Paper 2

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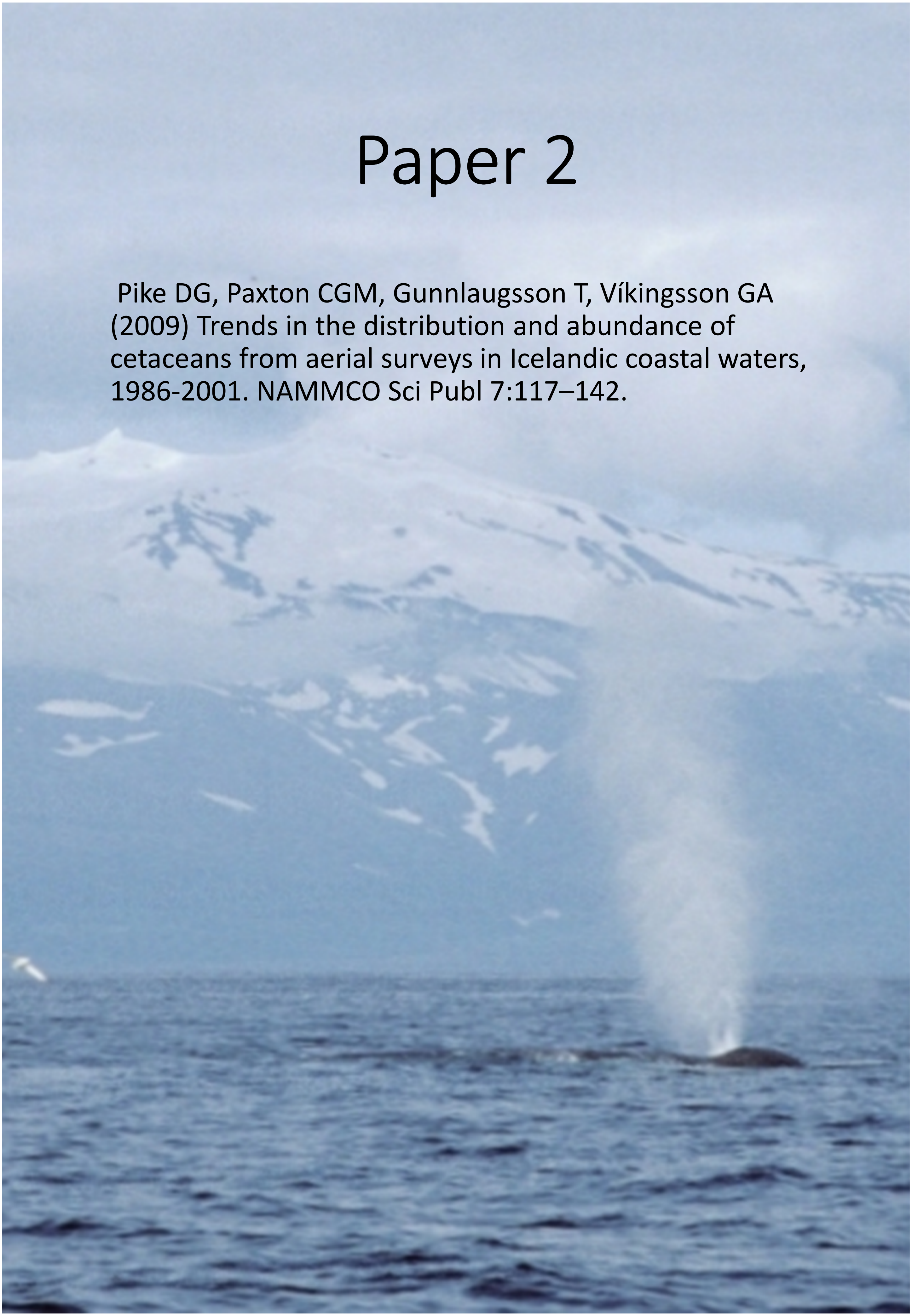

Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters, 1986-2001.

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ABSTRACT

Aerial surveys were carried out in coastal Icelandic waters 4 times between 1986 and 2001 as part of the North Atlantic Sightings Surveys. The surveys had nearly identical designs in 3 of the 4 years. The target species was the minke whale (*Balaenoptera acutorostrata*) but all species encountered were recorded. Sighting rate and density from line transect analysis were used as indices of relative abundance to monitor trends over the period, and abundance estimates corrected for perception biases were calculated for some species from the 2001 survey. More than 11 species were sighted, of which the most common were the minke whale, humpback whale (*Megaptera novaeangliae*), dolphins of genus *Lagenorhychus*, and the harbour porpoise (*Phocoena phocoena*). Minke whales and dolphins showed little change in distribution or abundance over the period. There were an estimated 31,653 (cv 0.30) dolphins in the survey area in 2001. Humpback whales increased rapidly at a rate of about 12%, with much of the increase occurring off eastern and northeastern Iceland. In 2001 there were an estimated 4,928 (cv 0.463) humpback whales in the survey area. The relative abundance of harbour porpoises decreased over the period, but estimates for this species were compromised by uncorrected perception biases and poor coverage. The ecological and historical significance of these findings with respect to previous whaling activities and present-day fisheries is discussed.

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INTRODUCTION

Aerial surveys for cetaceans in Icelandic waters have been conducted for the past 20 years. Pioneering work was carried out by Hiby *et al.* (1984) who conducted limited surveys in offshore areas in 1982. Hiby *et al.* (1984) concluded that aerial surveys offered some advantages over shipboard surveys for coastal areas and that they could provide reliable estimates or indices of cetacean abundance. Further work was carried out in 1986 when a designed survey was planned to cover all coastal waters of Iceland approximately within the 600 m depth contour (Gunnlaugsson *et al.* 1988). The survey used line transect methods and the target species was the minke whale (*Balaenoptera acutorostrata*). The experience gained during this survey led the investigators to conclude that aerial survey was a valid methodology for this and other species. However, because the proportion of whales that were visible on or near the surface was not known, it was not possible to translate the estimates from this survey into estimates of absolute abundance.

This problem led to the adoption of cue–counting techniques in surveys conducted after 1986. In this methodology, described by Hiby and Hammond (1989), whale behaviours, such as blows or surfacings in the case of minke whales, are counted, rather than animals or groups of animals. The method has an important advantage over line transect techniques in that it is not assumed that all animals along the trackline are seen, but rather that all cues are seen. An estimate of the cueing rate of the target species is required to obtain an estimate of absolute abundance. The resulting cue–counting estimate is thus corrected for availability bias but double platform data are needed to correct for perception bias. However, some species, such as dolphins, do not exhibit obvious cues that can be counted from the air. The data collected for cue–counting does not preclude the development of standard line transect estimates, however.

The first aerial survey using cue–counting techniques in Icelandic waters was conducted in 1987 (Donovan and Gunnlaugsson 1989), and surveys using almost identical designs were conducted in 1995 and in 2001 as part of the North Atlantic Sightings Survey (NASS) programme. Estimates of abundance have been developed from all of the surveys for minke whales (Hiby *et al.* 1989, Borchers *et al.* 2009) but not for other species.

The availability of these 4 large survey datasets from the past 16 years provides an important opportunity to assess temporal trends in the distribution and abundance of several species of cetaceans in Icelandic coastal waters. Some of the species seen in the surveys, such as minke and humpback whales, have been the targets of past commercial whaling in the area (Sigurjónsson and Gunnlaugsson 1990) and populations might therefore be expected to be increasing. Whaling for minke whales has recently resumed on a small scale as part of a research project (Anonymous (MS) 2003). Dolphins and harbour porpoise (*Phocoena phocoena*) are subject to by-catch in Icelandic waters (Víkingsson *et al.* 2004) but information on abundance is limited (Sigurjónsson and Víkingsson 1997).

Estimates derived from these surveys will be negatively biased not only due to the number of animals that are submerged when the survey plane passes over (availability bias), but also due to the number of animals missed by observers (perception bias). Cue–counting analysis can be used to correct for availability bias, but cue data are available only for minke whales and then not from the first (1986) survey. Double platform data can be used to correct for perception bias, but double platform methodology was fully implemented only on the 2001 survey. However even biased estimates are valuable for these species both because no other estimates are available and because they can be used as indices of relative abundance to determine temporal trends in the populations, assuming there are no systematic trends in the biases.

In this paper we present results from 4 NASS aerial surveys around Iceland. Changes in distribution over the period will be assessed qualitatively. For comparison of abundance between surveys, the best index that is available from all surveys will be used. This ranges from simple encounter rate to density corrected for perception bias, for some species and surveys. Absolute abundance estimates of minke whales using cue–counting are presented by Borchers *et al.* (2009) for the 1987 and 2001 surveys and will not be dealt with in this paper.

MATERIALS AND METHODS

Survey design

The design of the 1986 survey was somewhat different from that used in subsequent years (Gunnlaugsson *et al.* 1988, see Fig. 1a). Inner blocks in areas where high densities were expected were surveyed using parallel tracks spaced at 5 nm intervals perpendicular to the coastline. Offshore areas and inshore areas where lower densities were expected were surveyed using a zig zag pattern. To obtain block estimates comparable with later surveys, a post stratification to blocks identical to the 1987 and 1995 surveys was done. Because a single post stratified block might consist of 2 or more sub blocks with unequal coverage probability, post strata estimates were obtained by combining individual estimates from sub strata.

The 1987 (Donovan and Gunnlaugsson 1989), 1995 and 2001 surveys all used essentially the same block structure and track layout (Fig. 1b).

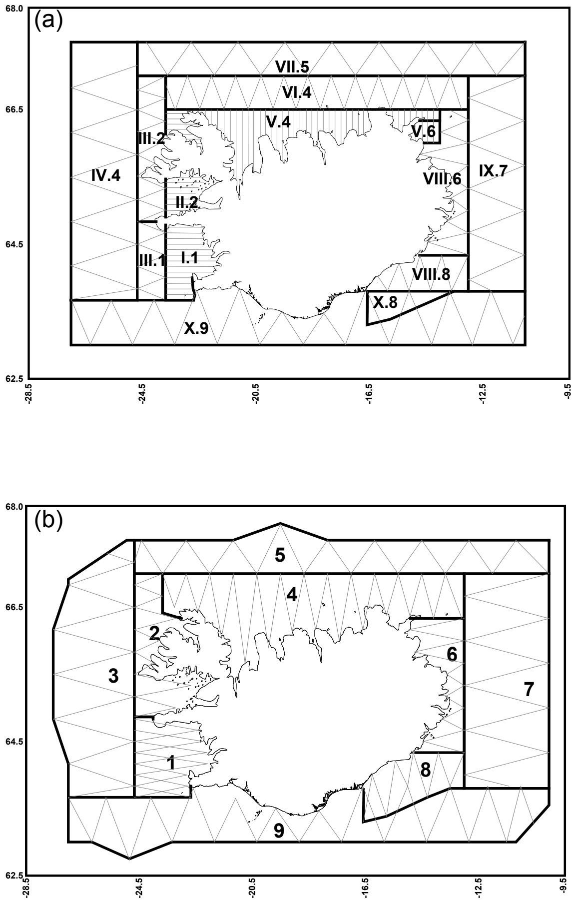

__Fig. 1.__ Survey plans, showing block definitions (numbers) and planned tracklines for a) 1986 and b) 2001. For 1986, the original block numbers are in Roman numerals, and the post-stratified block numbers are in Arabic. The 1987 and 1995 surveys used the same design as in 2001, except that blocks 5, 7 and 9 were extended eastwards from 11° to 10° W in 2001.

