

Estimates of the abundance of minke whales (*Balaenoptera acutorostrata*) from Faroese and Icelandic NASS shipboard surveys.

Daniel G. Pike¹, Thorvaldur Gunnlaugsson², Gísli A. Víkingsson², Geneviève Desportes^{3,4} and Dorete Bloch⁴

¹1210 Ski Club Road, North Bay, Ontario, P1B 8E5, Canada

²Marine Research Institute, P.O. Box 1390, IS 121 Reykjavík, Iceland

³GDnatur, Stejlestræde 9, DK-5300 Kerteminde, Denmark

⁴Faroese Museum of Natural History, Fútalág 40, FR 100 Tórshavn, Faroe Islands

ABSTRACT

North Atlantic Sightings Surveys for cetaceans were carried out Northeast and Central Atlantic in 1987, 1989, 1995 and 2001. Here we provide estimates of density and abundance for minke whales from the Faroese and Icelandic ship surveys. The estimates are not corrected for availability or perception biases. Double platform data collected in 2001 indicates that perception bias is likely considerable for this species. However comparison of corrected estimates of density from aerial surveys with a ship survey estimate from the same area suggests that ship surveys can be nearly unbiased under optimal survey conditions with high searching effort. There were some regional changes in density over the period but no overall changes in density and abundance. Given the recent catch history for minke whales in this area, we would not expect to see changes in abundance due to exploitation that would be detectable with these surveys.

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INTRODUCTION

Periodic synoptic cetacean sightings surveys have been conducted in the Eastern and Central North Atlantic (NASS) in 2001, 1995, 1989 and 1987 (Borchers *et al.* 2009, Pike *et al.* 2009, Víkingsson *et al.* 2009, Øien 2009). The surveys have been conducted from late June to early August, except in 1989 when the survey started and ended about 2 weeks later. The target species of the surveys have varied among the participating countries and over survey years. For Iceland, the fin whale (*Balaenoptera physalus*) has been the target species of all shipboard surveys (Víkingsson *et al.* 2009), while minke whales (*Balaenoptera acutorostrata*) have been the target of the coastal aerial surveys (Borchers *et al.* 2009, Pike *et al.* 2009). For the Faroes,

the target species have been pilot (*Globicephala melas*), northern bottlenose (*Hyperoodon ampullatus*) and large baleen whales for the first 3 surveys, and minke and fin whales for the 2001 survey. While the methods employed have been harmonized among participating countries, they are also optimized for the target species.

The minke whale is among the most difficult whales to count effectively. It is relatively small and cryptic, occurs singly or in very small groups, and surfaces for only very short periods of time. The blow is generally not visible. Thus specialized methods must be employed to produce unbiased estimates of abundance for this species, usually involving the use of

independent observer platforms and a form of cue-counting (Schweder 1999). Estimates derived from standard line transect methodology (Buckland *et al.* 2001) will be negatively biased because of whales missed by observers (perception bias) and whales that were under water when the vessel passed thus invisible (availability bias). For shipboard surveys of minke whales, these biases can lead to underestimates of 50% or more of absolute abundance (Schweder 1999, Schweder *et al.* 1997, Skaug *et al.* 2004). Independent observer data are available only from the 1995 Faroese survey and from the 2001 survey, so correction for perception bias is not possible for the other surveys.

Nevertheless even biased estimates can be used to describe trends in relative abundance, if the bias is assumed to be constant over the period. In addition, estimates that are known to be negatively biased can be used as minimum estimates for management purposes when no other estimates are available.

Estimates of minke whale abundance from some of these surveys have been presented. Gunnlaugsson and Sigurjónsson (1990) provided estimates for several whale species from the 1987 Icelandic and Faroese surveys. However these estimates used non-standard methods and the minke whale estimate was corrected for perception and availability biases, and is therefore not directly comparable to other estimates. A partial estimate from the 1989 Icelandic survey was provided by Gunnlaugsson and Sigurjónsson (1991), for only the southern areas covered by that survey, but again this used non-standard methods. An estimate from the Icelandic shipboard component of the 1995 NASS was reported in the Report of the NAMMCO Scientific Committee for 1997 (NAMMCO 1998), but the estimate was apparently calculated at the meeting and no details were provided.

The North Atlantic Marine Mammal Commission (NAMMCO) has tasked its Scientific Committee with carrying out assessments of the Central Stock of minke whales (Donovan 1991), using the best data available (NAMMCO 2004). Here, we present abundance estimates from Faroese and Icelandic ship surveys which, along with estimates from the NASS

aerial surveys around Iceland (Borchers *et al.* 2009), were used in these assessments. Minke whale abundance is here estimated using standard and comparable methods from survey to survey, to enable inter-survey comparison of abundance. While we will present and discuss the implications of the double independent observer data collected in 1995 and 2001, estimates will be presented without bias correction to preserve comparability between surveys.

MATERIALS AND METHODS

Vessels and field methodology for the Faroese and Icelandic shipboard surveys have been described elsewhere (1987: Sigurjónsson *et al.* 1989; 1989: Sigurjónsson *et al.* 1991, Joyce *et al.* (MS) 1991, 1995 and 2001, Víkingsson *et al.* 2009).

