Distribution and abundance of large whales in Norwegian and adjacent waters based on ship surveys 1995-2001

Nils Øien

Institute of Marine Research, P.O.Box 1870 Nordnes, N-5817 Bergen, Norway

ABSTRACT

The abundances of large whale species are presented for the northeast Atlantic from near-complete survey coverage in 1995 and from multiple partial-area surveys during 1996-2001. These Norwegian shipboard surveys were generally conducted with 2 independent observer platforms, except for single-platform surveys during part of 1995. Tracking procedures implemented for minke whales – *Balaenoptera acutorostrata* (the target species) meant that the surveys had to be conducted in passing mode, and there were therefore only limited opportunities for closing on sightings to determine species identity and school size. Abundance estimates for large whale species (fin – *Balaenoptera physalus*, humpback – *Megaptera novaeangliae* and sperm whales – *Physeter macrocephalus*) were obtained by combining sightings from both platforms, and applying standard distance sampling techniques to the smeared and truncated perpendicular distances for each species. Abundance estimates for the 2 survey groupings (1995 and 1996-2001) summarised over comparable areas were: fin whales, 5,034 (cv 0.209) and 6,409 (cv 0.18); humpback whales, 1,059 (cv 0.248) and 1,450 (cv 0.29); and sperm whales, 4,319 (cv 0.199) and 6,207 (cv 0.22). The estimated cv's are likely underestimates and specifically the combined partial-area survey cv's do not include additional variance due to possible distributional shifts between years. Inclusion of a new survey stratum north of Iceland (block NVS) in the later set of surveys revealed a high additional abundance there of fin whales 3,960 (cv 0.538) and humpback whales 3,246 (cv 0.512). The high humpback whale estimate for this stratum confirms the Icelandic survey findings of a large humpback whale population summering in that area.

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INTRODUCTION

Shipboard sightings surveys with minke whales (*Balaenoptera acutorostrata*) as the target species have been conducted in Norwegian and adjacent waters as part of management needs, but also as contributions towards the synoptically conducted NASS (North Atlantic Sightings Surveys) surveys, during the summer seasons around July in each of the years 1987, 1989 and in 1995 (Schweder *et al.* 1997). In 1996-2001 a 6 year programme was conducted to survey the northeast Atlantic with smaller effort annually (Øien and Schweder MS 1996). The survey methodology has been improved over these years to ensure the best possible estimates of minke whale abundance (Schweder *et al.* 1997, Skaug *et al.* 2004). Although minke whales are the primary survey target, sightings of other whale species were also recorded, and large whale abundance estimates were published for the earlier surveys in 1988 and 1989 (Øien 1990, Christensen *et al.* 1992a). The surveys conducted prior to 1995, however, covered subsets of the total area covered in 1995, and surveys conducted after 1995 have been partial in annual coverage such that

the total area of interest was covered over a 6-year cycle. Thus the 1995 survey stands out as the only synoptic survey that together with the Icelandic and Faroese surveys covered a major part of the Northeast Atlantic that year. In this paper results from analyses of the large whale data from the Norwegian 1995 and 1996 2001 surveys are presented. Large whales have in this paper been used as a common term for fin (*B. physalus*), sei (*B. borealis*), blue (*B. musculus*), humpback (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus*).

MATERIAL AND METHODS

Study area

The sightings surveys covered the north-eastern Atlantic north and east of 56°N and 5°W, covering the North Sea, the Norwegian Sea, the Greenland Sea and the Barents Sea. Based on experience on minke whale densities from earlier surveys as well as historic minke whale catch statistics, the study area was divided into 19 survey blocks at the planning stage (Fig. 1). One of these blocks (NVS, northeast of Iceland) was not surveyed in 1995, however all blocks were surveyed over the period 1996 2001.

Table 1. Summary of block coverage over the survey period 1995-2001 in the North-eastern Atlantic by year and the number of vessels which conducted primary search effort within each block.

	Survey year:						
Block	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
FI	1	2					
NOS	4	2					
LOC	1	1				1	
JMC	1		1				
NVN	1		2				
NVS	0		2				
NSC	2			2			
NS	2			2			
BJ	2				1		
VSN	1				1		
VSI	1				1		
SV	1				1		
NON	2				2		
VSS	2				1		
SVI	1				1		
BAW	1				1		
BAE	1					2	
KO	1						1
GA	1						1

Survey design, implementation and sightings procedures

In 1995, 11 vessels conducted the survey over the period 5 July to 8 August (Table 1). Three of the vessels were sealing or whaling vessels, 4 were from the Coast Guard (former fishing vessels) and the remaining 4 vessels were chartered from their usual activity as standby vessels at oil platforms. Each of the survey blocks was covered by 1 (12 blocks), 2 (5 blocks) or 4 vessels (1 block, Table 1).

During 1996-2001, 2 vessels conducted the surveys in mid summer centred around July in each of the years. Five of the 6 vessels involved were provided by the Coast Guard (former fishing vessels), and 1 was a whaling vessel. Half of the survey blocks were covered by 2 vessels, the remainder by 1 vessel (Table 1).

All vessels were equipped with 2 independent platforms. The upper platform was typically a barrel on the mast and the other platform was an arrangement on the wheelhouse roof. In 75% of the cases the 2 platforms were placed one above the other, otherwise the barrel was on a mast in the stern in front of the wheelhouse. The platform heights (eye-height above sea level) varied from 11.6 to 16.5 m for the upper platforms (the barrels) and from 6.0 to 12.2 m for the lower (wheelhouse) platforms. Some of the vessels had closed barrels.

The survey and sightings protocols are detailed in Øien (MS 1995). The main issues were as follow: Primary searching speed was 10 knots. Acceptable conditions for primary searching were defined as a meteorological sightability of greater than 1 km and sea states of Beaufort 4 or less. The main sector of searching is that of 45° to each side of the track line. The surveys were conducted in "passing mode", such that sightings were never closed on. In 1995 there were 3 or 4 teams of observers on each vessel, each team consisted of three observers. Four team vessels worked around the clock on a 24 hour schedule, while arrangements on the 3 team

vessels varied according to available light conditions, and some of the effort was conducted as single platform search from the upper platform only. Usually the watches were organised in 6 hour periods. The observers (111 in number) were mostly experienced minke whalers, but there were also people with experience from survey activities in other parts of the world, including the International Whaling Commission's (IWC) IDCR-SOWER cruises in the Antarctic.

In the 1996 2001 surveys there were 4 teams of observers on each vessel, each team consisted of 2 observers and all surveys were conducted with two platforms. The vessels operated for 18 hours each day divided into 2-hour watches. Most of the 74 observers involved over this period were experienced minke whalers.

