, an estimate of 538,000 (CV=0.339) was obtained for the area surveyed by Icelandic vessels in 1989. With no stratification the estimate was 611,000 (CV=0.354). A chi-squared test for differences in the observed perpendicular distance distribution between vessels also proved non-significant, and thus data were pooled across vessel for subsequent estimation of effective search half-width. However, the effective search half-width was stratified by nationality, as different nations used different vessel types and survey methods. A plot of the fitted detection curve for the pooled data from Icelandic vessels in 1989 is shown in Fig. 4a.

The distribution of school size was highly skewed (Table 4). Although large schools influence the final abundance estimate appreciably, too few were detected to allow satisfactory stratification. Parameter estimates are shown by school size in Table 5. School size intervals of 1–10, 11–45 and >45 animals were selected. The first cutpoint was selected because it split the number of schools of at most 45 animals into two groups of equal sample size. The value of 45 was selected because it provided a sample size for 'large schools' that was just sufficient to allow estimation of effective search half-width, and because there was no natural break in recorded school sizes below this value. No significant differences in the effective search half-width were found by school size. The smallest estimated effective search half-width was for small schools, as might be expected. However, estimated correlation between school size and (untruncated) perpendicular distance of the school from the trackline was very close to zero ($r=0.012$; $p>0.1$) while the