Post stratification

The surveys were stratified originally based on oceanographic and geographic features and the expected densities of the target species. Since the minke whale was not the target species of these surveys, some post-stratification was warranted. In addition, parts of the shipboard surveys overlapped with the area covered by aerial surveys in 1987, 1995 and 2001 (Fig. 1). Since independent and relatively unbiased estimates for minke whales have been generated from the aerial surveys (Borchers *et al.* 2009), post stratification was used to derive estimates from the ship surveys for the area outside of the aerial survey block. Blocks that overlapped the aerial survey area were parted into sub-blocks occurring in and out of the aerial survey area. These were analysed separately to produce estimates for inside and outside of the aerial survey area. This was done for all years including 1989, even though there was no aerial survey in that year, so that comparable estimates for areas outside the aerial block could be made across surveys. However for the 2001 survey there was insufficient effort within the aerial block to derive an abundance estimate, so effort and sightings from this block were not included in the analysis for that year.

In 1995 all of the minke whale sightings in Block 9 (Fig. 1) occurred in a narrow strip near the western edge of the block. Because there was

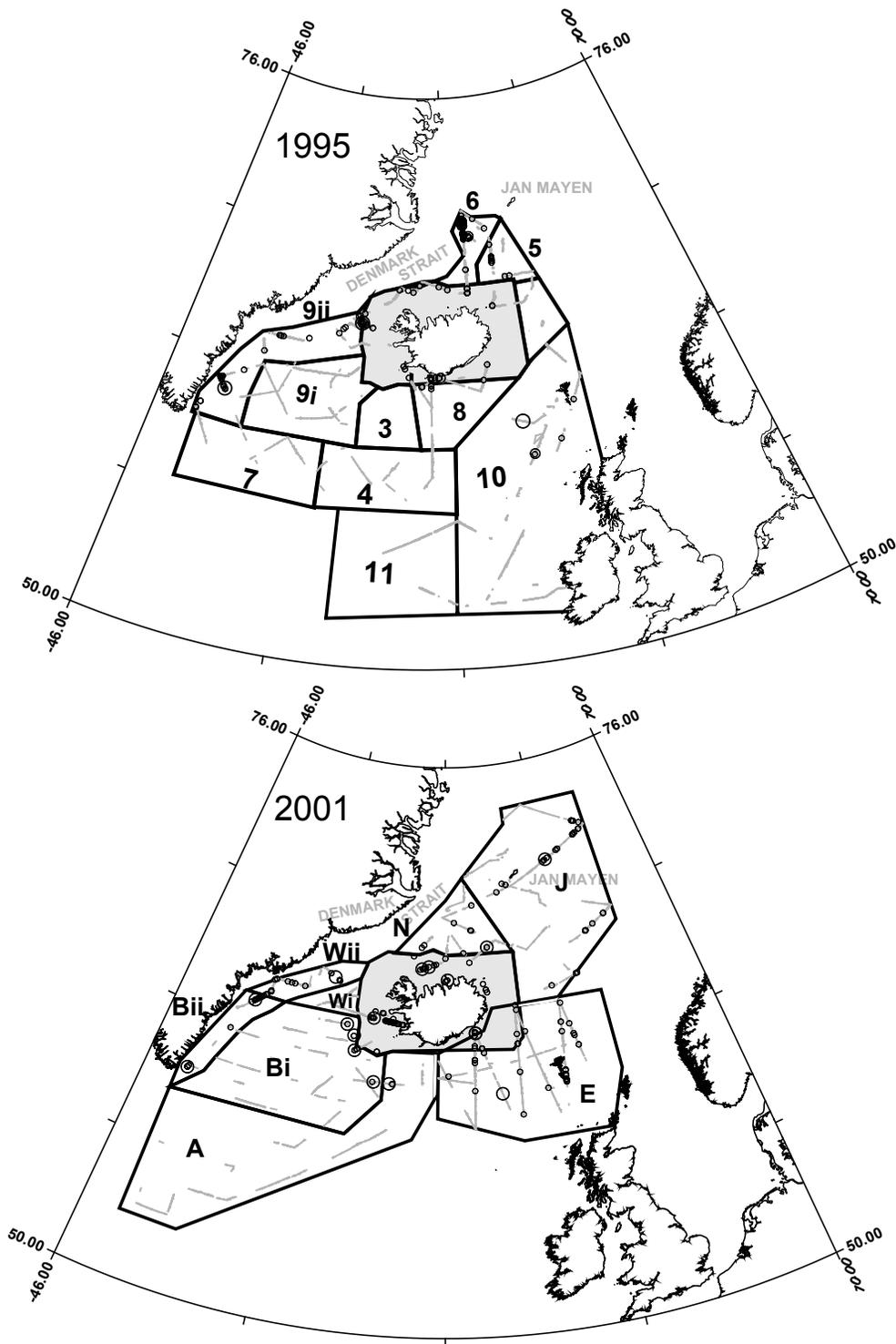


Fig. 1. Stratification, survey effort at Beaufort 3 or less, and sightings of minke whales for Faroese and Icelandic NASS ship surveys. The aerial survey block is shaded, and for 1995 those blocks included in the estimation of abundance are outlined in bold. Symbol size is proportional to group size from 1 to 4.