Species, radial distance estimated by eye, angle from the transect line as read from an angle board, and school size were reported for each sighting. When the species seen was assumed to be a minke whale, specific tracking procedures were followed, which may have compromised recording of other species. Species identification was usually categorized as certain for large whales, but because the survey was conducted in passing mode, sometimes sightings were recorded as *'blows from large whales*'. Regular training in distance estimation was conducted during the surveys, and accuracy of distance estimation and angle board readings was tested by separate experiments with buoys as targets. While error models from these experiments were incorporated by simulation in the development of minke whale estimates from these surveys (Skaug *et al.* 2004), an approach with smearing distances and angles (Buckland *et al.* 2001) was used in the large whale abundance estimates.

Abundance estimation

Data analyses were carried out using standard line transect methods in the DISTANCE 4.1 Release 2 software package (Thomas *et al.* 2002). The data from the 2 sightings platforms on each vessel were combined to constitute 1 data set after a post-cruise duplicate judgement. Duplicate judgements were made based on plots of the vessel track and information on time and position relative to vessel taking into consideration the progress of 300 m per minute when searching and allowance for a 50% error in recorded radial distance. However, a component of subjectivity in judgement is involved.

Abundances were calculated by block as

$$(1) \qquad N = \tfrac{1}{2}\,(n/L)(g(0)/esw)(s)(A)$$

where:
(n/L) ~ sighting rate of schools, calculated from conducted primary search effort L on pre-planned transects lines;
esw ~ effective search half width estimated as $f(0)$, i.e. perpendicular distance probability density function evaluated on the transect line;
$g(0)$ ~ detection function evaluated on the transect line, and assumed to be $\equiv 1$;
s ~ estimated school size within the block;
A ~ area of the block.

The estimation of *esw* was based on fitting detection function models to the perpendicular distance data pooled over all blocks surveyed as initial inspection modelling by block and globally revealed that only a couple of blocks would support enough data for a block-wise fitting for fin whales and even fewer for the other species. The models explored comprised the hazard rate and half normal models, eventually with correction terms. Choosing among models was based on Akaike's information criterion (AIC), goodness of fit test statistics and visual inspection of data and model, especially around the transect line. The exploration of the data included truncation options and smearing options due to possible rounding of recorded distances and angles to sightings. Consideration of smearing was done following the model of uniform smearing over the sector defined by the angle range $(\Theta-\phi, \Theta+\phi)$ and distance range $(r*(1-s), r*(1+s))$, where Θ and r are the measured angle and distance to the sighting, and ϕ is the smearing angle and s is the proportional sector of distance to use as the basis for smearing; these were chosen on a trial basis and by inspection of angle and distance distributions (Buckland *et al.* 2001). Prior to smearing, data were grouped into intervals.

School sizes were estimated by block since there appeared to be some variation in different areas. The estimate used was usually the mean of observed school sizes, a few excep-

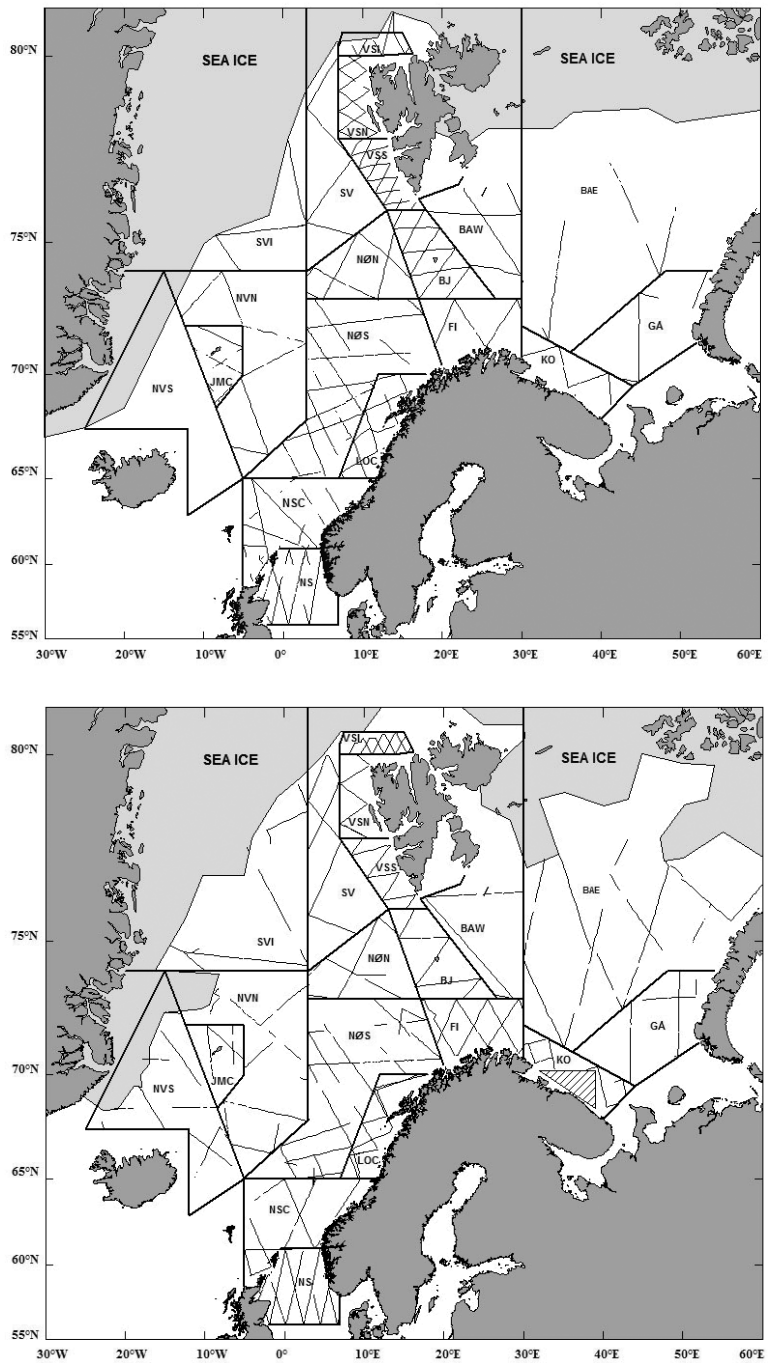

Fig. 1. *Survey blocks and realised primary search effort on predetermined transect lines during the 1995 (Fig. 1 a) and 1996-2001 (Fig. 1 b) sightings surveys. The block NVS to the north and east of Iceland did not receive any coverage during the 1995 survey.*

tions to this was when a detection bias in their size estimation was demonstrated by regressing ln(s) against detection probability. If this regression was significant at the $P < 0.15$ level, the mean group size in the block was calculated from this regression instead. In the case of duplicate sightings, the group size as observed from the upper barrel (platform 1) was used.