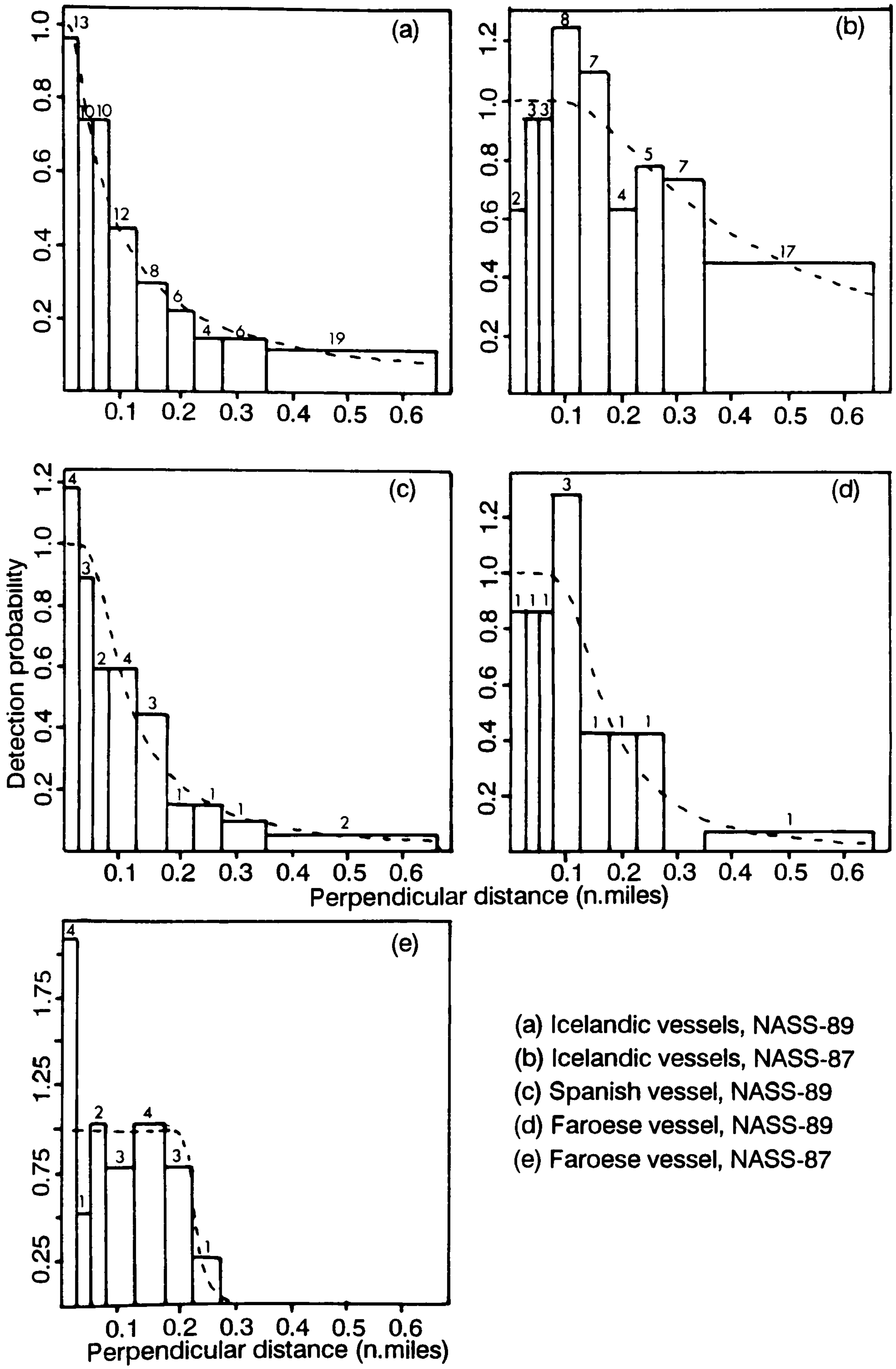

Fig. 4. Fits of the hazard rate model to the pooled perpendicular distance data.

Table 3

Number of sightings (after truncation but before smearing), effective search half-width, encounter rate and mean school size by vessel, pilot whale data, NASS-89. Standard errors in parentheses. Values in the same column with different superscript letters differ significantly ($p<0.05$).

Vessel	Number of sightings, n	Effective search half-width (nm)	Encounter rate (schools/100nm)	Mean school size, $\bar{s}$
Sk	31	0.323 (0.137)^a	1.38 (0.33)^a	32.6 (7.3)^a
AF	24	0.157 (0.092)^a	0.81 (0.21)^a	19.2 (4.2)^a
Hv8	21	0.150 (0.053)^a	1.32 (0.44)^a	25.7 (3.4)^a
Hv9	14	0.087 (0.058)^a	0.97 (0.27)^a	26.1 (7.6)^a
All Icelandic	90	0.163 (0.047)$^{\alpha}$	1.09 (0.17)$^{\alpha}$	26.4 (3.1)$^{\alpha}$
Faroese	11	0.214 (0.078)$^{\alpha}$	0.70 (0.28)$^{\alpha\beta}$	13.5 (5.1)$^{\beta}$
Spanish	19	0.156 (0.052)$^{\alpha}$	0.55 (0.15)$^{\beta}$	16.1 (5.0)$^{\alpha\beta}$

Table 4

School sizes (after truncation but before smearing), Icelandic pilot whale data, NASS-89.

School size	1-10	11-20	21-30	31-40	41-50	51-70	71-90	91-120	121-150
Frequency	38	16	15	7	4	1	3	4	2

Table 5

Number of sightings (after truncation but before smearing), effective search half-width and encounter rate by school size, Icelandic pilot whale data, NASS-89. Standard errors in parentheses. Values in the same column with different superscript letters differ significantly ($p<0.05$).

School size	Number of sightings, n	Effective search half-width (nm)	Encounter rate (schools/100nm)
1-10	38	0.143 (0.043)^a	0.44 (0.11)^a
11-45	38	0.272 (0.108)^a	0.47 (0.08)^a
>45	14	0.232 (0.158)^a	0.18 (0.04)^b

estimated correlation between log school size and perpendicular distance was in fact negative ($r = -0.045$; $p>0.1$). Given no indication of a relationship between school size and perpendicular distance, subsequent analyses were not stratified by school size.

Abundance estimates under the preferred analysis method are given in Tables 6–8. Plots of the fitted detection curves for the pooled data from Icelandic vessels in 1987, for Faroese 1987 and 1989 data, and for Spanish 1989 data are shown in Figs 4b-e.

The abundance estimate from the Icelandic NASS-89 data is high relative to the estimate from NASS-87 data. This arises both because high abundance estimates were obtained for the southern blocks, which were not covered in 1987, and because estimated abundance was higher on average in 1989 for blocks covered in both surveys. The surveys were carried out earlier in the summer in 1987 than in 1989, so it is possible that more animals are present in the blocks covered in both surveys in late summer. Comparison of Tables 3 and 9 shows that estimated effective search half-widths were narrower for 1989

Table 6

Abundance estimates by block, Icelandic pilot whale data, NASS-87 and NASS-89.