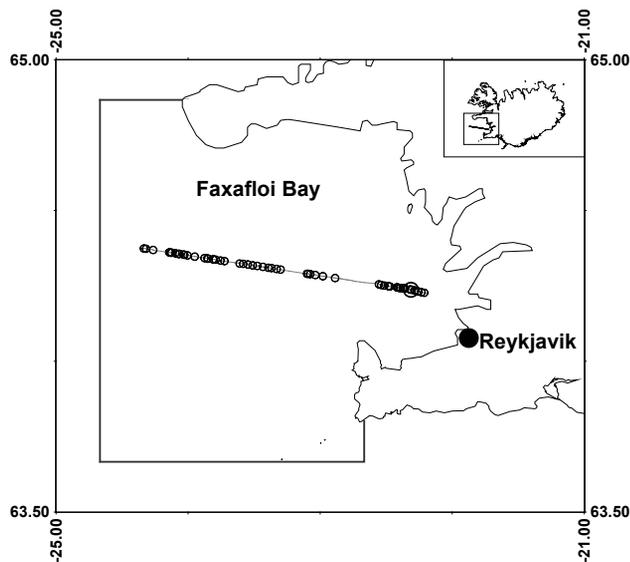


Fig. 2. Ship transect through Faxaflói Bay carried out on 25 June 2001. All sightings of minke whales were of single animals except for 1 sighting of 6 animals indicated by the larger symbol.

more effort under acceptable sighting conditions in this part of the block, there was a potential for positive bias since areas of minke whale concentration and relatively high coverage probability coincided. To assess this we post stratified Block 9 into a western strip in which all sightings were made (9X), and the remainder of the block where there were none. The data were analyzed using both the post-stratified and original Block 9.

A similar situation occurred with the 2001 survey, when weather and ice-related revisions were made to the survey plan in the W and B blocks (Fig. 1), resulting in coverage probabilities that were substantially higher in some parts of these strata than in others. Sightings of minke whales were highly clustered close to the northern and western edges of the W and B blocks, presumably in association with the pack ice edge. This corresponded to an area of high coverage probability. Because of this, an estimate using the original block structure would likely have a positive bias. This problem was addressed by post-stratification to create narrow blocks (Bx and Wx) at the western edges of Blocks B and W. The post-stratification was designed to encompass the extra transects at the western edges that led to coverage probability being higher in these areas. For comparison the analysis was also carried out using the original stratification.

One of the vessels made a transit through Faxaflói Bay near Reykjavík on June 25, 2001

(Fig. 2). This area is within Block 1 of the aerial survey area, and has the highest density of minke whales observed in Icelandic waters (Borchers *et al.* 2009). As the ship and aerial survey data are analysed using quite different methods, it is of interest to determine if the density estimates from the 2 survey methods are similar. We have therefore estimated the density of minke whales along the ship transit in Faxaflói Bay, for comparison with the estimate for the same area from the aerial survey by Borchers *et al.* (2009). The transit through Faxaflói Bay was done on the first day of the survey in fine weather with a Beaufort Sea State of 1 throughout. The entire team, including both shifts of observers on both the primary and secondary platforms, was observing during most of the transit. Observer effort was therefore higher than during the rest of the survey.

Data analysis

All sightings recorded as minke whales and likely minke whales were included in the analysis. In the 1995 Faroese survey and in the 2001 Icelandic and Faroese surveys this included sightings from both the primary and tracker platforms, but multiple sightings of the same animal were not included. All sightings and search effort recorded at a Beaufort Sea State (BSS) greater than 3 were discarded before analysis. This resulted in a loss of 12 sightings and 30% of survey effort in 1987, 38 and 43% in 1989,

12 and 40% in 1995, and 7 and 36% in 2001 respectively. Realized survey effort and sightings of minke whales at $BSS \leq 3$ are shown in Fig. 1.

In the 1989 NASS, 2 whaling vessels were used that had a higher primary platform and 2 single manned barrels. In addition 2 research vessels were used, which had only 1 single manned barrel. Exploratory analyses indicated that the perpendicular distance functions exhibited by the 2 vessel types had different functional forms. Therefore the 1989 survey was analyzed as 2 separate surveys, 1 by the whaling vessels and 1 by the research vessels. The Faroese vessel had 2 platforms each with 2 or 3 observers and was classified as a “whaling vessel” as it covered parts of the same blocks as these ships and in any event made only 4 sightings of minke whales at BSS 3 or less. Since the coverage by these 2 vessel types did not overlap, the estimates were added to derive the total estimate.

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). The estimation of the model parameter effective strip half width (*esw*) was pooled over geographical strata. Estimation of expected pod size ($E(s)$) was done by stratum unless there were no significant differences between strata. Estimation of encounter rate (n/L) was done separately for each stratum. A variety of models for the detection function $g(x)$ 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 considered for inclusion in the model to improve precision and reduce bias. 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. Beaufort Sea State, as recorded and in various classifications, vessel identity, and visibility (nm) were considered as covariates. To determine if there was size bias in pod detectability, $\ln(s)$ was regressed against the estimated detection probability. If this re-

gression 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.

Calculation of abundance:

Abundance in each block was calculated as follows:

$$(1) \quad N_i = \frac{n_i \cdot f(0) \cdot [E(s)]_i \cdot g(0) \cdot A_i}{2L_i}$$

Where:

- N_i = number of whales in block i ;
- n_i = number of pods detected in block i ;
- $f(0)$ = probability density function of perpendicular distances from the line evaluated at zero distance, adjusted for covariates;
- $g(0)$ = probability that a whale on the trackline is sighted, here assumed to be 1;
- A_i = Area of block i ;
- L_i = survey effort (nm) for block i ;
- $[E(s)]_i$ = mean pod size in block i .