Sighting rate variances were empirically estimated based on transect legs. The confidence intervals of the abundance estimates were calculated assuming that estimated abundance is log-normally distributed (Buckland *et al.* 2001).

RESULTS

General

During the 1995 survey, 25,000 km of primary transects were conducted (Fig. 1a) over an area of 2,827,000 km² (Table 2). Most search effort was conducted in Beaufort Sea State (BSS) 2 (33%) and 3 (40%), but some was in BSS 0 and 1 (17%) and BSS 4 (10%).

A total of 30,480 km of primary transects were searched over the survey period 1996-2001 (Fig. 1b), covering a total area of about 3,210,263 km² (Table 3). The distributions of search effort by Beaufort Sea State were 13% in BSS 0 and 1, 29% in BSS 2, 37% in BSS 3 and 22% in BSS 4.

There were about 600 records of large whale sightings during the 1995 survey. Of these, 40% were classified as fin whales, 20% as sperm whales, 8% as humpback whales and 1% as blue or sei whales. The remaining 31% were categorized as 'unidentified large whale'. Blue whale sightings at Spitsbergen and north of Jan Mayen, and sei whale sightings in the Norwegian Sea and near Jan Mayen are not considered further here.

There were about 950 records of large whale sightings during the 1996-2001 survey period. Of these, 32% were classified as fin whales, 22% as sperm whales, 12% as humpback whales and 1% as blue or sei whales. In addition, 33% were categorized as 'unidentified large whale'. The percentages of the different categories, including that of 'unidentified large whale', were very similar to those seen in the 1995 survey data. The blue (west off Spitsbergen and north of Jan Mayen) and sei (around Jan Mayen) whale sightings (totally 15 sightings from both platforms, including duplicates) will not be considered further here.

A duplicate judgement analysis was performed on the large whale data where sightings under the two platform configuration were evaluated and classified either as 'Duplicate' or 'Non duplicate'. Since no judgement of duplicates is made in the field, the judgements may be fairly subjective. Apparent cases are when the time stamps and/or distance and angle information are corresponding; beyond that, consideration must be made of the vessel track and progress and any ancillary information as for example observed swim directions.

If one observer of a duplicate sighting recorded 'unidentified large whale' while the other recorded a species name, the species name was used for that sighting. On two occasions, the species identification differed between the two observers, with one observer recording it as a fin whale and the other as a sperm whale. In these two instances, additional notes by the team leaders in the wheelhouse confirmed them as sperm whale sightings.

Comparisons of 'unidentified large whale' sightings are shown in Tables 4–5.

For duplicate sightings, the data from the platform from which the whale was first seen (as recorded), have been used in the combined platforms analyses. If this sighting lacked information on either radial distance or angle to sighting, the other platform's data were used (3 cases in 1995, 5 cases in 1996-2001).

There was evidence of rounding of angle and distances in the data, typically radial distances were rounded to the nearest 500 m above 1,000 m, and angles were rounded to the nearest 10°. An example plot of radial distances illustrating this is shown in Fig. 8.

Table 2. The 1995 synoptic survey: Area, transect lengths and distribution of primary sightings by block and species. The headings '1' and '2' means number of sightings from upper and lower platform, respectively, while numbers listed under '+' are sightings recorded during single platform search; 'D' are judged duplicates between platforms 1 and 2.

Block	Area	Transect length		Large whales				Fin whales				Humpback whales				Sperm whales				Totals			
		total	single platform																				
	km²	km	%	1	+	2	D	1	+	2	D	1	+	2	D	1	+	2	D	1	+	2	D
BAE	478,956	1,131	0	4		2	2	1		1	0					0		1	0	5	0	4	2
GA	159,224	737	0					2		0	0	0		1	0					2	0	1	0
KO	94,034	722	0	1		0	0					1		1	1					2	0	1	1
FI	94,145	744	50	1		0	0		5											1	5	0	0
NOS	394,260	4,462	14	19		10	3	4	1	3	3	4		4	1	32	1	33	17	59	2	50	24
LOC	93,839	1,561	57		6			2	3	0	0					2	3	2	2	4	12	2	2
VSI	8,665	363	0					2		4	2					1		1	0	3	0	5	2
VSN	19,618	790	0	33		11	4	29		50	23					2		2	2	64	0	63	29
VSS	29,114	1,039	11	18	1	13	5	13		23	11									31	1	36	16
BAW	96,477	1,010	52																	0	0	0	0
BJ	73,731	1,453	47	3	1	7	1	22	1	13	6	8	12	11	6	1	1	1	0	34	15	32	13
NON	88,141	1,206	24	6		1	0	2	1	3	2	0		1	0					8	1	5	2
SV	87,197	770	0	13		7	4	12		17	7					2		1	1	27	0	25	12
SVI	131,091	794	46	4	1	1	1	3		2	2	1		1	1					8	1	4	4
NSC	308,918	2,683	0	1		1										8		11	5	9	0	12	5
NS	259,502	2,847	0																	0	0	0	0
NVN	343,594	1,591	6	10		12	6	6		6	3					6		8	4	22	0	26	13
JMC	66,893	854	0					3		3	3									3	0	3	3
Total	**2,827,399**	**24,757**	16	**113**	**9**	**65**	**26**	**101**	**11**	**125**	**62**	**14**	**12**	**19**	**9**	**54**	**5**	**60**	**31**	**282**	**37**	**269**	**128**

Fin whales

The sightings of fin whales as made from platform 1 (see Tables 2 and 3) are shown in Fig. 2. They were found all over the survey area but especially west of Spitsbergen and in the Jan Mayen area.

A hazard rate model provided the best fit to the combined platform data grouped, truncated at a perpendicular distance of 4,000 m and smeared with smearing parameters $\phi = 5°$ and $s = 0$. The fitted detection functions are shown in Fig. 5 and resulted in *esw* of 1,526 m and a total survey estimate of 5,034 (cv 0.21) for 1995 (Table 6) and for 1996-2001 an *esw* of 1,378 m and abundance for the total area surveyed of 10,369 (cv 0.24) (Table 7). The estimate for the latter period that corresponds to the 1995 estimate (that is, with block NVS removed) is 6,409 (cv 0.18).

Humpback whales

Humpback whales were mainly found around Bear Island in 1995, while they in the survey period 1996-2001 were distributed over a much wider area from northern Norway to north of Spitsbergen as well in the Norwegian Sea and around Jan Mayen. Many humpbacks were also seen north and east of Iceland in a survey block which was not covered in the 1995 survey. The distributions of humpback whale sightings from platform 1 are shown in Fig. 3.