The block structure was similar to that used in 1986 except that the size of the inshore blocks was increased by extending them farther offshore, eliminating the midshore blocks. A zig zag track layout was used in all blocks. In 2001 blocks 5, 7 and 9 were extended eastwards from 11° to 10° W, to achieve better coverage of a major concentration of humpback whales in the area.

In all surveys realised effort depended primarily on the weather. The full design was not completed in any year. As the survey progresses and some blocks are done, there is less flexibility to survey where the weather is good, and the whole design can not be completed unless ideal conditions prevail.

Aircraft and equipment
A Partenavia Observer P-68, with 1 bubble window on each side of the plane was used in all surveys. A satellite navigation system was used to locate and fly the track lines. The target altitude was 229 m, and the target ground speed was 90 nm/hr (46 m/s), however minor variations from these target values were sometimes required because of weather conditions.

In 1986 data recording was done by the cruise leader using paper forms. In other years data was entered by voice and recorded on separate cassette tapes for each of the 4 observers. When the microphone was opened, a time and position signal from the GPS was also recorded on the tape, so that the time and position of every observation was known. Time and position data were also transferred via modem to a laptop computer every minute while on effort.

Declination angles were measured with a hand held declinometer, and lateral angle from the nose of the airplane (required for cue–counting surveys) was estimated using a laptop angle board.

Data collection
The survey crew consisted of the pilot and cruise leader in the left and right front seats, and 2 primary observers in the right and left rear seats, using the bubble windows. In general the observers were experienced whale observers. There was some overlap in observers between surveys, and in some years (1986, 1987 and 1995) the primary observer positions were shared by more than 2 observers. The primaries maintained full observational effort throughout the surveys.

The pilot and cruise leader also recorded sightings. In the first 3 surveys, the front and rear platforms were not isolated from one another and therefore these data could not be used to correct for perception bias. Isolation was maintained briefly as an experiment in the 1987 survey (Donovan and Gunnlaugsson 1989) and these data have been used to correct absolute abundance estimates for minke whales (Hiby *et al.* 1989, Borchers *et al.* 2009). In the 2001 survey, the primary observers were visually isolated from the pilot and cruise leader using a curtain, and aural isolation was maintained while on effort by removing the intercom microphones. Therefore this survey was run in true "double platform" (Hiby and Hammond 1989) mode and these data have been used to derive absolute abundance estimates for minke whales (Borchers *et al.* 2009). Here we use them to correct line transect estimates for dolphins and humpback whales (see below).

In addition to recording cetacean sightings, the cruise leader also monitored all changes in survey effort and environmental conditions, including the beginning and end of each transect, aircraft drift angle, ground speed, altitude, interruptions in effort, weather conditions, Beaufort sea state, visibility, sightability (subjective scale, 3 levels) and glare (start and end angle 1995 and 2001, presence/absence in 1986 and 1987). Off effort sightings were also recorded when possible.

The 1986 survey was conducted as a line transect survey, and perpendicular distance to the sighting was required. This was obtained by measuring the declination angle to the centre of the sighting when the sighting was abeam. In other years cue–counting methods were used, which require a measurement of the radial distance from the observer to the cue position. For minke whales, the cue was a single dive, taken as the moment the back disappeared underwater. For other species, a cue was simply a sighting of a group of animals. The following data were recorded for every cue sighted: time at which cue sighted, angles of declination and from the head of the aircraft, time at which the angles were measured, position when the angles were measured, cue type and school size. Minke whales that did not show a cue were recorded as "seen under water". If possible the declination angle and time when the cue position was abeam was also recorded.

The surveys were conducted mainly in passing mode, but sightings were sometimes investigated for species identification. Survey effort was abandoned if Beaufort sea state increased above 3, or if fog, mist or heavy rain obscured visibility, unless these conditions were expected to improve further along the transect.

Data analysis

Data preparation

All data collected at Beaufort sea state >4 was dropped prior to analysis. For minke whales and harbour porpoises, all data collected at Beaufort sea state >3 was dropped.

For the 1986 survey, perpendicular distance was measured with a declination measurement when the sighting was abeam and the perpendicular distance is calculated as follows:

(1)

$$X = ALT \bullet \tan(90 - \alpha)$$

where:

ALT = altitude;

X = perpendicular distance to sighting;

For later surveys, perpendicular distance was measured with a declination angle and a lateral angle from the head of the airplane as follows:

(2)

$$R = ALT \bullet \tan(90 - \alpha)$$

Then:

(3)

$$X = R \bullet \sin(\beta)$$

where:

R = radial distance to sighting at time measurements were recorded;

α = declination angle to sighting;

β = angle from the head of the airplane to the sighting, corrected for aircraft drift angle;

Abundance estimation

For line transect abundance estimates only sightings from the rear (primary) observers were used. The role of the front (secondary) observers changed somewhat over the course of their surveys, and we therefore considered that their efficiency as observers might have changed. The role of the primary observers has remained more or less constant over all the surveys. Data from the secondary observers in 2001 was used to derive an estimate of the proportion of visible animals seen on the trackline ($g(0)$) for some species for that year as described below.

Estimation of density and abundance was attempted only in cases where 30 or more sightings with valid perpendicular distances were available. At least some surveys for minke whales, humpback whales, dolphins and harbour porpoises fulfilled that criteria. Data analyses were carried out using the DISTANCE 4.0 (Thomas *et al.* 2001) software package and stratified line transect methods (Buckland *et al.* 2001). In the case of the double platform analyses the data were analysed as per Laake and Borchers (2004) using an unpublished package in *R* (Ihaku and Gentleman 1996).

Model selection

Right truncation distances were chosen by visual inspection of the perpendicular distance histograms, and typically about 10% of the sightings with greatest perpendicular distances were discarded. For some datasets, there was an unexpectedly low number of sightings near the trackline, extending out about 100 m from the trackline. In these cases left truncation was employed, and the detection function was calculated excluding data within 100 m from the trackline.

Calculation of effective strip width (*esw*) was pooled over geographical strata while encounter rate (*n/L*) was calculated separately for each stratum. Group size (*s*) was calculated separately for each stratum if there were significant ($P<0.05$) differences between strata; otherwise a mean over all strata was used. We expected that there would be bias in the detection of large vs. small groups, particularly for dolphins which have highly variable group sizes. To determine if there was size bias in group detectability, ln(*s*) was regressed against the estimated detection probability. If this regression was significant at the $P<0.15$ level, the detection of groups was considered to be size biased and the estimate of mean group size was adjusted using this regression.

A variety of models for the detection function *f(x)* were initially considered, and the final model was chosen by minimisation of Akaike's information criterion (AIC) (Buckland *et al.* 2001), goodness of fit statistics and visual inspection of model fits. Covariates were then considered for inclusion in the model to improve precision and accuracy. Covariates were assumed to affect the scale rather than the shape of the detection function, and were incorporated into the detection function through the scale parameter in the key function (Thomas *et al.* 2001). Covariates were retained only if the resultant AIC value was lower than that for the model without the covariate.

In the case of minke whales, relative, rather than absolute measures of density were desired, as estimates of absolute abundance are available for this species for some surveys (Borchers *et al.* 2009). Our general strategy for this species was to model each dataset in as similar a manner as possible. We therefore chose to use the hazard rate model for the detection function, although this model did not provide the best fit in all cases. This eliminates the effect of model choice on the estimate of relative abundance. We found, for example, that choosing the half normal model (which provided a better fit in some cases) consistently resulted in higher estimates of density than the hazard rate model. In addition, left truncation of the distance data was indicated for 3 of the datasets. Since we had no knowledge of the true shape of the detection function in the area that was truncated, we chose the conservative approach of choosing the hazard rate model which assumes this part of the detection function is flat.

Correction for missing distances

For some observations, data to calculate perpendicular distance was either not collected or not useable. We utilised these observations in the calculation of *n/L* by assuming that the distribution of perpendicular distances for these observation was the same as in the dataset as a whole. Therefore, the number of observations to be included in the calculation of *n/L* was derived separately for each block, as follows (Innes *et al.* 2002):

(4)

$$n_i = n_{1i}\left(1+\frac{n_{2i}}{n_{3i}}\right)$$

where:

n_i = number of observations in block i used to calculate *n/L*;

n_{1i} = total number of observations with perpendicular distances after truncation in block i;

n_{2i} = total number of observations without perpendicular distances in block i.

n_{3i} = total number of observations with perpendicular distances in block i;

Similarly the variance of n was corrected as follows:

(5)

$$\mathrm{var}(n_i) = \mathrm{var}(n_{1i})\left(1+\frac{n_{2i}}{n_{3i}}\right)^2$$

Calculation of density:
Density in each block was calculated as follows:
(6)

$$D_i = \frac{n_i \bullet f(0) \bullet E(s)}{2L_i}$$

where:

D_i = density of whales in block i;
n_i = number of groups detected in block i;
$f(0)$ = probability density function evaluated at perpendicular distance 0;
L_i = survey effort (nm) for block i;
$E(s)$ = mean group size.

Because the block structure used in 1986 was different than that used in other years, post-stratification was employed to facilitate block comparisons between surveys (Fig. 1). Coverage probability varied among the post stratified 1986 blocks making up a post-1986 block, so density was calculated separately for each post-stratified block, and the density of the post 1986 block was derived as the area-weighted average of the post-stratified block densities. Similarly variance for the post 1986 blocks was calculated using an area weighted average of the variance of *n* (and *s* if estimated separately by block), and common variances for *esw* (and *s* if a pooled estimate was used) which were pooled over blocks.

Variances for *D* were calculated in DISTANCE, and log-normal confidence intervals were used (Buckland *et al.* 2001).

Correction for animals missed by observers
In the 2001 survey sufficient double platform data were collected for humpback whales and dolphins to correct density estimates for the bias caused by visible animals being missed by observers (corrected cue-count estimates for minke whales are provided by Borchers *et al.* 2009). A conditional detection (*i.e.* probability of detection of a particular observer position (front or back) given the animal was seen) probability could be calculated using the method of Laake and Borchers (2004). Essentially each observer position can be used as a control for the other observer position so the specific conditional probability for each position can be calculated. The bias in $g(0)$ can then be estimated and the abundance estimate from the conventional line transect method adjusted. A variety of variables were considered in this *point independence* analysis. Model selection was forward and models were selected that minimised the AIC.