Variance combined from encounters by legs, *esw* and $E(s)$ was calculated in DISTANCE, and log normal confidence intervals for N are presented (Buckland *et al.* 2001).

As the transit in Faxaflói comprises only 1 leg (*i.e.* 1 sample), no variance could be calculated for that density estimate.

RESULTS

Distribution

The distribution of minke whale sightings in all surveys is shown in Table 1 and Fig. 1. In 1987, minke whales were concentrated in Faxaflói Bay in the aerial survey area off southwest Iceland (see Fig. 2), on the western side of Denmark Strait near the East Greenland ice edge, near Jan Mayen and around the Faroe Islands. Few minke whales were sighted in the southern parts of the survey area.

In 1989 a large number of sightings were made in the southeast part of the aerial survey area and again in Faxaflói Bay. There was some concentration of sightings in the western part of Denmark Strait, but few were sighted around the Faroes. Minke whales were also sighted in the

Table 1. Stratification and survey effort in Faroese and Icelandic NASS ship surveys, 1987-2001. A-surface area; k-number of transects; L-survey effort at Beaufort 3 or less; COV-% coverage of the block; n-number of minke whale sightings at Beaufort 3 or less. AERIAL-aerial survey block; TOTAL OUT-area outside of the aerial survey block; TOTAL-entire survey area.

SURVEY	BLOCK	A (nm ²)	k	L (nm)	COV (%)	n
1987	2	3,661	7	169	0.52	1
1987	7	75,285	8	675	0.10	0
1987	8	40,920	12	682	0.19	5
1987	9	35,074	9	441	0.14	7
1987	17	29,766	20	1,526	0.57	9
1987	26	5,912	4	174	0.33	3
1987	27	40,193	6	634	0.18	3
1987	36	41,396	6	612	0.17	0
1987	37	58,111	6	808	0.16	7
1987	47	74,490	5	866	0.13	3
1987	88	39,618	9	828	0.23	0
1987	93	19,176	8	769	0.45	16
1987	94	46,344	10	955	0.23	8
1987	95	69,401	7	473	0.08	0
1987	AERIAL	81,369	39	1,889	0.26	117
1987	TOTAL OUT	579,347	117	9,612	0.19	62
1987	TOTAL	660,716	156	11,501	0.19	179
1989	26	5,912	2	31	0.07	1
1989	10	236,185	15	713	0.12	3
1989	36	41,396	8	500	0.27	0
1989	40	107,851	2	397	0.08	1
1989	50	99,734	5	639	0.14	6
1989	60	131,450	5	680	0.12	4
1989	70	88,578	7	219	0.04	0
1989	88	39,618	8	471	0.19	4
1989	93	19,176	3	234	0.19	5
1989	94	46,344	11	672	0.33	13
1989	95	69,401	8	791	0.18	1
1989	AERIAL	35,516	10	668	0.30	120
1989	TOTAL OUT	885,645	71	5,405	0.12	39
1989	TOTAL	921,161	81	6,073	0.13	159
1995	3	22,687	0	0	0.00	0
1995	4	67,708	6	382	0.18	0
1995	5	35,225	7	309	0.28	9
1995	6	12,931	6	326	0.81	65
1995	7	67,708	5	333	0.16	0
1995	8	43,057	5	314	0.23	5
1995	9i	59,815			0.00	0
1995	9ii	55,122	13	490	0.29	36
1995	10	198,692	8	870	0.14	4
1995	11	62,509	2	277	0.14	0
1995	AERIAL	65,526	18	616	0.30	34
1995	TOTAL OUT	625,454	62	4,073	0.21	119
1995	TOTAL	690,980	80	4,689	0.22	153
2001	A	190,577	10	794	0.10	4
2001	Bi	129,740	11	972	0.17	8
2001	Bii	21,491	6	153	0.16	18
2001	E	126,884	10	1,674	0.30	25
2001	J	145,847	10	1,218	0.19	32
2001	N	31,781	7	454	0.33	7
2001	Wi	10,581	3	225	0.49	0
2001	Wii	17,573	229	5	0.01	12
2001	TOTAL OUT	674,474	286	5,495	0.19	106
	Faxaflói		1	56		67

extreme south of the survey area in Blocks 50 and 60, areas that were not covered in the other surveys. There appeared to be a gap in minke whale distribution between this area and the areas where minke whales were found farther north.

In 1995 minke whale sightings were concentrated in the northern part of Block 6, and along the northern and western edges of Block 9 on the western side of Denmark Strait. Here the whales were presumably associated with the pack ice edge, which formed the northern border of Block 9. There were no sightings in the southeastern portion of Block 9, nor in the other southern offshore blocks (3, 4, 7 and 8), and only 4 sightings around the Faroes.

In 2001 sightings were concentrated along the western edges of Blocks W and B near the ice edge off East Greenland. Encounter rates were less in the waters north of Iceland (Blocks N and J) and around the Faroes (Block E). Virtually no sightings were made in the deep waters southwest of Iceland (Block A and central Block B). Sightings were also common during ship transits within the aerial survey block, but these sightings were not included in the analysis of abundance.

The route of the 2001 transit in Faxaflói and sightings of minke whales there are shown in Fig. 2. Minke whales occurred almost entirely as single animals and were distributed rather evenly along the transect line. A total of 67 sightings were recorded (Table 1).