For both data sets, a hazard rate model was found to give the best fit to the combined platform data grouped, truncated at a perpendicular distance of 3,000 m and smeared with smearing parameters $\phi = 5°$ and $s = 0.5$. The fitted detection functions (Fig. 6) resulted in an *esw* of 1,494 m and a total survey estimate of 1,059 animals (cv 0.25) for 1995 and for 1996-2001 an *esw* of 1,445 m and abundance for the total area surveyed of 4,695 animals (cv 0.39) (Tables 8-9). The estimate directly comparable to the 1995 estimate (i.e. with block NVS estimate excluded) is 1,450 (cv 0.29).

Sperm whales

In Fig. 4 is given the distribution of sperm whale sightings from platform 1 from the 1995 and 1996-2001 sightings surveys. The vast majority of the sightings were made in the Norwegian Sea south of the Mohn ridge between Jan Mayen and Bear Island, but there were a few exceptional sightings north of Spitsbergen.

Table 3. Area, transect lengths and distribution of primary sightings by block and species, 1996-2001. The headings '1' and '2' means number of sightings from upper and lower platform, respectively; 'D' are judged duplicates between platforms 1 and 2. In addition there are a few sightings of sei whales (5 from both platforms, blocks NVN and JMC, no duplicates), and of blue whales (10 sightings in all, blocks NVN, JMC, SV and SVI, 2 duplicates).

Block	Area	Transect length	Large whales			Fin whales			Humpback whales			Sperm whales			Totals		
	km²	total km	1	2	D	1	2	D	1	2	D	1	2	D	1	2	D
BAE	492,171	3,313	7	4	0	4	4	0				0	1	0	11	9	0
GA	159,224	1,011	1	1	1	1	2	1	1	0	0				3	3	2
KO	94,034	862															
FI	94,145	1,680	8	1	1	5	7	4	2	2	1				15	10	6
NOS	394,260	4,420	17	29	8	4	3	2	3	2	2	69	59	39	93	93	51
LOC	93,839	2,006	10	8	1	2	0	0	2	0	0	18	26	10	32	34	11
VSI	8,665	439	0	3	0							2	0	0	2	3	0
VSN	19,618	568	8	15	2	28	19	14	1	1	1				37	35	17
VSS	29,114	684	14	11	2	10	8	2	5	5	2				29	24	6
BAW	123,082	845	2	1	0				2	3	2				4	4	2
BJ	73,731	886	5	1	0				5	3	3	2	4	1	12	8	4
NON	88,141	940	0	1	0				0	1	0	1	1	0	1	3	0
SV	91,523	987	12	10	6	27	24	19	1	0	0				40	34	25
SVI	189,072	1,070	7	4	2	6	5	5							13	9	7
NSC	308,918	2,767	11	4	0	8	6	4	1	1	1	4	2	2	24	13	7
NS	259,502	3,808	1	2	1										1	2	1
NVN	324,808	1,902	10	12	3	12	8	6	2	1	1	6	8	5	30	29	15
JMC	66,893	616	15	9	1	22	25	16	4	3	2				41	37	19
NVS	299,523	1,676	26	44	14	40	28	23	41	24	18	1	1	1	108	97	56
Total	**3,210,263**	**30,480**	**154**	**160**	**42**	**169**	**139**	**96**	**70**	**46**	**33**	**103**	**102**	**58**	**496**	**447**	**229**

Table 4. Species identification and reclassification based on judged duplicate sightings from the two platforms, 1995 survey.

		Converted to					
Platform	From	fin	blue	sei	humpback	sperm	Total
1	'unidentified large whale'	24	0	1	1	6	32
2	'unidentified large whale'	8	0	1	0	1	10
1	fin	-	0	0	0	1	1
2	fin	-	0	0	0	1	1
Total		32	0	2	1	9	44

Table 5. Species identification and reclassifications based on judged duplicate sightings and additional information from the two platforms, data 1996-2001.

		Converted to					
Platform	From	fin	blue	sei	humpback	sperm	Total
1	'unidentified large whale'	16	1	0	3	3	23
2	'unidentified large whale'	29	1	0	3	7	40
1	fin	-	0	0	0	1	1
1	sperm	0	0	0	1	-	1
Total		**45**	**2**	**0**	**7**	**11**	**65**

For the 1995 data a half normal model gave the best fit to the combined platform data grouped and truncated at a perpendicular distance of 3,000 m, and again smearing was used with smearing parameters ϕ = 5° and s = 0.5. The fitted detection function is shown in Fig. 7 and resulted in an esw of 1,197 m and a survey estimate of 4,319 animals (cv 0.20). Detailed results are given in Table 10.

For the 1996-2001 data set, a hazard rate model was found to give the best fit to the combined platform data grouped, truncated at a perpendicular distance of 3,000 m and smeared with smearing parameters ϕ = 5° and s = 0.5. The fitted detection function is shown in Fig. 7 and resulted in an esw of 1,066 m and a total survey estimate of 6,375 animals (cv 0.22). Part of this, which is within the same total area as the 1995 survey, is 6,207 (cv 0.22) animals. Results are summarised in Table 11.

Table 6. Estimated abundance for fin whales for the shipboard survey in 1995, based on the combined data from platforms 1 and 2. Estimates that include single-platform effort are shaded.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE			0.0017682	1.838	1.00	0	0.00057923	1.841	277	1.841	12	6,290
GA			0.0027151	0.537	2.00	0	0.0017788	0.546	283	0.546	59	1,363
KO									0			
FI			0.0067250	0.822	2.60	0.432	0.0057277	0.934	539	0.934	68	4,284
NOS			0.0011206	0.710	1.20	0.167	0.00044052	0.735	174	0.753	43	695
LOC			0.0032037	0.627	1.00	0	0.0010495	0.635	98	0.635	27	357
VSI			0.011019	1.978	1.50	0.193	0.0054146	1.990	47	1.990	2	1,020
VSN	1,526	0.0956	0.069825	0.313	1.3156	0.063	0.030093	0.334	590	0.334	290	1,202
VSS			0.023998	0.339	1.7200	0.170	0.013521	0.391	394	0.391	179	867
BAW									0			
BJ			0.02001	0.480	1.1834	0.063	0.0077570	0.493	572	0.493	194	1,684
NON			0.0033158	0.507	1.2500	0.200	0.0013578	0.553	120	0.553	35	409
SV			0.026597	0.257	1.1444	0.087	0.0099708	0.288	869	0.288	439	1,721
SVI			0.0037779	0.956	1.00	0	0.0012376	0.961	162	0.961	13	2,067
NSC									0			
NS									0			
NVN			0.0055346	0.326	1.3333	0.177	0.0024174	0.383	831	0.383	360	1,916
JMC			0.0035111	0.376	1.00	0	0.0011502	0.388	77	0.388	32	187
Total									**5,034**	**0.2091**	**3,314**	**7,647**

DISCUSSION

Estimation problems

The surveys described here were conducted with two platforms on each vessel; these platforms have been operated independently of each other and in a symmetrical way and with naked eye search. This is a specific adaptation of sightings procedures to the estimation method that we have implemented for minke whales (Skaug *et al.* 2004) but this also implies that the data collection may not be optimal for other species sighted during these surveys. One specific concern is about large whale sightings, which usually are seen at much larger distances than minke whales and smaller cetacean species for which detection cues usually are parts of the body in our waters.