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, $\hat{N}$	CV($\hat{N}$)	95% confidence interval
1987	1	1	2542.1	136	1.079	(24, 763)
	2	1	18926.3	271	0.594	(92, 796)
	7	11	75215.1	4651	0.814	(1149, 18819)
	36	6	44172.5	5753	0.707	(1651, 20051)
	88	12	59848.0	11325	0.577	(3960, 32388)
	93	15	21760.7	17339	0.608	(5774, 52066)
	94	10	46092.4	14147	0.781	(3656, 54744)
	95	1	69396.1	4240	0.778	(1101, 16326)
	All	57	337953.2	57864	0.362	(29074, 115164)
1989	36	16	44172.5	47195	0.408	(21857, 101904)
	40	10	107842.0	74503	0.522	(28484, 194869)
	50	25	99750.0	217950	0.458	(92611, 512923)
	60	3	131458.0	112138	0.777	(29157, 431288)
	70	7	88571.0	42109	0.523	(16052, 110461)
	88	9	59848.0	31889	0.633	(10215, 99549)
	93	2	21760.7	1783	0.597	(604, 5260)
	94	9	46092.4	46786	0.579	(16314, 134171)
	95	9	69396.1	37026	0.550	(13528, 101340)
	All	90	668890.7	611378	0.354	(312023,1197933)

Table 7

Abundance estimates by block, Faroese pilot whale data, NASS-87 and NASS-89.

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, $\hat{N}$	CV($\hat{N}$)	95% confidence interval
1987	17	15	29599	55112	0.521	(21108, 143895)
	37	1	69394	4275	0.880	(968, 18871)
	47	3	73492	5392	0.732	(1495, 19453)
	All	19	172485	64779	0.454	(27752, 151209)
1989	10	5	195560	26122	0.689	(7702, 88593)
	20	6	40625	22887	0.898	(5068, 103357)
	All	11	236185	49009	0.614	(16186, 148389)

Table 8

Abundance estimates by block, Spanish pilot whale data, NASS-89.

Year	Block	Number of sightings, n	Size of block (nm^2)	Abundance estimate, $\hat{N}$	CV($\hat{N}$)	95% confidence interval
1989	21	15	244390	128080	0.571	(45241, 362604)
	22	4	170900	12235	0.633	(3924, 38148)
	All	19	415290	140316	0.541	(52015, 378518)

Table 9

Number of sightings (after truncation but before smearing), effective search half-width, encounter rate and mean school size by vessel, pilot whale data, NASS-87. Standard errors in parentheses. Values in the same column with different superscript letters differ significantly ($p<0.05$).

Vessel	Number of sightings, n	Effective search half-width (nm)	Encounter rate (schools/100nm)	Mean school size, $\bar{s}$
Sk	30	0.532 (0.097)^a	0.96 (0.27)^a	31.3 (9.3)^a
AF	3	-	0.25 (0.09)^b	7.7 (2.6)^a
Ke	24	0.264 (0.130)^a	0.70 (0.21)^a	13.9 (4.3)^a
All Icelandic	57	0.438 (0.094)$^\alpha$	0.74 (0.14)$^\alpha$	22.7 (5.3)$^\alpha$
Faroese	19	0.234 (0.023)$^\beta$	0.41 (0.17)$^\alpha$	102.0(22.6)$^\beta$

than 1987, leading to higher abundance estimates. Only vessel *Sk* detected sufficient pilot whales in both surveys to allow estimation of effective search half-widths by vessel, and these were high relative to other vessels. The estimated search width for vessel *Sk* was higher in 1987 than in 1989, but the difference was not significant. For the Icelandic data, mean school size was low in 1987 relative to 1989, except for vessel *Sk*. On average, encounter rates for Icelandic vessels were lower in 1987 than in 1989. If Icelandic blocks 40, 50, 60 and 70 and both Spanish blocks are excluded from analyses, so that the 1989 estimate is broadly comparable with the total estimate from Icelandic and Faroese data, the 1989 estimate is 191,000 animals (CV=0.330), compared with 123,000 animals (CV=0.294) for 1987. These estimates do not differ significantly ($p>0.1$), so that the observed large differences in abundance estimates for 1987 and 1989 might be explained largely or wholly by the wider area included in the 1989 analyses. If abundance estimates from Icelandic, Faroese and Spanish data are summed, excluding the estimate for Faroese block 20, which is largely within Icelandic block 88, the total abundance for the entire area surveyed during NASS-89 is estimated as 778,000 animals (CV=0.295).