Trends
Trends in abundance for minke whales, humpback whales, dolphins and harbour porpoises were examined in 2 ways. Firstly based on the above abundance or sighting rate estimates, depending on which was available for all surveys, by estimating the average overall log-linear rate of increase/decrease in the whole area (LL method). Confidence intervals for the rates of increase were estimated using a parametric bootstrapping procedure, assuming a log-normal distribution for density or encounter rate (Buckland *et al.* 2001), and calculating 5,000 re-sampling estimates of exponential slope. This approach can be applied to the entire survey area only for years in which there was effort in all blocks so separate rates were calculated for the entire survey area (1986, 1995 and 2001) and only those blocks covered in 1987 (all years). In the abundance estimates the effect of environmental factors is assumed to be reflected in the estimation of *esw* and it is assumed that the probability of detection on the trackline has had no trend with time.

Alternately a generalised linear model (GLM) was fitted to the number of all animals seen (whole crew) per nautical miles flown on effort. The expected number of sighted animals in year y in block i and conditions j during effort $e_{y,i,j}$ is given by:
(7)

$$\ln \hat{s}_{y,i,j} = \ln e_{y,i,j} + \ln d_i + y \ln t + \mathrm{w}_j + c_j + \mathrm{g}_j$$

where:

d_i is estimated relative density in block i.
t is the estimated trend.
w_j, c_j, g_j are estimated wind, cloud cover and glare factors (negative exponents) that are at zero in best conditions.

With an assumed Poisson error distribution the negative log likelihood is given by summing over all indices:
(8)

$$\ln L = \Sigma\, [\hat{s}_{y,i,j} - s_{y,i,j} \ln \hat{s}_{y,i,j} + \ln(s_{y,i,j}!)]$$

Table 1. Characteristics of aerial surveys flown in Icelandic coastal waters, 1986-2001. *K* – number of transect lines flown.

YEAR	BLOCK	AREA (nm²)	K	EFFORT (nm)
1986	1	4,088	25	737
	2	4,104	21	376
	3	12,474	7	346
	4	12,039	58	1,430
	5	9,513	11	364
	6	3,766	23	565
	7	9,589	10	384
	8	3,685	16	337
	9	16,838	19	759
	TOTAL	76,096	190	5,298
1987	1	4,418	11	663
	2	3,988	12	398
	3	14,066	2	89
	4	12,392	29	1,251
	5	9,471	10	281
	6	3,602	0	0
	7	9,589	0	0
	8	3,728	10	255
	9	17,408	15	610
	TOTAL	78,662	89	3,548
1995	1	4,418	13	765
	2	3,988	9	229
	3	14,066	10	606
	4	12,392	26	1,251
	5	9,471	16	551
	6	3,602	12	422
	7	9,589	8	380
	8	3,728	12	418
	9	17,408	18	778
	TOTAL	78,662	124	5,399
2001	1	4,418	13	819
	2	3,988	10	299
	3	14,066	8	542
	4	12,392	23	1,002
	5	10,782	10	370
	6	3,602	12	364
	7	14,384	9	519
	8	3,728	12	420
	9	18,186	16	662
	TOTAL	85,546	113	4,998

The last term is ignored during minimization as the observed number of sighted animals is then a known constant.

Here s is the number of animals rather than sightings. This avoids the need to estimate average group size, or else assume no trend therein. As the number of animals was used rather than the number of sightings, the modelled variance is necessarily underestimated, so the variance was obtained by bootstrapping. The reported coefficients of variation and confidence intervals from the bootstrap were calculated from the estimated log-linear trend based on 1,000 re-samplings and are given in Table 9. Each observation (re-sampling unit) is the number of animals sighted and corresponding miles on effort by block and environmental factors, split for each side of the plane, typically about half an hour. This procedure should also capture most of the variation due to local lumpiness of sightings and correlation in environmental conditions. Environmental factors considered were: 3 Beaufort sea state categories 0-2, 3 and 4, except for harbour porpoises where effort in sea state 4 was excluded; cloud cover in 4 categories, clear (0-25%), lightly cloudy (26-50%), cloudy (51-75%) and overcast (76-100%). Glare was considered for each side of the plane. Glare has been recorded with a single glare angle or glare from angle to angle and sometimes classified as light, moderate or severe. The "light" classification was ignored and an on/off glare factor was considered affecting if there was any glare within 0° to 90° from track on that side of the plane.

This approach does not use *esw* or need other decisions in the model fitting associated with line transect estimates but assumes that the effective search area (corrected for environmental variables) has had no trend with time. This estimate of trend has minimal variance but refers to where the mass of the data lies. If the data is poorly balanced the additional assumption has to be made that this trend applies to the whole area.

As the effort was split by side of the plane, equipment failure on 1 side of the plane did not preclude the use of effort from the other side. Also effort on 1 side of the plane for some single days of effort with inexperienced observers making no sightings was excluded. In

1988 there was a limited aerial survey in block 1 (Faxaflói Bay) where the observer and scientist sitting on the right side of the plane had also participated in surveys in 1986 and 1987 and the observer again partly in 1995. Thus the 1988 effort for the right side of the plane was included in this sighting rate analysis.

RESULTS

Coverage

The coverage achieved depended primarily on the weather. Coverage was lowest in 1987, when blocks 3, 6 and 7 were missed almost entirely, and greatest in 1995, when most of every block was well covered (Table 1, Fig. 2). Coverage tended to be greatest in coastal blocks, as these were more accessible and tended to have better weather.

Distribution, abundance and trends

Table 2 and Fig. 2 show the distribution of sightings of cetacean groups. Tables 4 to 7 show the line transect abundance estimates for minke whales, humpback whales, dolphins and harbour porpoises respectively. Trends in sighting rates and sighting rates by blocks are given in Table 8 and Figures 4-8.

Minke whales

The numbers and general distribution of sightings of minke whales was remarkably similar between years. The areas of highest density were consistently block 1 (Faxaflói Bay, SW Iceland), block 8 (SE Iceland) and block 4 (N Iceland). Relatively few minke whales were seen in the offshore blocks. In 2001 more minke whales were seen in block 6 (E Iceland) than in earlier years.

Characteristics of the detection functions for each survey are shown in Table 3 and Fig. 3. For the 1986 dataset some “heaping” near the trackline is evident. The other datasets exhibited the opposite problem: depressed sighting frequencies near the trackline requiring left truncation. This problem was most severe in 2001 when left truncation out to 100 m from the trackline was used. It is apparent that the hazard rate model provides a relatively good fit to the data, although it was not the best model in every case. Effective strip half width did not vary significantly between years, but was highest in 1987 and lowest in 2001 (Table 4). Mean group size did not vary significantly between blocks within surveys or between survey years. Encounter rate differed by an order of magnitude between blocks, but was relatively consistent in the same blocks between years.

The GLM estimates of minke whale sighting rates (Table 9) were highest when skies were clear but similar for the other 3 cloud cover categories, so these were combined. Minke whale sighting rates were similar for Beaufort sea state 0-1 and 2 so these were also combined. Sighting rates were reduced in sea state 3 and 4 to 59% (cv 0.28) and 41% (cv 0.34) respectively. Clouds and glare reduced sighting rates to 91% (cv 1.5) and 75% (cv 0.45) respectively. The point estimates of rate of increase were positive for minke whales using both the LL (Table 8) and GLM methods, however it was not significantly different from 0.

Humpback whales

Humpback whales were found throughout the survey area but were most common off the west and east coasts of Iceland (Fig. 2). Few sightings were made in the 1986 and 1987 surveys (Table 2). In 1987, neither the offshore west or the entire east coast were covered, so the low numbers of humpback whale sightings are not unexpected. In 1986, these areas were covered; nevertheless few humpback whales were sighted. In 2001 sightings were concentrated off northeast Iceland, a large portion of which was not covered because of persistent fog. Similarly, northwest Iceland, where humpback whales were concentrated in 1995, was poorly covered in 2001. Even so, almost twice as many humpback whales were seen in 2001 as in 1995.

Sufficient sightings were available to estimate humpback whale abundance in 1995 and in 2001 (Tables 3 and 5, Fig. 3). The detection function for 2001 exhibited depressed sighting probability at a perpendicular distance of about 800 m, and a secondary peak at around 1,200 m. We surmise that this may have been due to high glare conditions experienced when a large proportion of the sightings were made, and consider the paucity of sightings at 800 m to be an

Table 2. Sightings of cetacean groups in Icelandic aerial surveys, 1986-2001. Only primary (rear seat) sightings are shown. BA – minke whales; LSP – *Lagenorhynchus* spp. dolphins, mainly L. *albirostris*; MN – humpback whales; PP – harbour porpoises; BP – fin whales; BM – blue whales; GM – long-finned pilot whales; OO – killer whales; PM – sperm whales; BB – sei whales; HA – northern bottlenose whales.

YEAR	BLOCK	BA	LSP	MN	PP	BP	BM	GM	OO	PM	BB	HA	OTHER
	1	55	36	0	1	0	0	0	1	0	0	0	4
	2	1	1	0	4	0	0	0	0	0	0	0	0
	3	4	2	4	0	6	0	0	0	0	0	0	2
	4	23	26	1	37	0	1	0	0	4	0	0	11
1986	5	11	12	0	1	0	0	0	0	0	0	0	2
	6	7	9	0	4	0	0	0	0	0	0	0	0
	7	3	0	6	0	0	0	0	0	0	0	1	0
	8	31	6	4	6	0	0	0	1	0	0	0	0
	9	5	15	1	3	2	0	5	1	1	0	0	2
	TOTAL	140	107	16	56	8	1	5	3	5	0	1	21
	1	70	23	1	4	0	10	0	0	0	0	0	0
	2	8	1	0	10	0	0	0	0	0	0	0	1
1987	3	2	0	1	0	0	0	0	0	0	0	0	0
	4	29	36	0	9	0	0	0	0	1	0	0	0
	5	3	4	0	2	0	0	0	0	0	0	0	1
	8	39	2	0	4	0	0	0	0	0	0	0	0
	9	17	2	2	1	0	0	2	0	0	0	0	0
	TOTAL	168	68	4	30	0	10	2	0	1	0	0	2
	1	78	45	6	9	0	1	0	1	0	0	0	2
	2	6	3	8	2	0	0	0	0	0	0	0	0
	3	9	4	37	5	2	0	1	0	3	0	0	2
	4	38	51	6	10	0	0	2	1	1	0	0	1
1995	5	5	11	9	0	1	0	0	1	0	0	0	2
	6	5	0	1	0	0	0	0	1	0	0	0	3
	7	1	1	15	0	1	0	0	0	0	0	1	4
	8	38	9	4	1	0	0	0	0	0	0	0	1
	9	13	22	3	21	7	0	6	0	0	0	0	0
	TOTAL	193	146	89	48	11	1	9	4	4	0	1	15
	1	73	22	15	2	1	3	0	1	1	0	0	1
	2	12	5	1	1	0	0	0	0	0	0	0	0
	3	10	3	17	1	4	6	1	0	1	4	0	0
	4	36	51	26	6	0	0	0	1	1	0	0	2
2001	5	8	7	8	0	1	0	0	0	1	0	0	0
	6	15	3	36	1	0	0	0	1	0	0	0	0
	7	3	5	54	0	2	0	0	0	0	0	0	0
	8	36	12	0	0	1	0	0	1	0	0	0	0
	9	8	8	1	2	2	0	0	0	0	0	0	0
	TOTAL	201	116	158	13	11	9	1	4	4	4	0	3

artefact. Inclusion of Beaufort sea state (BSS) as a covariate improved model fit, but the effect was opposite to that expected, with higher sea state leading to a wider strip width. We therefore chose to drop BSS as a covariate, and chose a model without adjustment terms so as not to fit the secondary peak in sightings. Effective strip half width and group size (*s*) were similar for both surveys, however inter block differences in *s* in 1995 precluded pooling *s* over blocks. Uncorrected abundance for the survey area is nearly twice as high in 2001 as in 1995.