For example, some negative bias is probably introduced in the estimates due to the fact that a large portion, about one third, of the large whale sightings made during the Norwegian sightings surveys has been classified as 'unidentified large whale'. At least 3 factors contribute to this situation: The surveys are conducted in passing mode where no sightings are closed upon; the target species is minke whale with much closer detection distances; and the observers are doing naked eye search. The passing mode status is due to the tracking procedure developed for minke whales and leads to a dominating focus on the search for this species. The effective search half-width for minke whales (Skaug *et al.* 2004) are in the range half to one third of that for fin, humpback and sperm whales in these surveys and thus detection of large whales may be influenced by the search pattern implemented for minke whales. The observers are instructed to dedicate the effort to minke whales and minke whale tracking which may potentially compromise observation of other species, especially at large distances. Binoculars are used to aid species identification but the identity is yet often not revealed. An examination of effective search half-widths for 'unidentified large whale' sightings resulted in estimates of 2,063 m (cv 0.0739) in 1995 and 2,023 m (cv 0.0674) in 1996-2001, indicating that they, on an average, are associated with larger sightings distances. It would therefore be expected that the unidentified sightings will not bias the estimates proportionally as much as their occurrence in the data set.

While sighting rates and expected school sizes have been estimated by block, the effective search widths have been fitted over each of the surveys since most blocks do not have a sufficient number of sightings to warrant separate detection functions to be fitted. Pooling robustness may however be questioned and a bias of unknown direction expected. It may be assumed that the bias should not be very large because the dominating blocks also have the highest estimates. In this connection it would also be appropriate to mention that the apparently worse weather conditions during the second survey could compromise the comparison of results between them since the estimates provided here are based on the assumption that $g(0)=1$.

For the 1995 survey, sighting rates under the analysis concept used here are negatively biased because 19% of total primary effort that year was conducted with only one of the two search platforms in operation (Schweder *et al.* 1997). Since there were specific blocks where single-platform data were collected, the effect is expected to be minor for fin whales and sperm whales, and of some concern for humpback whales. This is because most of the humpback whales in 1995 were clumped around Bear Island, within a block with a high proportion of single platform search.

The estimates presented here have not been corrected for detection and availability bias. While availability bias may be a serious concern for sperm whale estimates, given that these whales have long dive times (up to an hour), this is not expected to be of great importance to the fin and humpback whale estimates since these whales have a behaviour which includes frequent surfacings. Neither would detection bias be expected to be a large problem for any of these species since they either have conspicuous blows or show apparent behaviour at the surface. An analysis of $g(0)$ for fin whale data using mark-recapture distance sampling assuming point independence (Øien and Bøthun MS 2006), indicated $g(0)$ ranges for the single primary platform of 0.71-0.75 and for the combined platform 0.91-0.94. Although recognising that mark-recapture estimators may be positively biased especially with respect to handling availability issues, the combined platform analyses as have been used in most of the estimates presented in this paper,

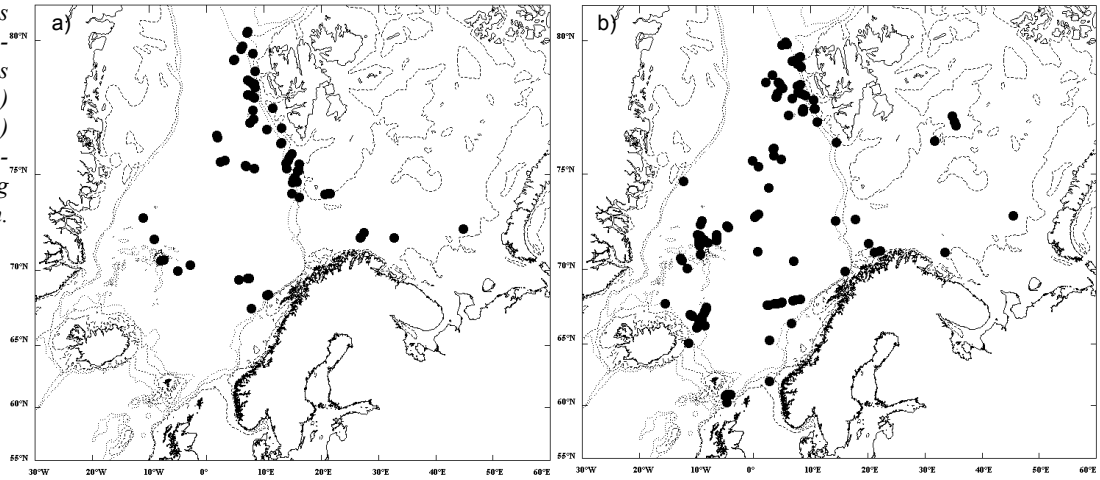

Fig. 2. *Distributions of sightings recorded as fin whales during the 1995 (a) and 1996-2001 (b) surveys from the upper platform during primary search.*

seem to indicate that the $g(0)=1$ assumption is of minor importance, at least for fin whales. However, both analyses are dependent on post-cruise duplicate judgements for which no uncertainty is accounted for in the final estimates of variance.

Fin whales

In 1995, most sightings were made in the Svalbard area, that is, along the continental slope from Bear Island and northwards to the northwest of Spitsbergen (survey blocks BJ, VSS and VSN). In the 1996-2001 survey period no fin whales were recorded on primary transects in the stratum around Bear Island, however, more fin whales were observed in the western and southern parts of the Norwegian Sea and around Jan Mayen. Investigations of stomach contents from fin whales caught in previous catch operations indicate that they are primarily feeding on krill species (Christensen *et al.* 1992b). The general distributions of fin whales as seen during the surveys described here are well in accordance with distributions of krill as revealed in trawl catches on research vessels of the Institute of Marine Research over the period 1990-1999 (Melle *et al.* 2004). Compared to pre-1995 surveys, the 1995-2001 distributions were more northerly; in 1988 fin whales were observed around Jan Mayen and within the Norwegian Sea; in 1989 there were two distinct occurrences, one in the northern Norwegian Sea and one in the Norwegian Sea west of northern Norway (Jan Mayen was not surveyed that year) (Øien 1990, Christensen *et al.* 1992).