DISCUSSION

General distribution

This is the first time a synoptic view of the entire area has been obtained. The geographical distribution found during the surveys is well in accordance with earlier published observations. For example Christensen (1977) reported a number of sightings off East Greenland from May-August 1974 and a single sighting southwest of Iceland. During a cruise in June-July 1981 at East Greenland and west of Iceland, Sigurjónsson (1983) encountered no pilot whales off Greenland, but observed 16 groups at the edge of the continental shelf and in deep waters west of Iceland. Martin *et al.* (1984) covering the latter area in 1982, located 5 groups of pilot whales. Sigurjónsson (1985) reported two sightings of pilot whales along the East Greenland coast in August 1993, but no animals were observed in any of the deep and shallow water areas covered around Iceland.

In the waters southwest of Iceland sightings of significant numbers of animals were made in both years. The clumped distribution in 1987 is due to unfavourable sightings conditions. The area at the continental edge south of Iceland was the only one resulting in sightings of pilot whales in extensive aerial surveys conducted in Icelandic coastal waters in June-July 1986 (3 sightings of 60 animals) and 1987 (7 sightings of 103 animals), respectively (Gunnlaugsson *et al.*, 1988; Donovan and Gunnlaugsson, 1989). Brown (1961) and McBrearty *et al.* (1986) had reported a number of summer sightings of pilot whales in deep waters farther south of Iceland, as was found in 1989.

The waters to the north, northeast and east of Iceland were covered under relatively good sightings conditions and the absence of pilot whales is in agreement with earlier surveys in these areas (Sigurjónsson, 1983; 1985; Martin *et al.*, 1984; Gunnlaugsson *et al.*, 1988; Donovan and Gunnlaugsson, 1989). Christensen's (1977) single sighting of 10 animals off Langanes, Northeast Iceland, in June 1974 is thus the only sighting so far of the species that far north in these waters. His summary of catches by Norwegian whalers (Christensen, 1975) shows a small number of takes east of Iceland and around Jan Mayen, proving the presence, although in small numbers, of this species in these waters.

A considerable number of sightings were made to the southeast of Iceland in both years. The only previously published sighting was a single group reported by Martin *et al.* (1984). The area further to the southeast, i.e. southwest of the Faroe Islands, had in 1987 by far the greatest occurrence of the species as one might expect given the ongoing fishery in Faroese waters. The fewer sightings in the area in 1989 reflect the level of primary effort and the cruise track. Evans (1980; 1987) reported sightings in the area between the Faroe Islands and the coast of Scotland. The relatively few sightings made during this survey west of Ireland and Great Britain are in conformity with Evans' (1987) observations of relatively low abundance in this area compared to the northernmost area of Scotland.

No pilot whales were seen in 1987 on the Norwegian survey vessels nor during the Norwegian aerial survey, which covered the Norwegian Sea northeast of our study area, the Norwegian coast and the Barents sea (Øritsland *et al.*, 1989), while only five groups were seen in 1989 (Øien, pers. comm.). This indicates that the species is scarce in the northernmost regions of the northeast Atlantic as also indicated by Christensen's (1977) summary of observations made in the different parts of North Atlantic (no pilot whales reported), although McBrearty *et al.* (1986) reported two sightings off North Norway.

In 1987, eleven sightings of 123 animals were made on board the Spanish survey vessel surveying south of 52°N, west of the British Isles and in the Bay of Biscay (Lens *et al.*, 1989), which is in accordance with earlier surveys by Spanish scientists (Aguilar *et al.*, 1983; Sanpera *et al.*, 1984; 1985; Sanpera and Jover, 1986) and from stranding records on the French coast. All were identified as long-finned pilot whales. The survey extended further to the west in 1989 and pilot whales were encountered throughout the area.

Abundance estimate

We regard our estimate of 778,000 (CV=0.295) as the best available estimate of the total stock of long-finned pilot whales in the northeastern Atlantic in summer. As explained in the Results section, the estimates from NASS-87 are lower. Our analyses of Icelandic and Faroese NASS-87 data yield a total estimate of 123,000 animals (CV=0.294). This is comparable with an estimate of 104,000 animals (CV=0.3), derived from estimates of 72,000 (CV=0.4) from Faroese NASS-87 data and 31,900 (CV=0.3) from Icelandic NASS-87 data given by Bloch *et al.* (1989b).