Abundance

The characteristics of the functions used to model the perpendicular distance distributions for each survey are shown in Table 2 and Fig. 3. In general there was a tendency for effective strip esw to be less in the 1987 and 1989 surveys compared with later surveys. In 1989 the research vessels had a greater esw than the whaling vessels. The half-normal function provided the best fit to all datasets except 1995, for which the hazard rate model fitted best. Beaufort Sea State was included as a covariate in 2 of 6 models, while vessel identity was used in the 1989 model for the research vessels.

Mean pod size did not differ significantly between blocks in any of the surveys, so a pooled

estimate of pod size was used to estimate density for each survey. Pod size was not correlated with detection probability, so the simple mean of pod size was used in the estimates.

Abundance estimates by block, for the areas inside and outside of the aerial survey area, and for the total area, are presented for each survey in Table 3. In 1995 and 2001, abundance was nearly the same for the original and post-stratified Blocks 9, B and W, however the cv was lower for the post stratified blocks. Density and abundance in the area outside of the aerial survey block was not significantly different ($P>0.05$) between surveys, but the point estimates in 2001 were substantially higher than in the other years. Density within the aerial survey block was similar in 1987 and 1995, the years in which the block received best coverage. Only the southern portions were covered in 1989, and density was extremely high in that survey, mainly because of a very dense aggregation of minke whales found off southeast Iceland. The coastal areas of Iceland were insufficiently covered in 2001 to derive an estimate.

The distribution of perpendicular distances in Faxaflói also showed a steep decline from the trackline, and a long tail (Fig. 3). A truncation distance of 1,400 m was chosen for these data,

and a half normal function with 1 cosine adjustments provided the best fit. The estimated density was 1.63 animals nm^{-2} . No variance estimate could be derived as only 1 transect was sailed.

DISCUSSION AND CONCLUSIONS

Potential biases

The estimates presented here are biased for a number of reasons. Firstly, they are not corrected for the whales that are submerged and not visible while within the field of view of the vessel (availability bias). Gunnlaugsson and Sigurjónsson (1990) estimated a $g(0)$ of 0.55 due to availability bias alone for the 1987 survey, and other ship surveys (summarized by Schweder *et al.* (1997)) have estimated similar values. Corrections for availability bias are difficult to apply to conventional line transect estimates, and cue-counting (Buckland *et al.* 2001, Laake and Borchers 2004) or similar behaviour based methods (*e.g.* Schweder *et al.* (1997), Skaug *et al.* (2004)) are to be preferred. We would not expect availability bias to vary greatly between surveys, considering that vessel speeds have been fairly constant for all surveys. Therefore, while the estimates presented here are certainly negatively biased due to availability, this factor should not affect their comparability.

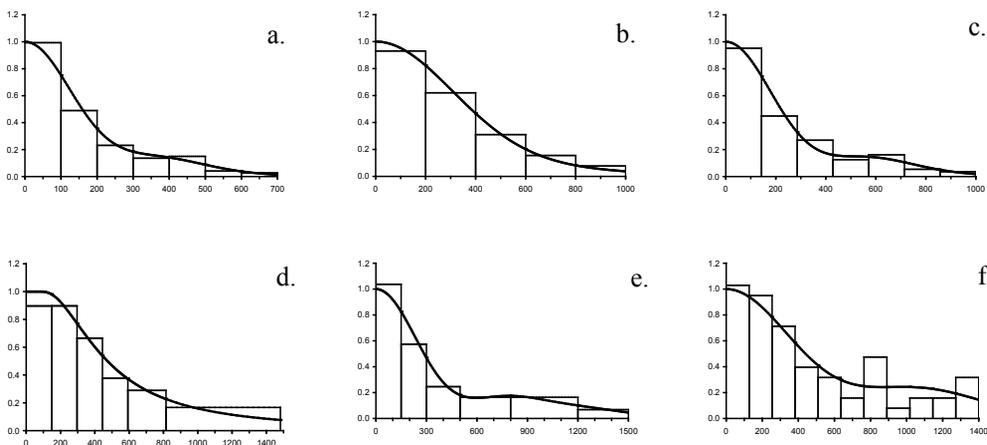


Fig. 3. Detection functions for minke whales from NASS ship surveys. See Table 2 for features of the models. a. 1987; b. 1989 research vessels; c. 1989 whaling vessels; d. 1995; e. 2001; f. 25 June 2001, Faxaflói.

Minke whales are difficult to spot from a ship, and even whales that are potentially visible are often missed by observers. This “perception bias” can be corrected using double platforms and various sight-resight based methods, summarized by Laake and Borchers (2004). For these surveys double platform data were available from the Faroese vessel in 1995 and all vessels in 2001, but not from the 1987, 1989, or 1995 Icelandic surveys. In 2001 between 0 and 50% of the minke whales seen by the tracker platform were also seen by the primary platform. This indicates that the negative bias due to visible animals being missed was substantial. The highest rate of duplication was achieved on the transect through Faxaflói Bay on June 25, when more than 50% of the tracker sightings were duplicated by the primary observers. It had been hoped that sightings made during transit in coastal waters (inside the aerial block) could be combined with other sightings in the estimation of $g(0)$. However on this day there were more observers on the primary platform than under normal operation, and the observers may have been more focussed on minke whales than under normal offshore operations, when the target fin whale was sighted much more frequently. Thus these data could not be combined with the offshore data for the purpose of estimating $g(0)$. We do not rule out the possibility of obtaining estimates from these data that would include some $g(0)$ correction, but clearly such estimates will have great associated uncertainties. A $g(0)$ correction derived for the 2001 data could not be applied to the earlier data sets, as the 2001 survey method used more active observers on 2 platforms than were employed on the earlier single platform surveys. In addition many of the observers have been used in more than 1 survey, so observer experience has increased steadily since the 1987 survey which could also affect the magnitude of perception bias.