The GLM estimates of humpback whale sighting rates showed little or a conflicting relation to sea state so it was dropped as an explanatory variable. Glare was dropped on the same grounds. Sighting rates were highest in cloud cover 26-50% and lowest in cloud cover 51-75%. This nonlinear relation to cloud cover was considered an artefact and the cloud cover categories were combined to 0-50% and 51-100%. Sighting rates were reduced to 94% (cv 5.6) in the latter category. Both the GLM and LL methods showed a significantly positive and similar rate of increase (Tables 8 and 9). Most of the increase in the survey area was attributable to increases in block 4 and blocks 6 and 7 off eastern Iceland. It appears that most of the increase in block 4 was attributable to increasing numbers in the eastern part of that block as well.

The proportion of visible animals that were missed by the primary observers was estimable for the 2001 survey only. The final conditional model had three variables, distance, glare and platform/observer position (primary and secondary) *g*(0) for the primary observer was estimated as 0.596. The *g*(0) corrected estimate of total abundance for the survey area in 2001 was 4,928 (95% CI 1,926 12,611).

Dolphins

Of a total of 437 sightings of dolphin groups in the 4 surveys, 400 (92%) were of white-beaked dolphins, 11 were of white-sided dolphins, 2 were of bottlenose dolphins and 24 were of unidentified species. We therefore combined all dolphin species into 1 category for analysis given that the overwhelming majority were white-beaked dolphins. Dolphins were sighted in all survey blocks and were the most numerous species group sighted after minke whales (Table 2, Fig. 2). They were most common off southwest Iceland (blocks 1 and 9), northeast Iceland (blocks 4 and 5) and southeast Iceland (blocks 8 and 9) in all years. They were nearly absent from the offshore blocks 3 and 7 in years when these blocks were well covered. Generally the distributional pattern was rather stable from survey to survey.

The size of dolphin groups ranged from 1 to 100 with a mean of 6.3 (95% CI 5.6 – 7.1) over all years. Mean group size adjusted for bias in the detectability of large vs small groups varied significantly between surveys, ranging from a low of 4.1 (95% CI 3.5 – 5.0) in 1995 to a high of 6.7 (95% CI 5.4 – 8.4) in 2001 (Table 6). (The mean group size of 7.7 recorded in 1987 is not directly comparable because it cannot be adjusted for size bias – see below).

Density was not estimable for the 1987 survey because perpendicular distances were not recorded for dolphins that year. Left truncation was used in the 2001 dataset but not for other years (Table 3). The hazard rate model provided the best fit for all years. The inclusion of observer identity as a covariate improved model fit for the 2001 dataset. Effective strip half width did not differ significantly between surveys (Table 6). Total uncorrected abundance ranged from 11,717 (95% CI 8,874 – 15,471) in 1995 to 18,706 (95% CI 13,912 – 25,152) in 2001 and did not vary significantly between years. Density varied significantly only in blocks 6 and 7, where density was 0 in some years (Table 6).

The GLM estimates of dolphin sighting rates were similar when skies were clear and with 26-50% cloud cover so these 2 categories were combined. Furthermore sea state did not affect sighting rates so it was dropped from the model. Cloud cover categories 51-57% and overcast reduced sighting rates to 80% (cv 1.5) and 70% (cv 0.6) respectively. Glare reduced sighting rates to 28% (cv 0.19). There was no significant trend in sighting rate as assessed by either method (Tables 8 and 9).

The proportion of visible animals that were missed by the primary observers was estima-

Table 3. Characteristics of perpendicular distance functions used in abundance estimates. LT – left truncation distance; RT – right truncation distance; *s* – group size estimation; Pooled – estimation pooled over all blocks; Block – estimation pooled by block; HZ – hazard rate; HN – half normal; COV – covariates included in model; BSS – Beaufort sea state.

YEAR	SPECIES	LT (m)	RT (m)	*s*	MODEL	COV
1986	BA	0	800	Pooled	HZ	none
1987	BA	75	900	Pooled	HZ	none
1995	BA	75	750	Pooled	HZ	none
2001	BA	100	600	Pooled	HZ	none
1986	LSP	0	1,000	Block	HZ	none
1995	LSP	0	1,400	Block	HZ	none
2001	LSP	100	1,000	Block	HZ	observer
1995	MN	0	1,700	Block	HN	BSS
2001	MN	0	2,000	Pooled	HN	none
1986	PP	100	500	Pooled	HZ	none
1995	PP	0	500	Pooled	HN	none

ble for the 2001 survey only. In this case the final model chosen explained the conditional probability of detection by the variables distance, group size and platform/observer position. For the primary observer *g*(0) was estimated at 0.591. The resulting *g*(0) corrected estimate of total abundance for the survey area in 2001 was 31,653 (95% CI 17,679 – 56,672).

Harbour porpoises

The distribution of harbour porpoise sightings varied greatly between surveys but their occurrence was mainly inshore (Fig. 2). In 1986 sightings were concentrated off central north Iceland in block 4. In 1987 they were more widely distributed off western, northern and southeastern Iceland. In 1995 sightings were concentrated off southwest Iceland. Few harbour porpoises were sighted in 2001 compared to earlier surveys.

Mean group size was 1.7 (95% CI 1.5 – 1.8) and did not vary significantly between survey years or blocks within survey years (Table 7). Correction for size bias in detection was not required and mean group sizes were used. Perpendicular distances were not recorded for this species in 1987, and only 13 sightings were made in 2001, so abundance could be estimated only for the 1986 and 1995 surveys. For the 1986 survey the data were truncated within 100 m of the trackline and a hazard rate model with no covariates provided the best fit, while the half normal model was best for the 1995 data (Table 3). Effective strip half width did not differ significantly between surveys. Total uncorrected abundance was 4,239 (95% CI 2,724–6,599) in 1986 and 5,156 (95% CI 3,027–8,739) in 1995.

The GLM estimates of harbour porpoise sighting rates were similar for clear skies and with 26-50% cloud cover so these 2 categories were combined. Sighting rates were reduced in Beaufort sea state 2 and 3 to 75% (cv 0.93) and to 20% (cv 0.17) respectively. Cloud cover categories 51-75% and overcast reduced sighting rates to 51% (cv 0.59) and 34% (cv 0.33) respectively. Glare reduced sighting rate to 80% (cv 1.2). There was a significant negative trend in sighting rate for harbour porpoises over the period of the surveys as assessed by both methodologies (Table 8 and 9). This was due primarily due to a sharp decline in sighting rate in the 2001 survey (Table 7).

Other species

Other species were seen in lower numbers and the numbers of sightings varied from survey to survey (Table 2). Fin (*B. physalus*), pilot (*Globicephala melas*), sperm (*Physeter macrocephalus*), and northern bottlenose (*Hyperoodon ampullatus*) whales occurred sporadically in the outer blocks of the survey area (Fig. 2). Sightings of blue whales (*B. musculus*) were confined almost exclusively to western Iceland, off the Snæfellsnes peninsula. Because of their low numbers and sporadic occurrence in the surveys, we did not attempt to estimate abundance or monitor trends in sighting rates for these species.

Table 4. Density (*D*) of minke whales from line transect analyses of Icelandic aerial surveys, 1986 to 2001. Coefficients of variation are in parentheses. *TOTAL* densities and totals in brackets are calculated excluding blocks 3, 6 and 7. *esw* - effective strip width; *s* - mean group size; *n/L* - encounter rate, whales per nautical mile.

YEAR	BLOCK	*esw* (m)		*s*		*n/L*		*D* (no/ nm^2)		95% CI
	1					0.0647	(0.19)	0.1315	(0.2327)	0.0821-0.2106
	2					0.0028	(0.88)	0.0026	(0.8899)	0.0004-0.0151
	3					0.0062	(0.53)	0.0147	(0.5530)	0.0041-0.0519
	4					0.0153	(0.25)	0.0426	(0.2868)	0.0243-0.0747
1986	5	413.9	(0.12)	1.056	(0.02)	0.0311	(0.41)	0.0735	(0.4357)	0.0290-0.1861
	6					0.0160	(0.42)	0.0346	(0.4475)	0.0143-0.0840
	7					0.0161	(0.51)	0.0380	(0.5342)	0.0120-0.1207
	8					0.0639	(0.16)	0.1446	(0.2062)	0.0942-0.2220
	9					0.0029	(0.85)	0.0069	(0.8603)	0.0014-0.0330
1986	*TOTAL*							0.0479	(0.2000)	0.0322-0.0713
1986	TOTAL							0.0406	(0.1879)	0.0279-0.0589
	1					0.0707	(0.17)	0.1434	(0.2167)	0.0906-0.2270
	2					0.0176	(0.55)	0.0357	(0.5671)	0.0112-0.1141
	3							0.0523	(0.7368)	0.0000-225.28
	4					0.0162	(0.23)	0.0329	(0.2619)	0.0195-0.0556
1987	5	507.8	(0.12)	1.112	(0.03)	0.0083	(0.74)	0.0169	(0.7525)	0.0035-0.0822
	6								(0.0000)	0.0000-0.0000
	7								(0.0000)	0.0000-0.0000
	8					0.1167	(0.28)	0.2366	(0.3117)	0.1210-0.4625
	9					0.0198	(0.41)	0.0402	(0.4368)	0.0165-0.0979
1987	*TOTAL*							0.0569	(0.1851)	0.0336-0.0931
	1					0.0782	(0.18)	0.2040	(0.2220)	0.1287-0.3235
	2					0.0262	(0.40)	0.0682	(0.4207)	0.0274-0.1701
	3					0.0067	(0.47)	0.0175	(0.4884)	0.0062-0.0491
	4					0.0205	(0.31)	0.0534	(0.3330)	0.0275-0.1037
1995	5	382.4	(0.11)	1.078	(0.03)	0.0091	(0.61)	0.0238	(0.6309)	0.0070-0.0810
	6					0.0119	(0.39)	0.0309	(0.4103)	0.0131-0.0731
	7					0.0025	(0.96)	0.0065	(0.9732)	0.0009-0.0449
	8					0.0714	(0.54)	0.1863	(0.5555)	0.0602-0.5768
	9					0.0180	(0.40)	0.0470	(0.4179)	0.0201-0.1095
1995	*TOTAL*							0.0695	(0.1984)	0.0471-0.1025
1995	TOTAL							0.0508	(0.1900)	0.0350-0.0737
	1					0.0667	(0.22)	0.2017	(0.2420)	0.1213-0.3355
	2					0.0250	(0.37)	0.0755	(0.3865)	0.0329-0.1734
	3					0.0116	(0.20)	0.0352	(0.2223)	0.0212-0.0584
	4					0.0253	(0.20)	0.0765	(0.2245)	0.0486-0.1204
2001	5	342.0	(0.08)	1.117	(0.03)	0.0162	(0.58)	0.0490	(0.5951)	0.0141-0.1703
	6					0.0420	(0.37)	0.1269	(0.3872)	0.0558-0.2890
	7					0.0042	(1.11)	0.0127	(1.1231)	0.0016-0.1018
	8					0.0747	(0.36)	0.2259	(0.3723)	0.1030-0.4952
	9					0.0113	(0.33)	0.0341	(0.3447)	0.0212-0.0550
2001	*TOTAL*							0.0688	(0.1643)	0.0498-0.0950
2001	TOTAL							0.0616	(0.1433)	0.0464-0.0816