Estimates from the northwestern Atlantic are substantially lower than our estimate. Hay (1982) estimated some 13,000 animals from an aerial survey of the Newfoundland area whilst Payne *et al.* (1993), concluded that there were 10,000–12,000 off the Northeastern coast of the USA. During the aerial survey off West Greenland in 1987, 460 pilot whales were sighted in 18 groups (Larsen *et al.*, 1989), indicating substantial occurrence of the species during the survey period. Although no pilot whales had been observed in earlier aerial surveys (in 1983, 1984 and 1985) in the same area, subsequent surveys have regularly encountered pilot whales. Their seasonal occurrence has also been reported by Christensen (1975; 1977) and Kapel (1975). However no population estimates exist for the area.

Possible biases

There are several potential biases in the abundance estimates. For example, for many schools detected by Icelandic vessels in 1989, no best estimate of school size was recorded. We adopted the conservative approach, using the low estimate when no best estimate was recorded. This gave an abundance estimate from Icelandic data of 611,000 animals (Table 6). If instead the mean of the low and high estimates is used, the corresponding estimate of abundance is 691,000 animals (CV=0.353).

Another source of potential bias is the assumption that all pilot whales on the trackline were detected ($g(0)=1$). Although pilot whales can dive for up to one hour, Mate (1989) observed that a satellite-monitored radio tagged pilot whale averaged a dive time of 40 seconds. The distance travelled by a sightings vessel in 40 seconds is less than 300m, and pilot whales usually travel in groups that are not entirely synchronised, so that sighting cues occur more frequently than the surfacing rate of a single animal. Thus it seems likely that most pilot whales near the trackline and with a similar surfacing rate to that observed by Mate will be seen, and that $g(0)$ for pilot whale groups will be close to unity. However, pilot whales sometimes show synchronous deep diving behaviour, and in the absence of adequate information on this behaviour, the possibility remains that a significant proportion of animals near the trackline remains undetected.

Perhaps more serious is the potential positive bias in estimates arising because of the method of recording large, loose aggregations of pilot whales. The first detected subgroup of such an aggregation, and hence the aggregation itself, will tend to be recorded closer to the trackline than the centre of gravity of the aggregation (which may explain why no correlation between school size and perpendicular distance was found) and mean school size will be overestimated, since large aggregations, occupying a substantial area, are more likely to be detected than small schools. We endorse strongly the recommendation of Bloch *et al.* (1989b), that 'as far as practical, every subgroup must be individually recorded and group sizes assessed (preferably while in passing or delayed closing mode) without any extrapolations.' It does not matter that the whole aggregation is not counted, provided most subgroups near the trackline are detected, and their sizes are estimated with reasonable accuracy. Provided robust methods of variance estimation are used, to take account of the strong clustering of subgroups, the analysis should be substantially less biased than an analysis based on aggregations. Using the data from vessel *Ke* in 1987, which were recorded in this way, a correction factor of 0.824 (CV=0.257; 95% confidence interval [0.330, 1.191]) was obtained. Although the confidence interval includes unity (no correction), it also extends as low as one third, corresponding to a reduction to one third of the uncorrected abundance estimate. The correction factor is an alternative to the solution adopted by Bloch *et al.* (1989b), who reduced Faroese school size estimates exceeding 100 animals to exactly 100, and Icelandic estimates exceeding 150 animals to exactly 150, in an attempt to reduce the bias caused by recording large schools too close to the trackline. At present, the correction factor is not applied, as it is unclear whether a correction calculated from data for vessel *Ke* in 1987 is appropriate for other vessels in either 1987 or 1989.

The counts of school size introduce another potential source of bias, especially when vessels operate in passing mode, when underestimation might be anticipated (Bloch *et al.*, 1989b). The decision whether to close with a sighting was made when animals were detected, and larger schools were more likely to be closed with. Thus it is not possible to associate effort with either mode, and mean school size during passing mode cannot be estimated by the observed mean size in closing mode. In future surveys, it might be advisable to determine in advance whether effort is to be carried out in passing mode or closing mode with respect to pilot whales, so that school size estimates from the two modes can be compared. The possibility of using a helicopter to confirm estimates at least for a proportion of schools might also be considered.

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