Many whales have a keen sense of hearing and it might be expected that they would respond to the presence of a noisy survey vessel. Palka and Hammond (2001) found that minke whales responded to survey vessels by swimming away from them (avoidance), with the response beginning at a radial distance of approximately 700 m in the Gulf of Maine. Density estimates that were corrected for responsive movement

were substantially ($>1.4x$) greater than uncorrected estimates. Although the response of minke whales to ships has not been evaluated in the Central Atlantic, we would expect it to be similar to that in other areas. Therefore, responsive movement is likely an additional source of negative bias for these estimates.

None of the surveys covered the inshore waters of East Greenland which generally have some ice cover at this time of year. Minke whales are known to enter the ice and are hunted annually in the coastal waters of east Greenland (Helms *et al.* 1997), but it is not known if they occur in high densities within the ice pack. The estimates here were not extrapolated into the coastal waters of East Greenland and therefore underestimate the number of minke whales in the Central Stock as a whole.

Given that all identified sources of bias are negative, it is certain that our results underestimate the abundance of minke whales, probably by a considerable amount. It also seems likely that at least one bias, that from visible whales being missed by observers, is unlikely to remain constant from one survey to the next, due to inter survey differences in vessel configuration and observer experience. Therefore any trends indicated by these results should be interpreted with caution.

Distribution

In this area minke whales occur in highest densities in the shelf waters of Iceland that were covered by aerial survey in 1986, 1987, 1995 and 2001 (Borchers *et al.* 2009, Pike *et al.* 2009). Outside of this area the distributional pattern did not change greatly between surveys. Minke whales tended to be concentrated on the western side of the Denmark Strait, close to the ice edge off East Greenland, in all years. They

Table 2. Characteristics of perpendicular distance functions used for NASS ship surveys. R-research vessel; W-whaling vessel; F-Faxaflói Bay transect; RT-right truncation distance; TRUNC.-percentage of observations lost after truncation; HN-half normal; HZ-hazard rate; BSS-Beaufort sea state.

SURVEY	RT (m)	TRUNC. (%)	MODEL	COV
1987	700	15	HN	BSS, 3 levels
1989 R	1000	16	HN	Vessel
1989 W	1000	10	HN	none
1995	1500	9	HZ	BSS
2001	1500	2	HN	none
2001F	1400	10	HN	none

were also common in the waters north of Iceland and around Jan Mayen Island. Southwest of Iceland, distribution seemed to vary between surveys, with minke whales being common around the Faroes in 1987 and 2001, but less so in 1989 and 1995. In general it would seem that minke whales in this area prefer relatively shallow, shelf areas during the summer.

The 1989 survey was conducted 2-3 weeks later in the season and extended farther south than the others. In that year there were sightings of minke whales in Blocks 50 and 60 in the far south of the survey area, that were clearly separated from sightings farther north by a wide gap in distribution (see Fig. 1). This may be indicative of a separation in summering stocks. Surveys south of 50° N and off eastern Canada would be useful in addressing this question, as virtually no other data are available for this area.

Abundance and trends

As indicated previously the estimates presented here are substantially negatively biased, and should be considered either as minimum estimates or as indices of relative abundance for assessing trends. Interpretation is also complicated by variations in spatial coverage and stratification of the surveys between years. In this respect it is more useful to compare density rather than abundance, as abundance is heavily dependent on the extent of the area covered.

Within the aerial survey area, coverage was best in 1987 and 1995, and density was not significantly different between these 2 surveys. Pike *et al.* (2009) in an analysis of relative abundance of minke whales in the aerial survey area also found no evidence of any change in density in the 4 surveys carried out between 1986 and 2001. Densities from the ship surveys were 30-40% of those from the 1987 aerial survey and 20-30% of those from the 2001 aerial survey (Borchers *et al.* 2009), however ship coverage in the area was very poor in 2001. The aerial survey estimates are corrected for availability and perception biases, so these ratios may give some indication of the level of negative bias inherent in the ship survey estimates. In contrast, the 2001 transit through Faxaflói Bay realized a minke whale density of 1.63 whales nm⁻², which is very similar to the best estimate from

the 2001 aerial survey in the same area of 1.74 whales nm⁻² (cv 0.22) (Borchers *et al.* 2009). This indicates that a ship survey may approach $g(0)=1$ for minke whales under optimal sighting conditions with high observer effort. The surfacing rate for minke whales has been estimated as 53 per hour in this area (Gunnlaugsson 1989). Therefore it is likely that most whales would surface within sight of the ship, and could be seen under optimal conditions.

In 1989 only the southern portion of the aerial survey area was covered, and density was extremely high in the area. This was mainly due to the coverage of a patch of very high density off southwest Iceland on 30 July, when about 75 animals were sighted in a distance of about 5 nm (Gunnlaugsson and Sigurjónsson 1991). High densities of minke whales have been observed in this area during the aerial surveys (Pike *et al.* 2009). It is an area of high freshwater inflow from glacial melt water, and of relatively high primary production and capelin abundance in some seasons (Vilhjálmsón 1994). The same area was covered in 1987 about 3 weeks earlier when comparatively few whales were seen. It may be that minke whales become more concentrated there as the season progresses. Alternatively distribution in this area may vary from year to year or simply be patchy.