Table 5. Abundance estimates of humpback whales from Icelandic aerial surveys, 1986-2001. *N'* – uncorrected abundance estimate; *g*(0) – proportion of visible whales on the trackline seen by primary platform observers; *N* – abundance estimate, corrected for *g*(0). Others as in Table 4.

YEAR	BLOCK	*esw* (m)		*s*		*n/L*		*D* (no nm^{-2})	*N'*		95% C.I.	*g*(0)		*N*		95% C.I.
1986	1					0.0000	(0)									
1986	2					0.0000	(0)									
1986	3			3.0	(0.72)	0.0145	(0.7)									
1986	4			1.0	(0)	0.0007	(1.173)									
1986	5					0.0000	(0)									
1986	6					0.0000	(0)									
1986	7			2.2	(0.347)	0.0208	(0.631)									
1986	8			2.0	(0)	0.0119	(0.606)									
1986	9			1.0	(0)	0.0013	(0.849)									
1986	*TOTAL*			1.5	(0.558)	0.0015	(0.457)									
1986	TOTAL			2.1	(0.616)	0.0060	(0.400)									
1987	1			2.0	(0)	0.0015	(0.982)									
1987	2					0.0000	(0)									
1987	3					0.0000	(0)									
1987	4					0.0000	(0)									
1987	5					0.0000	(0)									
1987	6															
1987	7															
1987	8					0.0000	(0)									
1987	9			1.5	(0.474)	0.0033	(0.612)									
1987	TOTAL			1.7	(0.347)	0.0012	(0.558)									
1995	1			1.8	(0.2722)	0.0065	(0.752)	0.009	42	(0.803)	9-187					
1995	2			1.4	(0.286)	0.0218	(0.995)	0.024	97	(1.038)	14-667					
1995	3			1.6	(0.085)	0.0578	(0.684)	0.074	1,037	(0.693)	254-4,227					
1995	4			1.0	(0.195)	0.0040	(1.081)	0.033	41	(1.101)	7-256					
1995	5	1158.7	0.073	1.1	(0.125)	0.0127	(0.627)	0.012	110	(0.643)	32-381					
1995	6			1.0	(0)	0.0024	(0.667)	0.002	7	(0.671)	2-26					
1995	7			1.1	(0.077)	0.0316	(0.373)	0.027	262	(0.388)	111-619					
1995	8			1.5	(0.333)	0.0096	(0.505)	0.011	13	(0.61)	13-143					
1995	9			1.0	(0)	0.0026	(1.137)	0.002	36	(1.139)	5-245					
1995	*TOTAL*			1.5	(0.14)	0.0071	(0.381)	0.007	369	(0.396)	170-800					
1995	TOTAL			1.6	(0.081)	0.0190	(0.392)	0.021	1,674	(0.445)	656-4,269					
2001	1					0.0159	(0.435)	0.017	76	(0.446)	30-191			128	(0.582)	40-410
2001	2					0.0000	(0)			(0)				0	(0)	
2001	3					0.0277	(0.437)	0.030	422	(0.449)	156-1,139			708	(0.584)	203-2,469
2001	4					0.0259	(0.505)	0.028	349	(0.515)	128-945			586	(0.636)	175-1,956
2001	5	1248.5	0.070	1.5	(0.072)	0.0216	(0.654)	0.234	253	(0.661)	65-978	0.596	(0.374)	424	(0.76)	92-1,955
2001	6					0.0933	(0.351)	0.101	364	(0.365)	170-783			611	(0.522)	211-1,765
2001	7					0.0926	(0.463)	0.100	1,444	(0.474)	520-4,012			2,423	(0.604)	687-8,548
2001	8					0.0000	(0)			(0)				0	(0)	
2001	9					0.0000	(0)			(0)				0	(0)	
2001	*TOTAL*			1.4	(0.084)	0.0117	(0.360)	0.013	707	(0.338)	347-1442			1,186	(0.504)	451-3,120
2001	TOTAL			1.5	(0.072)	0.0313	(0.257)	0.034	2,937	(0.273)	1,665-5,182			4,928	(0.463)	1,926-12,611

DISCUSSION

The abundance estimates provided here for humpback whales, dolphins and harbour porpoises are the first for these species in Icelandic coastal waters. However all the estimates are known to be biased, some highly so. When biased estimators are used to assess trends in abundance, an underlying assumption is that the biases remain constant from year to year. Unfortunately this assumption is untestable in most cases.

Double platform data are available to estimate the proportion of visible animals missed along the trackline (perception bias) only for the 2001 survey. It has already been used to provide unbiased estimates of minke whale abundance for the 1987 and 2001 surveys (Borchers *et al.* 2009). This bias proved to be substantial for both humpback whales and dolphins (with 4/10 of the animals being missed by primary observers on the trackline). Since the magnitude of the bias can be expected to vary between observers and the same observers were not used in every survey, the assumption that this bias is constant for every survey is questionable. This emphasizes the requirement for including some method of estimating this bias, such as a double platform setup, in the survey design.

While we have implicitly assumed that all whales are available at the surface to be seen, this is obviously not the case: some whales must have been diving and therefore invisible to observers when the survey plane flew over. We do not know what proportion of the time these species are at or near the surface and therefore visible to observers. This again results in a negative "availability bias" for the estimates. Information on diving behaviour, obtained from satellite or radio telemetry, or from detailed behavioural observations, can be used to correct this bias (*e.g.* Heide-Jørgensen and Acquarone 2002, Innes *et al.* 2002, Kingsley and Gauthier 2002). Unfortunately such data are available only for minke whales for Icelandic waters (Gunnlaugsson 1989). Another promising method of simultaneously assessing perception and availability biases in aerial surveys is the "circleback" procedure proposed by Hiby (1999). We would expect this bias to be substantial for species which spend little time at the surface such as harbour porpoises and minke whales, perhaps less so for dolphins and humpback whales. However, given that the surveys cover the same area at the same time of year, we would not expect this bias to vary between surveys.

There have been some changes to the survey protocol that may have affected sighting rates for the primary and secondary platforms. In the earlier surveys the cruise leader in the front (*i.e.* secondary platform) right seat recorded environmental and survey data on paper forms, and thus his efficiency as an observer was compromised. From 1995 most of these observations were recorded orally, so that the cruise leader became more efficient. For this reason, and because the sighting characteristics of the 2 platforms were quite different, we used primary platform observations only in calculating line transect abundance estimates

Minke whales

The trends in relative abundance produced here differ from the changes in the estimates of absolute abundance from the cue–counting surveys of 1987 and 2001. Borchers *et al.* (2009) provided absolute abundance estimates using cue–counting procedures for minke whales from the 1987 and 2001 surveys of 24,532 (95% CI 13,399–44,916) and 38,071 (95% CI 25,908–55,945) respectively. Although the 1995 survey was conducted in cue–counting mode, double platform data were not collected and previous cue–counting estimates from this dataset (NAMMCO 1998) are now considered to be unreliable because of possible uncorrected biases (NAMMCO 2002). The 1987 estimate incorporated corrections for perception bias and random error in radial distance estimation, which introduces a positive bias in cue–counting estimates if it is substantial (Hiby *et al.* 1989, Borchers *et al.* 2009). It should be noted however that these corrections are based on very limited double platform data for the 1987 survey. These corrections were not found to be necessary in the 2001 estimation. The change in estimates of absolute abundance between 1987 and 2001 implies a population growth rate of about 3% over the period for the area covered in 1987. This does not differ from the trend in relative abundance over the 4 surveys conducted between 1986 and 2001 (Tables 8 and 9).

Table 6. Abundance estimates of *Lagenorhynchus* spp. dolphins, mainly L. *albirostris*, from Icelandic aerial surveys, 1986-2001. Symbols as in Tables 4 and 5.