When excluding the survey block NVS comprising the waters to the north and east of Iceland, there is no statistically significant increase in fin whale abundance in the survey area of the Norwegian vessels, and the same three blocks, NVN, SV and VSN, had the highest block abundance and accounted for 45% of the survey estimates both years. The three mentioned blocks are all on a potential migratory route along the ice edg-

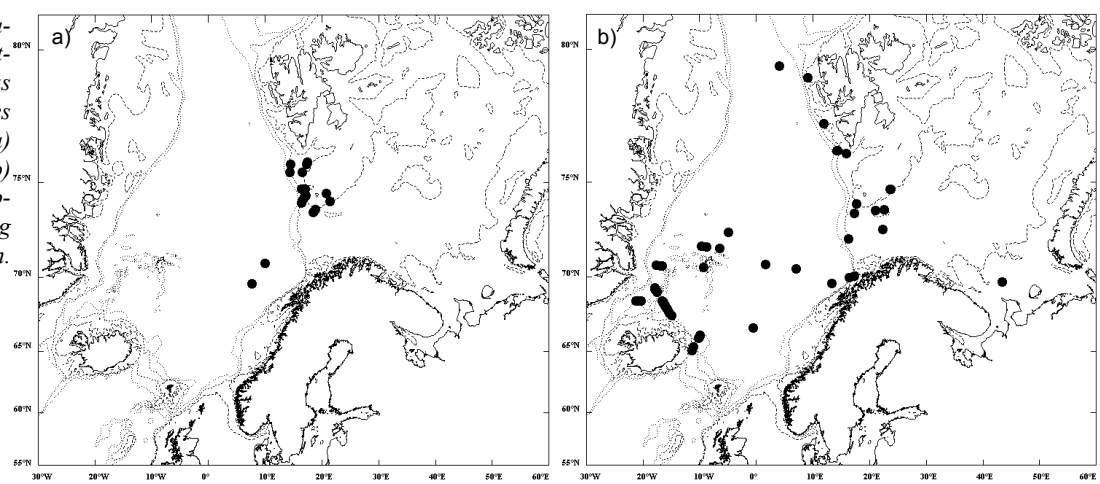

Fig.3. *Distributions of sightings recorded as humpback whales during the 1995 (a) and 1996-2001 (b) surveys from the upper platform during primary search.*

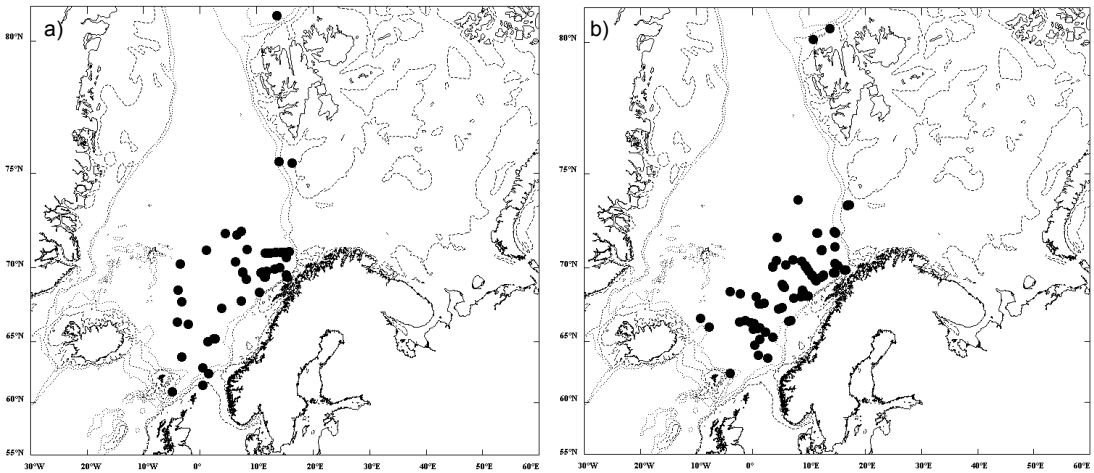

Fig.4. *Distributions of sightings recorded as sperm whales during the 1995 (a) and 1996-2001 (b) surveys from the upper platform during primary search.*

es between the Denmark Strait and Jan Mayen area and Svalbard, and may therefore represent migratory extensions of an Icelandic fin whale population. As described in Vikingsson *et al.* (2009) the main occurrence of fin whales in the Northeast Atlantic is found in Icelandic waters, while fin whales in Norwegian waters account for about 20% of the total abundance in the area.

Humpback whales

In 1995 the sightings were nearly exclusively made in the Bear Island shelf area, which is known to be an important habitat for humpbacks in summer time. Compared to earlier surveys, however, the 1995 distribution was much more focused around Bear Island, as both in 1988 and in 1989 most of the humpback whale observations were made in the Norwegian Sea far west off the continental slope. Within the Bear Island block (BJ) school sizes in 1995 varied between 1 and 5 animals, while in all other blocks observations were of single animals, thus indicating that in July 1995 a specific aggregation of humpbacks took place around Bear Island. The distribution of humpbacks over the 1996-2001 period showed a striking contrast to the 1995 distribution as the observations were more evenly spread out over a larger area more in line with the 1988 and 1989 distributions. During the period 1996-2001 the waters north and northeast of Iceland (survey block NVS) were also surveyed by Norwegian vessels and revealed a high abundance of humpbacks in the area of 3,200 animals (95% CI 1,140-9,260). Paxton *et al.* (2009) estimated an abundance of 10,521 (95% CI 3,716-24,636) humpbacks in the Icelandic component of NASS-95 and about 80% of these could be attributed to largely the same area as our survey block NVS. Although numerically not as high as found in Paxton *et al.* (2009), the estimate seems to confirm the general view that Icelandic waters hold a considerable population of summering humpbacks which may question the North Atlantic ocean-wide estimate of about 10,500 based on genetic and photo ID mark-recapture data (Smith *et al.* 1999).

The estimates derived in this paper do not indicate any changes over the years in summer abundance of humpbacks in the Barents and Norwegian Seas, bearing in mind that the 1995 estimate may be negatively biased.