Outside of the aerial survey area, density did not vary significantly between years but was higher in 2001 than in other years (Table 3). To assess variations in abundance on a smaller scale, we divided the survey area into 3 areas that received similar coverage in every survey (Table 4). In the Southwest density did not vary significantly from year to year but was highest in 2001 and 1989. In the Southeast, density was lower, although not significantly so, in 1995 than in any other year. In the Northeast, density was similar in 1987 and 2001, but markedly (although not significantly) higher in 1995. In all areas there was a tendency for density to be highest in 2001, but, as mentioned earlier, there is reason to believe that $g(0)$ may have been higher in this survey than in the others, thus confounding the interpretation of trends..

Table 3. Abundance of minke whales from NASS ship surveys. Superscript P indicates post-stratified blocks. Coefficients of variation are in parentheses. <i>esw</i> -effective strip half width; <i>E(s)</i> -expected school size; <i>n/L</i> -encounter rate; <i>D</i> -density. AERIAL-aerial survey block; TOTAL OUT-area outside of the aerial survey block; TOTAL-entire survey area.											
SURVEY	BLOCK	<i>esw</i> (m)		<i>E(s)</i>		<i>n/L</i> (no•nm ⁻¹)		<i>D</i> (no•nm ⁻²)		<i>N</i>	95% CI
1987	2					0.0059	(0.667)	0.0288		105 (0.671)	24-464
1987	6					0.0000		0.0000		0	
1987	7					0.0000		0.0000		0	
1987	8					0.0073	(0.377)	0.0356		1,458 (0.384)	649-3,278
1987	9					0.0159	(0.295)	0.0772		2,709 (0.304)	1,383-5,305
1987	17					0.0052	(0.352)	0.0255		758 (0.359)	367-1,567
1987	26	207	(0.07)	1.09	(0.026)	0.0173	(1.02)	0.0840		496 (1.023)	34-7,221
1987	27					0.0016	(0.627)	0.0077		308 (0.631)	70-1,348
1987	36					0.0000		0.0000		0	
1987	37					0.0074	(0.394)	0.0361		2,097 (0.401)	793-5,547
1987	47					0.0035	(0.367)	0.0168		1,254 (0.375)	472-3,331
1987	88					0.0000		0.0000		0	
1987	93					0.0169	(0.409)	0.0822		1,576 (0.415)	621-4,000
1987	94					0.0063	(0.465)	0.0306		1,416 (0.471)	518-3,868
1987	95					0.0000		0.0000		0	
1987	AERIAL							0.1205		9,809 (0.247)	5,970-16,104
1987	TOTAL OUT							0.0210		12,179 (0.162)	8,838-16,781
1987	TOTAL							0.0333		21,984 (0.151)	16,310-29,632
1989	26	419	(0.158)	1.09	(0.047)	0.0326	(1.08)	0.0775		458 (1.09)	0-11,214,000
1989	36	419	(0.158)	1.09	(0.047)	0.0000		0.0000		0	
1989	40	419	(0.158)	1.09	(0.047)	0.0025	(1.66)	0.0060		645 (1.66)	0-761,480,000
1989	50	419	(0.158)	1.09	(0.047)	0.0063	(0.756)	0.0149		1,482 (0.773)	236-9,299
1989	60	419	(0.158)	1.09	(0.047)	0.0044	(0.425)	0.0105		1,378 (0.456)	459-4,136
1989	70	419	(0.158)	1.09	(0.047)	0.0000		0.0000		0	
1989	88	292	(0.089)	1.14	(0.036)	0.0085	(0.432)	0.0307		1,216 (0.442)	456-3,243
1989	93	292	(0.089)	1.14	(0.036)	0.0214	(0.814)	0.0773		1,482 (0.819)	73-29,907
1989	94	292	(0.089)	1.14	(0.036)	0.0194	(0.397)	0.0699		3,238 (0.408)	1,367-7,670
1989	95	419	(0.158)	1.09	(0.047)	0.0013	(0.838)	0.0030		208 (0.854)	37-1,168
1989	10	292	(0.089)	1.14	(0.036)	0.0042	(0.461)	0.0152		3,589 (0.471)	1,384-9,303
1989	AERIAL							0.3797		13,487 (0.444)	4,779-38,060
1989	TOTAL OUT							0.0155		13,696 (0.235)	8,401-22,328
1989	TOTAL							0.0505		27,184 (0.257)	14,956-49,410
1995	3					0.0000				0	
1995	4					0.0000				0	
1995	5					0.0259	(0.505)	0.0442		1,558 (0.511)	486-4,997
1995	6					0.1779	(0.301)	0.3045		3,937 (0.311)	1,855-8,356
1995	7					0.0000				0	
1995	8	596	(0.072)	1.10	(0.034)	0.0159	(0.880)	0.0272		1,172 (0.884)	144-9,534
1995	9i					0.0000				0	
1995	9ii					0.0633	(0.245)	0.1084		5,972 (0.257)	3,479-10,252
1995	10					0.0046	(0.428)	0.0079		1,564 (0.436)	591-4,137
1995	11					0.0000		0.0000			
1995	AERIAL							0.0912		5,977 (0.386)	2,671-13,376
1995	TOTAL OUT							0.0209		13,065 (0.220)	8,444-20,215
1995	TOTAL OUT ^P							0.0227		14,203 (0.186)	9,798-20,589
1995	TOTAL							0.027558		19,042 (0.200)	12,801-28,325
1995	TOTAL ^P							0.0292		20,180 (0.181)	14,077-28,930
2001	A					0.0050	(1.19)	0.0117		2,227 (1.197)	266-18,661
2001	Bi					0.0082	(0.929)	0.0191		2,478 (0.938)	426-14,423
2001	Bii					0.1175	(0.334)	0.2725		5,856 (0.358)	2,552-13,438
2001	E	426	(0.127)	1.07	(0.023)	0.0149	(0.387)	0.0346		4,394 (0.408)	1,856-10,404
2001	J					0.0246	(0.273)	0.0572		8,335 (0.301)	4,417-15,729
2001	N					0.0154	(0.393)	0.0358		1,137 (0.414)	448-2,886
2001	Wi					0.0000				0	
2001	Wii					0.0523	(0.451)	0.1214		2,134 (0.469)	662-6,876
2001	TOTAL ^P							0.0394		26,562 (0.229)	16,939-41,650
2001	TOTAL							0.0384		25,929 (0.286)	14,747-45,590