YEAR	BLOCK	*esw* (m)		*s*		*n/L*		*D* (no nm^{-2})	*N'*		95% C.I.	*g(0)*		*N*		95% C.I.
	1			6.2	(0.225)	0.0611	(0.122)	0.722	2,953	(0.339)	1,501-5,810					
	2			1	(0)	0.0053	(2.515)	0.012	49	(0.903)	10-236					
	3			3.5	(0.143)	0.0058	(1.306)	0.049	614	(0.619)	159-2,364					
	4			3.7	(0.146)	0.0336	(0.263)	0.284	3,418	(0.389)	1,602-7,294					
1986	5	380.8	(0.117)	6.2	(0.253)	0.0329	(0.296)	0.537	5,106	(0.435)	2,150-12,125					
	6			2.4	(0.12)	0.0159	(0.425)	0.089	337	(0.308)	184-615					
	7					0					0-0					
	8			3.3	(0.435)	0.0089	(2.294)	0.077	282	(1.153)	45-1,771					
	9			5	(0.205)	0.0171	(0.365)	0.221	3,724	(0.395)	1,718-8,073					
	TOTAL			4.7	(0.10)	0.0261	(0.154)	0.309	15,533	(0.222)	10,058-23,989					
	TOTAL			4.3	(0.09)	0.0189	(0.155)	0.217	16,484	(0.214)	10,838-25,070					
	1			7.3	(0.2)	0.0347	(0.241)									
	2			3	(0)	0.0025	(3.101)									
	3															
	4			8.7	(0.318)	0.0288	(0.326)									
1987	5			5.5	(0.218)	0.0142	(1.069)									
	6															
	7															
	8			2.5	(0.282)	0.0079	(1.896)									
	9			6.5	(0.108)	0.0033	(3.041)									
	TOTAL			7.7	(0.199)	0.0144	(0.357)									
	1			5	(0.139)	0.0546	(0.22)	0.604	2,670	(0.281)	1,530-4,660					
	2			2	(0)	0.0117	(0.603)	0.052	206	(0.612)	57-736					
	3			4	(0.306)	0.0066	(0)	0.058	821	(0.323)	413-1,633					
	4			3.6	(0.151)	0.0386	(0.357)	0.304	3,761	(0.402)	1,724-8,206					
1995	5	418.8	(0.105)	4.8	(0.185)	0.0158	(0.54)	0.166	1,576	(0.58)	512-4,850					
	6															
	7			2	(0)	0.0026	(0.956)	0.012	112	(0.961)	16-756					
	8			2.7	(0.134)	0.0117	(1.913)	0.069	258	(1.92)	17-3,977					
	9			2.8	(0.217)	0.0217	(0.427)	0.133	2,314	(0.491)	896-5,971					
	TOTAL			4.2	(0.096)	0.0260	(0.201)	0.185	11,400	(0.219)	7,443-17,460					
	TOTAL			4.1	(0.093)	0.0185	(0.185)	0.149	11,717	(0.216)	7,684-17,864					
	1			3.6	(0.23)	0.0228	(0.358)	0.194	856	(0.435)	363-2,018			1,448	(0.476)	571-3,675
	2			3.3	(0.262)	0.0134	(0.451)	0.103	410	(0.53)	140-1,201			694	(0.564)	223-2,161
	3			3.3	(0.264)	0.0055	(0.465)	0.044	614	(0.542)	195-1,936			1,039	(0.575)	315-3,422
	4			6.1	(0.105)	0.0429	(0.327)	0.623	7,721	(0.355)	3,818-15,615			13,064	(0.404)	5,899-28,932
2001	5	391.6	(0.086)	6.1	(0.189)	0.0081	(0.53)	0.118	1,270	(0.57)	389-4,144	0.591	(0.194)	2,149	(0.602)	622-7,421
	6			7.3	(0.24)	0.0082	(0.501)	0.143	515	(0.563)	167-1,587			871	(0.595)	267-2,839
	7			6	(0.441)	0.0058	(0.744)	0.082	1,180	(0.869)	222-6,283			1,997	(0.89)	364-10,958
	8			16	(0.363)	0.0214	(0.37)	0.811	3,023	(0.526)	1,078-8,478			5,115	(0.56)	1,719-15,221
	9			6	(0.353)	0.0121	(0.618)	0.171	3,118	(0.718)	818-11,882			5,276	(0.743)	1,333-20,890
	TOTAL			6.8	(0.121)	0.0201	(0.216)	0.261	16,602		10,271-26,835			27,746	(0.300)	15,497-49,677
	TOTAL			6.7	(0.112)	0.0148	(0.192)	0.219	18,706	(0.229)	11,936-29,317			31,653	(0.300)	17,679-56,672

The slightly positive trend in relative abundance seen in the survey area as a whole is due primarily to the increases in blocks 1 and 4, both of which have relatively high densities of minke whales (Table 4). The increase in relative abundance may be at least partially a result of the cessation of minke whale hunting in Iceland in 1985. The average catch was 185 minke whales per year (1961-1985) in Icelandic coastal waters (NAMMCO 1999). Catching activities were concentrated in the coastal waters of northern Iceland (block 4), where the increase in density has been most pronounced, and northwestern Iceland (block 2) where survey coverage has been poor. However, given the marginal magnitude of the increase, particularly in sighting rates, it may simply be the result of a slight increase in sighting efficiency over the period.

The general pattern of distribution of minke whales around Iceland appears to be remarkably consistent at the time of year when the surveys were conducted (June/July). Outside of the survey area Pike *et al.* (2009) found little change in distribution and abundance of minke whales in offshore areas of Iceland, East Greenland and the Faroes Islands that were surveyed by ship in 1987, 1989, 1995 and 2001. Similarly Skaug *et al.* (2004) found no significant change in minke whale abundance in the Northeast and parts of the Central Atlantic over the same period, but did note some changes in distribution.

Humpback whales

The general distributional pattern of humpback whales was similar over all surveys, with most sightings being made off western and especially eastern Iceland, and some scattered sightings off the north coast. However, the far northeast and northwest of the survey area, which appear to have high densities of humpback whales in some years, were not well covered in 1986 (northwest) and 2001 (both). The 1987 survey did not cover the offshore western block 3 or any of the eastern blocks, and therefore did not cover the main areas of humpback whale distribution around Iceland: as a result only 4 primary sightings were made that year. This general pattern of distribution is similar to that observed in NASS and other ship surveys carried out between

1987 and 2003 (Pike *et al.* 2005), but in more recent surveys, more whales have been seen to the southwest and north of the country, outside of the aerial survey area. Thus there appears to be 2 summering areas for humpback whales in Icelandic waters, separated by a rather clear gap in distribution. It is not known to what extent these represent separate summering stocks.

There has been a substantial and significant increase in sighting rates and density over the course of the survey series (Tables 4, 8 and 9). The most substantial increases in terms of numbers have occurred in blocks 6 and 7 off eastern Iceland. Numbers have also increased off northern Iceland but it appears that most of this increase has occurred at the eastern extreme of the blocks (Fig. 2). For the entire survey, the increase in encounter rate implies an annual rate of population increase of 0.12, or 0.17 considering only the blocks covered in 1987 (Table 8), both of which are close to but not significantly ($P>0.05$) greater than the maximum rate of natural increase considered plausible for this species of 0.126 (Clapham *et al.* 2001). Similarly high apparent rates of increase have been observed for this species in the Antarctic (Matsuoka *et al.* (MS) 2004).

Additional evidence from other sources also suggests that the humpback whale feeding stock around Iceland has been increasing rapidly. Sigurjónsson and Gunnlaugsson (1990) used an index based on systematic sightings records from whaling vessels kept between 1970 and 1988 to derive an annual rate of increase of 0.116 for humpback whales off western Iceland, nearly identical to the rate of increase in relative abundance derived from the aerial surveys. Sightings of humpback whales were absent or quite rare at the beginning of this period. Sighting rates of humpback whales have also increased in NASS and other ship surveys conducted around Iceland between 1987 and 2003 (Pike *et al.* 2005).

Additional estimates of abundance are available from the 1987, 1995 and 2001 NASS ship surveys, which covered similar areas around Iceland and the Faroes (see Víkingsson *et al.*. 2009). Gunnlaugsson and Sigurjónsson (1990) provided an abundance estimate of 1,816 (cv 0.18) from NASS-87, for an area that included the aerial survey block. Paxton *et al.* (2009) provided estimates from spatial analysis of the 1995 and 2001 surveys, where the ship and aerial data were combined, of 10,521 (95% CI: 3,716–24,636) in 1995 and 14,662 (9,441–28,879) in 2001. In all 3 surveys the bulk of the estimates resulted from sightings within the aerial survey block. While these estimates are subject to perception and availability biases, these biases are certainly of lesser magnitude from a slow moving ship as opposed to a fast moving plane. Thus the NASS ship surveys confirm the positive trend in humpback whale abundance around Iceland seen in the aerial surveys.

Our best estimate of humpback whale abundance comes from the 2001 survey, corrected for bias due to visible whales missed by observers (Table 5). However this estimate is likely to be negatively biased due to whales that were diving when the plane passed over (availability bias). We do not have data on the diving patterns of humpback whales in Icelandic waters, so we cannot correct for this bias at present. In eastern Australian waters, the availability bias for aerial surveys conducted using a similar protocol was estimated to be between 0.25 and 0.41, thereby substantially increasing the uncorrected estimate (Bannister and Hedley 2001)..

Modern whaling began in Icelandic waters in 1868 and continued in its first phase until a total ban on whaling was imposed by the Icelandic parliament in1915, by which time stocks of blue, fin and humpback whales had been reduced to the point where whaling was barely profitable. In this period, about 3,000 humpback whales were estimated taken, mainly from land stations on the east and west coasts (Sigurjónsson and Gunnlaugsson 1990). The bulk of these were taken off eastern Iceland, where humpbacks are most abundant in recent surveys (Sigurjónsson and Gunnlaugsson 2006). Most of the catch around Iceland was taken over a period of a few years (Mitchell and Reeves 1983). Prior to this considerable whaling had occurred on possible breeding grounds (Mitchell and Reeves 1983), and unknown, but presumably small numbers of humpbacks were taken in earlier centuries in Icelandic coastal waters. Whaling continued for humpbacks in other areas of the North Atlantic, but not in Iceland where only 7 have been taken

Table 7. Abundance estimates of harbour porpoise, from Icelandic aerial surveys, 1986-2001. Symbols as in Tables 4 and 5.											
YEAR	**BLOCK**	***esw***		***s***		***n/L***		***D***	***N'***		**95% CI**
1986	1			2.0		0.0014	(0.834)	0.009	38	(0.889)	13-107
1986	2			1.5	(0.192)	0.0107	(0.506)	0.051	211	(0.819)	76-585
1986	3					0.0000		0.000	0		
1986	4			1.9	(0.091)	0.0259	(0.255)	0.216	2,600	(0.416)	0
1986	5	190.0	(0.161)	2.0		0.0027	(0.958)	0.023	222	(0.992)	66-748
1986	6			1.8	(0.274)	0.0071	(0.47)	0.051	193	(0.619)	59-625
1986	7					0.0000		0.000	0		0
1986	8			1.2	(0.143)	0.0178	(0.636)	0.163	599	(0.687)	159-2,255
1986	9			1.7	(0.2)	0.0040	(0.522)	0.022	377	(0.722)	155-918
1986	*TOTAL*			1.8	(0.073)	0.0103	(0.196)	0.081	4,047	(0.354)	2,578-6,352
1986	TOTAL			1.8	(0.07)	0.0072	(0.188)	0.056	4,239	(0.347)	2,724-6,599
1987	1			2.0	(0.355)	0.0060	(0.786)				
1987	2			1.4	(0.158)	0.0251	(0.352)				
1987	3					0.0000					
1987	4			1.8	(0.156)	0.0072	(0.357)				
1987	5			1.5	(0.333)	0.0071	(0.575)				
1987	6										
1987	7										
1987	8			1.3	(0.2)	0.0157	(0.736)				
1987	9			1.0		0.0016	(0.873)				
1987	TOTAL			1.6	(0.095)	0.0072	(0.220)				
1995	1			1.6	(0.156)	0.0118	(0.371)	0.059	259	(0.581)	121-555
1995	2			3.0	(0)	0.0087	(0.452)	0.030	121	(0.683)	48-306
1995	3			1.2	(0.167)	0.0083	(0.965)	0.058	809	(0.982)	238-2,754
1995	4			1.4	(0.117)	0.0080	(0.26)	0.056	691	(0.31)	463-1,031
1995	5	235.3	(0.162)			0.0000		0.000	0		0
1995	6					0.0000		0.000	0		0
1995	7					0.0000		0.000	0		0
1995	8			2.0		0.0024	(1.075)	0.000	0		0
1995	9			1.9	(0.113)	0.0270	(0.465)	0.188	3,276	(0.446)	1,860-5,771
1995	*TOTAL*			1.7	(0.074)	0.0129	(0.333)	0.085	4,347	(0.446)	2,471-7,648
1995	TOTAL			1.7	(0.071)	0.0099	(0.318)	0.066	5,156	(0.418)	3,027-8,783
2001	1			2.0	(0.5)	0.0024	(0.644)				
2001	2			1.0		0.0033	(0.877)				
2001	3			1.0		0.0018	(0.942)				
2001	4			1.7	(0.297)	0.0060	(0.461)				
2001	5					0.0000					
2001	6			2.0		0.0027	(0.772)				
2001	7					0.0000					
2001	8					0.0000					
2001	9			1.5	(0.333)	0.0030	(0.669)				
2001	*TOTAL*			1.6	(0.189)	0.0029	(0.340)				
2001	TOTAL			1.6	(0.165)	0.0022	(0.307)				

since 1915. The species was protected in these waters after 1954. Sigurjónsson and Gunnlaugsson (1990) concluded that the feeding stock around Iceland must have been reduced to a low level during the first phase of whaling in Icelandic waters. Given that a catch of about 3,000 animals apparently severely reduced humpback whale abundance around Iceland, and that the present uncorrected abundance estimate from this survey is about 5,000 animals and the actual abundance off Iceland is much higher (Paxton *et al.* 2009), it seems likely that the feeding stock around Iceland has recovered from overexploitation and has certainly reached and is probably above its historical abundance level in this area.