Sperm whales

Most sperm whales were sighted in the Norwegian Sea off the continental slope west of northern Norway, and a few blocks in this area were the main contributors to the sperm whale abundance estimates both for 1995 and 1996-2001. Considerable numbers of sightings were relatively evenly spread out over most of the Norwegian Sea south of about 73°N. A few sightings have also been made far north of Spitsbergen, which is quite unexpected from what we have usually thought about their occurrence in these waters (Rice 1998). The 1995 and 1996-2001 distributions are relatively similar to the 1989 survey distribution, except that more whales were observed in the southern Norwegian Sea in 1995. The 1988 sperm whale survey distribution showed the same patterns in the northern Norwegian Sea, but in that survey the southern part was not covered (Christensen *et al.* 1992a).

Although not statistically significant, there are indications that the summer abundance of sperm whales in the central Norwegian Sea has increased over the years, especially with reference to the survey block NOS.

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Table 7.
Estimated abundance for fin whales for the shipboard surveys 1996-2001, based on the combined data from platforms 1 and 2.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE			0.00211132	0.5669	1.2857	0.1434	0.00098589	0.5910	485	0.591	155	1,514
GA			0.0019775	0.9647	1.00	0	0.00071756	0.9684	114	0.968	12	1,078
KO									0			
FI			0.0041671	0.4839	1.4286	0.1414	0.0021601	0.5113	203	0.511	69	596
NOS			0.00090504	0.4889	1.00	0	0.00032841	0.4963	129	0.496	48	352
LOC			0.0004985	0.8654	1.00	0	0.00018089	0.8696	17	0.870	3	90
VSI									0			
VSN	1,378	0.0855	0.067163	0.2708	1.3030	0.0623	0.031756	0.2907	623	0.291	315	1,231
VSS			0.023395	0.6302	1.500	0.0861	0.012734	0.6418	371	0.642	90	1,523
BAW									0			
BJ									0			
NON									0			
SV			0.029065	0.3763	1.3667	0.0822	0.014414	0.3945	1,319	0.3945	521	3,341
SVI			0.0055819	0.2716	1.00	0	0.0020255	0.2848	383	0.285	199	738
NSC			0.0036135	0.6403	1.200	0.1667	0.0015735	0.6671	486	0.667	124	1,901
NS									0			
NVN			0.0078847	0.4885	1.0312	0.0472	0.0029504	0.4980	958	0.4980	334	2,747
JMC			0.048665	0.3432	1.1170	0.0579	0.019724	0.3579	1,319	0.358	532	3,271
NVS			0.026876	0.526	1.3556	0.0747	0.01322	0.5382	3,960	0.538	1,259	12,450
Total									**10,369**	**0.240**	**6,277**	**17,128**

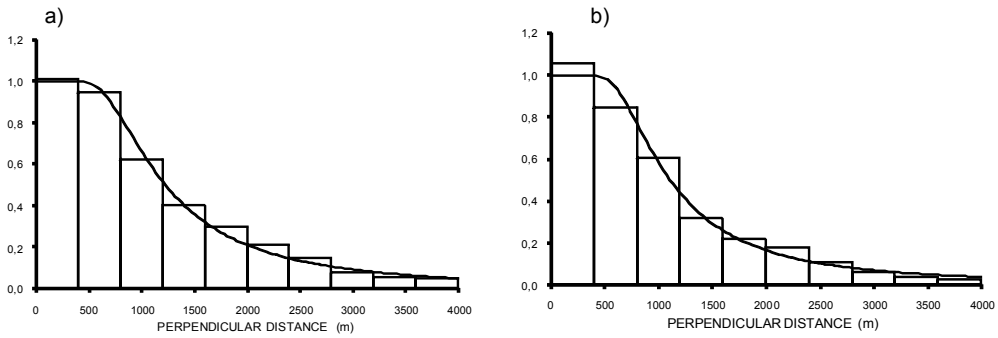

Fig. 5. *Detection functions for fin whales combined for platforms 1 and 2 from (a) the 1995 survey and (b) the 1996-2001 surveys. The vertical axis shows the detection probability.*

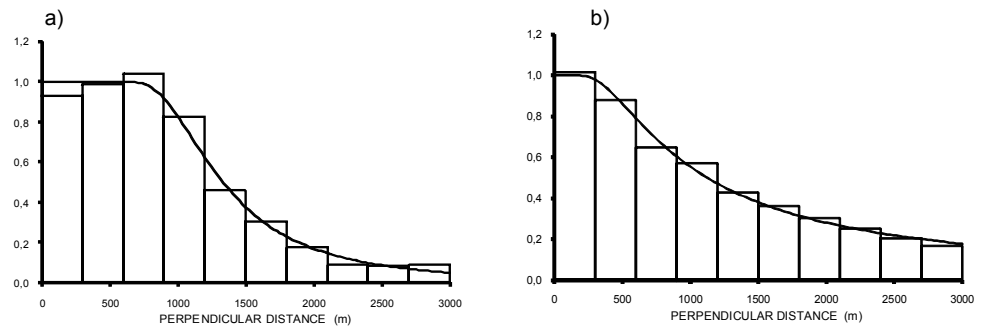

Fig. 6. *Detection functions for humpback whales combined for platforms 1 and 2 from the 1995 survey (a) and from the 1996-2001 survey (b). The vertical axis shows the detection probability.*

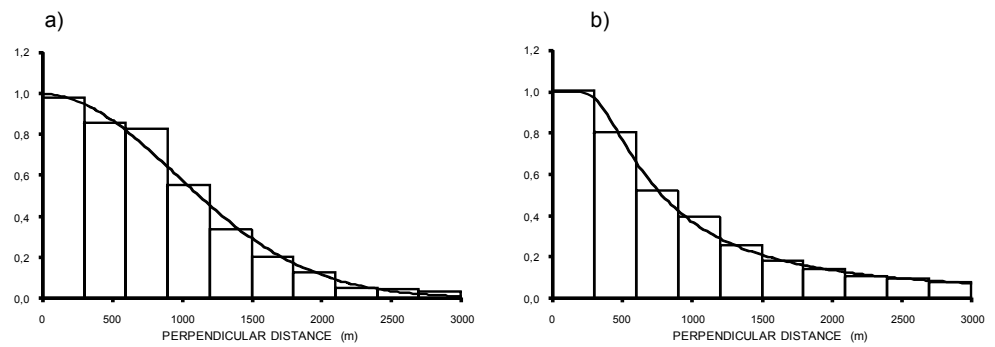

Fig. 7. *Detection function for sperm whales combined for platforms 1 and 2 from the 1995 survey (a) and from the 1996-2001 survey (b). The vertical axis shows the detection probability.*