Management implications

Most of the area covered in these surveys falls within the Central Stock Area as defined by the International Whaling Commission (Donovan 1991), with the exception of the area around the Faroe Islands which lies within the North-eastern Stock Area. Whaling in the Central Stock Area has been carried out in coastal Icelandic waters beginning around 1930, and by Norway around Jan Mayen Island beginning in the 1950s. The most intensive catching period was from 1965-1969, when catches averaged 451 per year, after which catches declined to an average of 292 per year from 1980-1984 (NAMMCO 1999). Minke whale hunting ceased in Iceland in 1986 and only resumed at a very low level in 2003. Including Norwegian catches, harvests since 1986 in the Central Stock Area have averaged 36 per year (NAMMCO 2004).

The NASS ship survey results examined here provide no evidence that the size of the minke whale population in the survey area has changed appreciably between 1987 and 2001. However, because of the lack of precision of the estimates, only very large changes would be detectable. Nevertheless these results are in accordance with those from the aerial surveys around Iceland (Pike *et al.* 2009). The NAMMCO Scientific Committee reviewed the status of the Central Stock in 2003, based on available estimates of abundance, life history parameters and various catch series including corrections for estimated by catch and unreported catch (NAMMCO 2004). Modelling indicated that the stock had not been appreciably impacted by past whaling, and that current abundance was at

least 85% of its pre-exploitation level. Therefore the lack of a detectable trend in minke whale abundance in this area is not unexpected.

The abundance estimates presented here are negatively biased to an unknown but probably substantial degree. From a management perspective, this may not be terribly important, since harvesting is occurring at a very low level at present and even the minimal numbers reported here are more than adequate to support such harvests. Moreover, all harvesting occurs either in coastal Icelandic waters or around Jan Mayen, areas for which better estimates of minke whale abundance are available from Icelandic aerial surveys (Borchers *et al.* 2009) and Norwegian surveys (Schweder *et al.* 1997, Skaug *et al.* 2004) respectively. However, improved estimates of minke whale abundance may be desirable for other reasons, including the assessment of interactions with fisheries and monitoring the effects of environmental change.

Improving abundance estimates for minke whales in this area would require significant modifications in the field methodology used. This is complicated by the fact that the minke whale is not the target species of the survey and is absent or occurs in very low density throughout much of the survey area. Optimizing the survey for minke whales may come at the expense of its efficiency for the other target species. However the occurrence of minke whales seems quite predictable so it would be possible to stratify the survey such that areas of high minke whale density are covered using modified methodology.

Table 4. Comparison of density (*D*) and abundance (*N*) of minke whales from NASS ship surveys by area. Coefficients of variation are in parentheses. See Fig. 1 and Table 1 for block definitions. SW: 1987 Blocks 2, 93, 94, 95 and 36; 1989 Blocks 36, 93, 94 and 95; 1995 Blocks 3, 4, 7 and 9; 2001 Blocks A, B and W. SE: 1987 Blocks 7, 17, 27, 37, 47 and 88; 1989 Blocks 10 and 88; 1995 Blocks 8 and 10; 2001 Block E. NE: 1987 Blocks 8 and 9; 1989 not surveyed; 1995 Blocks 5 and 6; 2001 Blocks J and N.

YEAR	AERIAL		SW		SE		NE	
	<i>D</i> (no·nm ⁻²)	<i>N</i>	<i>D</i> (no·nm ⁻²)	<i>N</i>	<i>D</i> (no·nm ⁻²)	<i>N</i>	<i>D</i> (no·nm ⁻²)	<i>N</i>
1987	0.1205	9,809 (0.247)	0.0172	3,097 (0.307)	0.0141	4,418 (0.239)	0.0548	4,167 (0.244)
1989	0.3797	13,487 (0.444)	0.0279	4,928 (0.337)	0.0174	4,805 (0.374)	NA	
1995	0.0912	5,977 (0.386)	0.0219	5,972 (0.257)	0.0113	2,736 (0.457)	0.1141	5,495 (0.271)
2001	NA		0.0343	12,695 (0.339)	0.0346	4,394 (0.408)	0.0533	9,473 (0.276)

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