The Years of the North Atlantic Humpback (YoNAH) study was a large scale mark recapture study conducted from 1992-1993 (Stevick *et al.* 2003). The resultant abundance estimate for the entire North Atlantic basin was 11,570 (95% CI 10,290-13,390). Estimates from individual feeding areas are not yet available, however, so we cannot compare our results directly to those from YoNAH. However, YoNAH sampling effort for the Icelandic feeding area was concentrated in western Icelandic waters. No sampling effort was applied to eastern Iceland in 1992, and effort there in 1993 was quite limited. If large numbers of humpback whales occurred off eastern Iceland in 1992 and 1993, as they did in 1995 and in 2001, the estimate resulting from YoNAH may be biased.

Dolphins

Species identity was often uncertain for the dolphins. However in all surveys the great majority of dolphin sightings have been identified as white-beaked dolphins, with white sided and common dolphins comprising less than 3% of the total. In all years, a relatively small proportion (4-11%) of the dolphin sightings were not identified to species. Dolphins were not the target species of the surveys, and the observers were not necessarily expert at distinguishing dolphin species from the air. Moreover, it is difficult to distinguish these species at the altitude and speed flown, and little survey effort was expended in confirming species identifications of dolphins. Ancillary data, including species composition in strandings and by-catch as well as opportunistic sightings data, indicate that the white-beaked dolphin is the overwhelmingly dominant dolphin species in Icelandic coastal waters (Víkingsson unpublished data). Thus, we are confident that most of the sightings were of white-beaked dolphins, with a small proportion of white-sided dolphins and possibly bottlenose dolphins as well.

The distribution of dolphins was remarkably consistent over the surveys, with sightings concentrated in the southwest, northeast and southeast of Iceland, in relatively coastal waters. Sightings of *Lagenorhynchus* spp. dolphins have also been common on the NASS ship surveys carried out in 1987, 1989, 1995 and 2001, and also in other surveys with cetacean sighting effort conducted in the 1980's and 1990's (Sigurjónsson *et al*. 1989, 1991, Víkingsson *et al*. (MS) 2002). These surveys indicate the same pattern of distribution in coastal waters as the aerial surveys, but a continuous distribution of sightings extending far offshore, particularly in Denmark Strait between Iceland and Greenland. The deep waters to the north and east of the survey area have produced few dolphin sightings. As with the aerial surveys, species identification and group size estimation has been problematic on the ship surveys. Nevertheless it appears that the distribution of *Lagenorhynchus* spp. dolphins is continuous to the offshore in this area, so the estimates reported here likely do not apply to a stock unit. No other information on the stock structure of white-beaked or white-sided dolphins in this area is available.

Northridge *et al.* (1997) reviewed the distribution of white-beaked and white-sided dolphins throughout the North Atlantic. White-beaked dolphins were found to be more common than white-sided dolphins in European waters, around Iceland, Greenland and off eastern Canada. White-sided dolphins were more common around the Faroes, off the United States east coast and in areas farther to the south, and had a more oceanic distribution than white-beaked dolphins in most areas. Thus the dominance of white-beaked dolphins in Icelandic shelf waters is not surprising. However the distributions of the 2 species overlapped in many areas.

Density and sighting rates did not vary significantly for the total survey area or, for the most

Table 8. Rate of increase/decrease in the survey area assessed using log-linear regression (LL method). "Total87" includes only those blocks covered in 1987. *R* – annual rate of increase; PAR – parameter used in determining *R; D* – Density; *n/L* – encounter rate. Species as in Table 2.

SPECIES	AREA	*PAR*	*R*	cv	95% CI
BA	Total87	D	0.02	0.656	(-0.01, 0.05)
BA	Total	D	0.03	0.560	(0.00, 0.06)
MN	Total87	n/L	0.17	0.228	(0.10, 0.25)
MN	Total	n/L	0.12	0.293	(0.05, 0.19)
LSP	Total87	n/L	0.01	2.980	(-0.03, 0.04)
LSP	Total	n/L	-0.02	1.017	(-0.05, 0.02)
PP	Total87	n/L	-0.06	0.368	(-0.10, -0.02)
PP	Total	n/L	-0.07	0.312	(-0.11, -0.03)

Table 9. Rate of increase/decrease in the survey area assessed using the GLM method. *R* – annual rate of increase. Species as in Table 2.

SPECIES	*R*	cv	95% CI
BA	0.015	0.74	(-0.007, 0.031)
MN	0.108	0.25	(0.063, 0.155)
LSP	0.016	1.27	(-0.016, 0.051)
PP	-0.048	0.45	(-0.801, -0.011)

part, for individual blocks (Fig. 4, Tables 6, 8 and 9). Density was lowest in 1995 and highest in 2001. However, this difference is due mainly to apparent differences in mean group size between 1995 and 2001. Mean group size, corrected for bias due to sightability, was lower in 1995 than in all other years and significantly lower than in 2001 (Table 6). In fact mean encounter rate was actually lower in 2001 than in 1995. Estimation of group size can be problematic for dolphins because they occur in tightly packed schools and are very active, often leaping out of the water and changing direction quickly. The problem is exacerbated for more distant sightings. Different observers may be differentially biased in their estimation of group size. Periodic closure on dolphin groups to confirm group size and calibrate group size estimates would be required to reduce this problem. Although lacking confirmatory data, we consider it unlikely that mean dolphin group size would show year to year variation. If estimates of dolphin abundance are desired from future surveys, better methods of determining group size, or at least calibrating observer estimates of group size, should be investigated.

There is a small traditional dolphin hunt in Iceland, and they are taken as by-catch in some fisheries. The level of by-catch has not yet been estimated but appears to be considerably lower than that for harbour porpoises in the same area (Víkingsson *et al.* 2004). White-sided and common dolphins are taken in drive hunts in the Faroes, but takes of white-beaked dolphins are very rare there (Bloch 1998). Thus there is little reason to expect anthropogenic changes in the dolphin population size in the area.

The best available estimate of abundance for the area is that for 2001, corrected for bias caused by visible animals being missed by observers (Table 6). However this estimate may be negatively biased because some animals are presumably underwater and not visible when the plane passes over. We would expect this bias to be small, however virtually no information is available on the diving habits of this species. Satellite tracking of 1 white-sided dolphin indicated that most dives by this similar species were of less than 1 minute in duration (Mate and Stafford 1994)

Little information is available on the density of *Lagenorhynchus* spp. dolphins in other areas of the North Atlantic. The Small Cetacean abundance in the North Sea (SCANS) survey covered the North Sea, southern Norwegian Sea, Celtic Sea and the English Channel in 1994 (Hammond *et al.* 2002). Sightings of *Lagenorhynchus* spp. dolphins, mainly *L. albirostris*, were concentrated in the western North Sea. The highest density realized in any block was 0.319 animals nm^{-2}, but most areas had far lower densities than this. This is roughly comparable to the overall density of dolphins in Icelandic waters, but the density in some blocks was more than twice this. It therefore appears that the density of white-beaked dolphins is relatively high around Iceland.