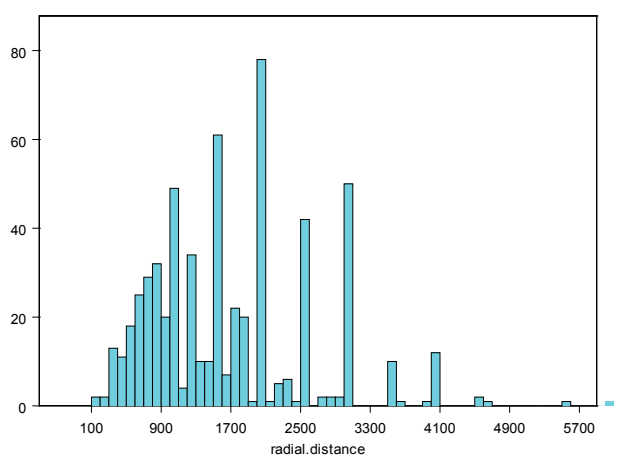

Fig. 8. *Histogram of radial distances recorded for all sightings of large whales (unidentified, fin, humpback and sperm whales) in the 1995 survey. Rounding seems to be especially apparent for distances above 1000 m.*

Table 8. Estimated abundance for humpback whales for the shipboard survey in 1995, based on the combined data from platforms 1 and 2. Estimates that include single-platform effort are shaded.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE									0			
GA			0.0013575	0.537	1.00	0	0.00045438	0.559	72	0.559	16	334
KO			0.0013842	1.061	1.00	0	0.00046331	1.072	44	1.072	3	661
FI									0			
NOS			0.0015689	0.318	1.00	0	0.00052512	0.353	207	0.353	102	421
LOC									0			
VSI									0			
VSN	1,494	0.1544							0			
VSS									0			
BAW									0			
BJ			0.016367	0.252	1.6246	0.102	0.0088997	0.312	656	0.312	344	1,253
NON			0.00082896	0.846	1.00	0	0.00027746	0.860	24	0.860	4	160
SV									0			
SVI			0.0012593	0.824	1.00	0	0.00042150	0.838	55	0.838	6	517
NSC									0			
NS									0			
NVN									0			
JMC									0			
Total									**1,059**	**0.2480**	**645**	**1,738**

Table 9. Estimated abundance for humpback whales for the shipboard surveys 1996-2001, based on the combined data from platforms 1 and 2.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE									0			
GA			0.00098874	0.6843	1.00	0	0.00034204	0.717	54	0.717	10	291
KO									0			
FI			0.0011906	0.5259	2.0	0.50	0.00082373	0.757	78	0.757	13	461
NOS			0.00067878	0.5675	1.333	0.25	0.00031308	0.656	123	0.656	35	431
LOC									0			
VSI									0			
VSN	1,445	0.2148	0.0020865	0.9355	1.00	0	0.00072178	0.960	14	0.960	2	107
VSS			0.011335	0.63	1,50	0.1782	0.0058819	0.689	171	0.689	41	710
BAW			0.0035495	0.4795	1.6667	0.20	0.0020465	0.562	252	0.562	68	940
BJ			0.0056403	0.5718	1.00	0	0.0019512	0.611	144	0.611	34	601
NON			0.0010642	0.9451	1.00	0	0.00036814	0.969	32	0.969	4	248
SV			0.00085024	1.1822	1.00	0	0.00029413	1.202	27	1.202	2	292
SVI									0			
NSC			0.00036135	0.9246	1.00	0	0.000125	0.949	39	0.949	6	238
NS									0			
NVN			0.0010513	0.7745	1.5	0.333	0.00054551	0.870	177	0.870	34	926
JMC			0.0081108	0.2451	1.80	0.208	0.0050504	0.387	338	0.387	153	745
NVS			0.025171	0.4597	1.2444	0.0683	0.010836	0.512	3,246	0.512	1,137	9,264
Total									**4,695**	**0.391**	**2,124**	**10,378**

Table 10. Estimated abundance for sperm whales for the shipboard survey in 1995, based on the combined data from platforms 1 and 2. Estimates that include single-platform effort are shaded.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE			0.00088410	1.084	1.00	0	0.00036941	1.087	177	1.087	18	1,701
GA									0			
KO									0			
FI									0			
NOS			0.011064	0.274	1.0400	0.0269	0.0048078	0.287	1,896	0.287	1050	3,421
LOC			0.0032037	0.691	1.20	0.200	0.0016064	0.715	151	0.715	37	617
VSI			0.0055097	0.481	2.00	0	0.0046043	0.488	40	0.488	13	122
VSN	1,197	0.0791	0.0025316	1.032	1.00	0	0.0010578	1.035	21	1.035	3	142
VSS									0			
BAW									0			
BJ			0.0020651	1.154	1.6667	0.200	0.0014381	1.174	106	1.174	12	932
NON									0			
SV			0.0022457	0.552	1.00	0	0.00093834	0.558	82	0.558	20	339
SVI									0			
NSC			0.0048092	0.339	1.2308	0.135	0.0024731	0.374	764	0.374	358	1,630
NS									0			
NVN			0.0062860	0.401	1.20	0.111	0.0031518	0.423	1,083	0.423	404	2,901
JMC									0			
Total									**4,319**	**0.1987**	**2,903**	**6,424**

Table 11. Estimated abundance for sperm whales for the shipboard surveys 1996-2001, based on the combined data from platforms 1 and 2.

Survey block	*esw*		Sighting rate (no. per km)		School size		Density (no. per km²)		Abundance		95% confidence interval	
	estimate	cv	estimate	cv	estimate	cv	estimate	cv	estimate	cv	lower	upper
BAE			0.00030188	1.121	1.00	0	0.0001416	1.128	70	1.128	10	466
GA									0			
KO									0			
FI									0			
NOS			0.019431	0.220	1.1124	0.0303	0.010139	0.258	3,997	0.258	2,373	6,733
LOC			0.016786	0.562	1.0294	0.0286	0.0081054	0.578	761	0.578	234	2,472
VSI			0.0045568	0.634	1.00	0	0.0021374	0.648	19	0.648	5	71
VSN									0			
VSS	1,066	0.1320							0			
BAW									0			
BJ			0.0048748	0.769	1.25	0.200	0.0028582	0.805	211	0.805	33	1,330
NON			0.0021284	0.458	1.00	0	0.00099833	0.477	88	0.477	29	268
SV									0			
SVI									0			
NSC			0.0014454	0.385	1.25	0.200	0.0008475	0.453	262	0.453	103	667
NS									0			
NVN			0.0042052	0.477	1.25	0.1309	0.0024656	0.512	801	0.512	280	2,294
JMC									0			
NVS			0.00059649	0.743	2.00	0	0.0005596	0.755	168	0.755	36	775
Total									**6,375**	**0.216**	**4,163**	**9,762**

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