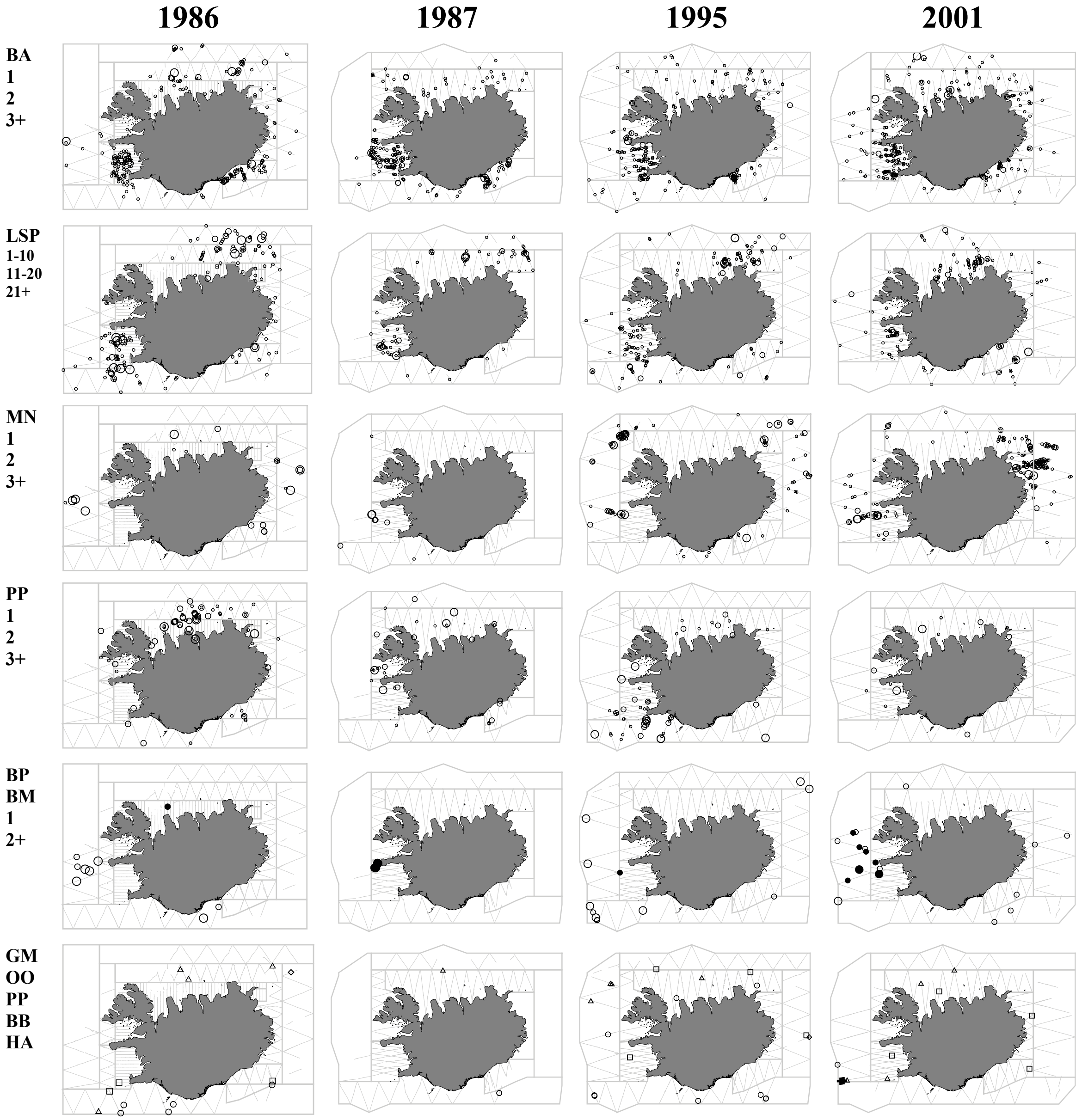

__Fig. 2.__ Sightings of cetacean groups around Iceland during NASS aerial surveys, 1986-2001. Only on-effort sightings by the primary observers at Beaufort sea state of 4 or less are shown. The numbers on the left identify the group sizes represented by the smallest to largest symbols. Species: BA – minke whales; LSP- Lagenorhynchus spp. dolphins, mainly L. albirostris; MN – humpback whale; PP – harbour porpoise; BP – fin whale; BM – blue whale (solid symbols); GM – long-finned pilot whale (circle); OO – killer whale (square); PM – sperm whale (triangle); BB – sei whale (cross); HA – northern bottlenose whale (diamond).

Sigurjónsson and Víkingsson (1997) calculated an approximate total abundance of dolphins from the NASS-87 ship survey of 76,600 for Icelandic and adjacent waters. The area covered by this survey included the entire aerial survey block as well as areas farther offshore. The estimate was calculated using an assumed *esw* of 1,482 m, and no estimate of variance was derived. Nevertheless this estimate seems quite consistent with that from the aerial surveys, since it is derived from a larger area and is likely not subject to the same degrees of perception and availability biases as the aerial survey. However, the estimate may be severely compromised because of responsive movement by the dolphins. Hammond *et al.* (2002) found that white-beaked dolphins were attracted to the survey vessels, as did Cañadas *et al.* (2009) for common dolphins. This can lead to substantial positive bias in vessel surveys if no corrections are made. On the other hand, the choice of an unrealistically high *esw* may have biased the estimate downward (Sigurjónsson and Víkingsson 1997). Further work is planned to refine abundance estimates for dolphins from the NASS ship surveys.

Little is known about the diet of white-beaked dolphins in Icelandic waters. In European waters white-beaked dolphins appear to feed mainly on gadoid fish, including Atlantic cod (*Gadus morhua*) (Kinze *et al.* 1997). Preliminary results from an ongoing study in Icelandic waters show a diet consisting predominantly of gadoid fish in this area as well (Víkingsson and Ólafsdóttir 2004). Given the importance of these species to commercial fisheries, and the relatively high density of white-beaked dolphins in Icelandic waters, the competitive interaction between this species and commercial fisheries is a potential concern.

Harbour porpoises

The distribution of harbour porpoises around Iceland has shown substantial variation, with areas of highest density occurring in a different area in each survey (Fig. 2). The diet of harbour porpoises in Icelandic waters is dominated by capelin (*Mallotus villosus*), at least in the late winter and early spring when most sampling has been done (Víkingsson *et al.* 2003). Therefore one might expect the distribution of harbour porpoises to be related to the distribution of capelin in this area. Capelin spawn of southern Iceland in the late winter, and the larvae drift in a clockwise direction around Iceland to the main feeding grounds off northern Iceland (Vilhjálmsson 1994). We would therefore expect harbour porpoises to occur off northern Iceland during the summer months. This was indeed the case in 1986, but in 1995 most animals were seen southwest of Iceland, where capelin is unlikely to occur in large numbers in mid summer. Unfortunately virtually no information is available on the diet of harbour porpoises in mid summer in this area, but there are indications from early summer and autumn that harbour porpoises shift towards sandeel (*Ammodytidae* sp.) as a main food item at this time of the year (Víkingsson *et al.* 2003). Clearly, the distribution of harbour porpoises shows considerable annual and probably seasonal variation in this area, and this may affect the estimates of abundance.

There was a significant negative trend in average sighting rate for the survey area of -0.07 (0.06 considering only blocks covered in 1987) and -0.049 from the GLM analysis annually over the period 1986-2001. Most of this decrease was due to substantially lower numbers seen in the 2001 survey (Table 7). Taken at face value, this indicates that the abundance of harbour porpoises had decreased to less than 1/2 of its 1986 level by 2001. Although there is no directed take of harbour porpoises in Iceland, there is an as yet undetermined level of by-catch in gill net fisheries (Víkingsson *et al.* 2004). The effort of these fisheries has however decreased considerably in recent decades. Nevertheless, given that both the stock size and the level of removals are unknown, we cannot exclude the possibility that the population size of harbour porpoises around Iceland has decreased in recent years due to removals above sustainable levels.

Nevertheless there are some reasons to be sceptical about this conclusion. Harbour porpoises are probably the most difficult cetacean to see from an airplane or ship, because they are small and have an inconspicuous appearance and behaviour pattern. Aerial surveys for harbour porpoises require specialised methods (*e.g.* Hammond *et al.* 2003, Laake *et al.* 1997) that were not applied in these surveys. For example, a dedicated harbour porpoise survey would likely have been flown at lower altitude, and effort would have been restricted to even better weather conditions than on these surveys. Also, the observers were focussed on minke whales and probably had varying abilities to spot harbour porpoises. It may be that the observers used in the later surveys, were simply ineffective observers for this species. In this respect it is noteworthy that there was no overlap of observers between the 2001 and the earlier surveys.

Uncorrected point estimates from the 1986 and 1995 surveys were not significantly different from one another (Table 7). These are certainly underestimates because they are not corrected for perception or availability biases, both of which can be substantial for this species. Laake *et al.* (1997) estimated a $g(0)$, incorporating both sources of bias, of 0.292 (SE 0.107) for aerial surveys of harbour porpoise. The estimate for observers inexperienced in sighting harbour porpoises, as were used in these surveys, was 0.079 (SE 0.046), implying that our estimates might be more than an order of magnitude too low. Clearly, obtaining accurate estimates of harbour porpoise abundance in Icelandic waters will require both modification of the survey protocol and specialised training for observers. In addition, special methods would have to be employed to estimate both the perception and availability components of $g(0)$.

Given these caveats, the aerial survey series does provide the first description of distribution and relative abundance in Icelandic waters for this species. Harbour porpoises are probably the cetacean species subject to the highest levels of incidental take in Icelandic waters in recent years. The apparent decline in relative abundance between 1986 and 2001 is cause for concern and should be investigated further. In order to estimate the sustainability of the ongoing by-catch, estimates of the present by-catch of harbour porpoises are urgently required as well as absolute abundance estimates for the area.

Other species

Most of the other species sighted have an offshore, deep water distribution and are therefore not commonly sighted in the shelf waters around Iceland. Most sightings of fin whales were at the outer edge of the aerial survey area (Fig. 2), but this species is the most common one sighted in ship surveys in the Icelandic offshore (Víkingsson *et al.* 2009). Similarly blue, long-finned pilot, killer, sperm, sei (*B. borealis*) and northern bottlenose whales have been far more commonly sighted in the ship surveys. Blue whales recurrently appear in the deep waters off Snæfellsnes in western Iceland in the summer months, and several were sighted in this area in the 1987 and 2001 surveys. Killer whales also occur in inshore waters in the fall and winter but do not appear to be common there in the summer months (Sigurjónsson *et al.* 1988). In no case were sightings of these species numerous enough to warrant any further analysis.

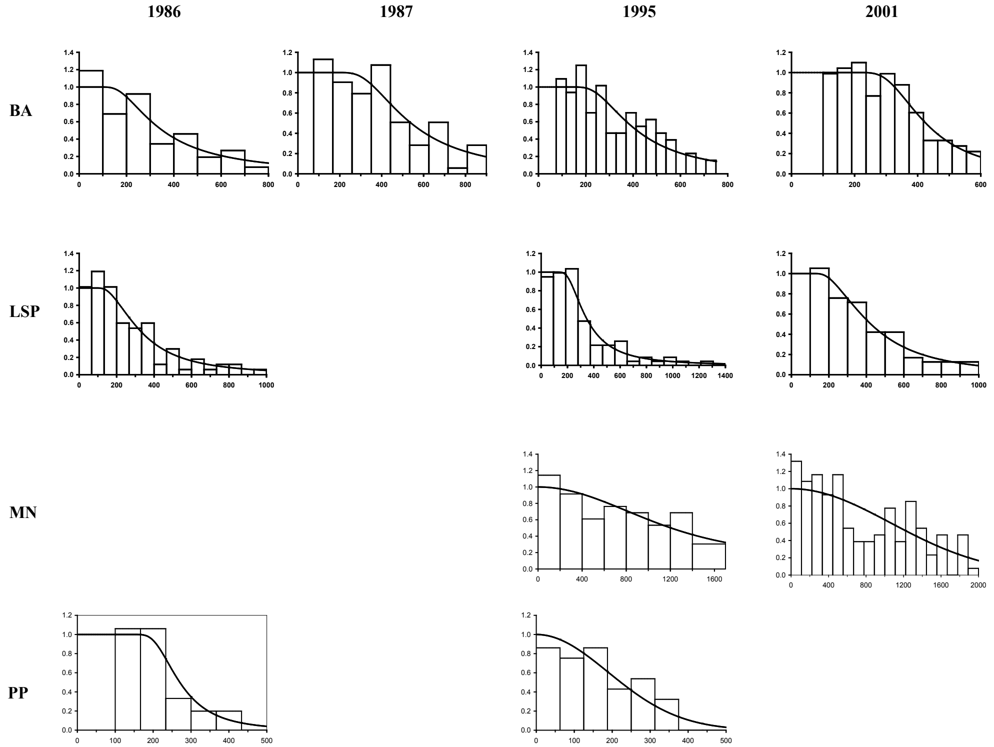

Fig. 3. *Perpendicular distance functions for minke whales (BA), Lagenorhynchus spp. dolphins (LSP), humpback whales (MN) and harbour porpoises (PP). The line shows the fit of the model to the data.*

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