Estimates of large whale abundance in Greenlandic waters from a ship-based survey in 2005

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ABSTRACT

A ship-based line transect survey of large whales in East and West Greenland was conducted in September 2005. The survey platform primarily targeted capelin, *Mallotus villosus*, using acoustic methods and systematically covered the east and west coasts of Greenland from the coast to the shelf break (approximately 200m). The surveyed area comprised 81,000km² in East Greenland and 225,000km² in West Greenland. A total of 194 sightings of 13 cetacean species were obtained and standard line transect methods were used to derive abundance estimates of the four most commonly encountered large cetaceans. Fin whales, *Balaenoptera physalus*, were most abundant in East Greenland (3,214, 95% CI=980-10,547) with lower abundances estimated for West Greenland (1,980, 95% CI=913-4,296). Sei whales, *B. borealis*, were frequently encountered in the same areas as fin whales, but the estimated abundance in East Greenland (763, 95% CI=236-2,465) was lower than in West Greenland (1,599, 95% CI=690-3,705). Humpback whales, *Megaptera novaeangliae*, were found both in offshore and coastal areas of West Greenland (1,306, 95% CI=570-2,989) and in low numbers in East Greenland (347, 95% CI=48-2,515). Finally, common minke whale, *B. acutorostrata*, abundance was estimated at 1,848 (95% CI=197-17,348) for East Greenland and 4,479 (95% CI=1,760-11,394) for West Greenland. Inclusion of sightings of unidentified large baleen whales in West Greenland distributed in proportion to species and strata increased abundance estimates for fin, sei, and humpback whales to 2,824 (95% CI=1,346-5,925), 2,009 (95% CI=948-4,260), and 1,514 (95% CI=560-4,089), respectively. Despite good conditions and considerable effort, few cetaceans were observed in the northernmost strata in West Greenland. This suggests that the southbound fall migration of large whales from North West Greenland had already started by the time the survey was initiated. The abundance estimates presented in this study are negatively biased. No corrections were applied for whales missed by observers or for whales submerged during the passage of the survey platform, which should cause a particularly large negative bias, for the estimates of common minke whale abundance.

KEYWORDS: FIN WHALE; COMMON MINKE WHALE; HUMPBACK WHALE; SEI WHALE; SURVEY-VESSEL; NORTHERN HEMISPHERE; ABUNDANCE ESTIMATE; *g*(0); DISTRIBUTION

INTRODUCTION

Information on the abundance of large whales in Greenland waters, including fin whales, *Balaenoptera physalus*, sei whales, *B. borealis*, humpback whales, *Megaptera novaeangliae*, and common minke whales, *B. acutorostrata*, is scarce and outdated. During 1982/83, the first ship-based cetacean sighting surveys were conducted in West Greenland by the Greenland Fisheries Research Institute (m/v *Regina Maris* and m/v *Kathleen*). Inclement weather conditions prevented the collection of sufficient sightings for abundance estimates from these surveys and no abundance estimates were calculated. After this, aerial surveys were used as the survey platform to increase coverage during the relatively small window of time when survey conditions are optimal in Greenlandic waters.

Between 1983 and 1993, visual aerial surveys of large cetaceans were conducted nine times in West Greenland. Only two times during this decade (cue-counting surveys in 1987/88 and again in 1993) did the surveys provide useful abundance estimates of large whales (Hiby and Hammond, 1989; Larsen, 1995; Larsen *et al.*, 1989). From these surveys, fin whale abundance was estimated at 1,096 (95% CI=520-2,100) in West Greenland in 1987/88 (IWC, 1992). In 1993, another estimate of approximately 200 fin whales was obtained, but was considered unrealistically low due to poor survey coverage (Larsen, 1995). In 2002 and 2004, visual aerial photographic surveys were conducted (Witting and Kingsley, 2005) and resulted in an estimated abundance of fin whales (980, 95% CI=402-2,392), similar to that obtained in 1987/88.

Abundance estimates of common minke whales were also obtained from the cue counting survey in 1993 and were estimated at 8,371 (95% CI=2,414-16,929) whales in West Greenland (Larsen, 1995). This estimate was larger (but not significantly different) than the estimate obtained on the 1987/88 survey (3,266 common minke whales, 95% CI=1,700-5,710) (IWC, 1990, p.43). The visual photographic surveys in 2002 and 2004 resulted in an abundance estimate of only 510 common minke whales (95% CI=138-1,889). This estimate was considered problematic for a number of reasons, including the fact that it seemed unrealistically low because the annual take in West Greenland (about 170 common minke whales) has remained relatively stable for the past 20 years (for a full discussion see [2006]). Sei whale abundance has never been estimated in Greenland.

Humpback whale abundance has been estimated in Greenland based on visual and photographic surveys, as well as photo-identification (ID) techniques. Photo-ID surveys for humpback whale abundance were conducted off West Greenland in July and August 1988-93 (Larsen and Hammond, 2004). The surveys covered the coast between 62° and 66°N offshore to the 200m depth contour. A combined estimate over five years of surveys resulted in an estimate of 360 humpback whales (95% CI=314-413) in summer. Other estimates of humpback whale abundance in West Greenland include a line transect analysis of the visual aerial survey data from 1993 (Kingsley and Witting, 2001), which resulted in an uncorrected estimate of 599 (95% CI=237-1,512), as well as an estimate of 400 humpbacks based on sightings of 3 whales (CV=0.64) collected during aerial photographic surveys in 2002 and 2004 and the assumption that humpback whales spend a quarter of their time at the surface. However, no variance was associated with the coarse correction factor applied to these data (Witting and Kingsley, 2005).

It is important to notice that except for the photographic surveys in 2002-04, all previous surveys were conducted between mid July and late-August to cover the peak occurrence of common minke whales along the West Greenland coast. In particular common minke whales have shown affinity for southbound movements in September (Heide-Jørgensen *et al.*, 2001; Víkingsson and Heide-Jørgensen, 2005) and surveys conducted in September may not capture all of the whales found earlier in the summer.

In 2004, the Scientific Committee of the International Whaling Commission (IWC) had stated that it is difficult to provide satisfactory advice on sustainable takes from Greenlandic stocks without recent and robust abundance estimates (IWC, 2005). Available estimates of all large baleen whale abundance in West Greenland waters at that time were either outdated or unreliable. Thus, there was an urgent need for abundance estimates in Greenland given that common minke and fin whales are taken annually in Greenlandic waters, with removals in West Greenland between 1999-2004 averaging 172 common minke whales and 9 fin whales. Additionally, a total of 9 humpback whales were caught in 2004/05 as bycatch in pond nets and in a crab fishery that utilises bottom traps attached to surface buoys.

This manuscript reports on a ship-based survey of large cetaceans conducted in West and East Greenland in September 2005. Abundance estimates were developed for all large whale species where sufficient sightings were available. These provide updated abundance estimates for large cetaceans in Greenland waters as well as updating knowledge on distribution and numbers at both coasts. A simultaneous aerial survey provided additional information about abundance and distribution of large whales in West Greenland (Heide-Jørgensen *et al.*, 2007).

METHODS

Field methods

The Icelandic fisheries research vessel r/v *Bjarni Saemundsson* RE 30 (length 56m and height to upper deck 7m) was used as the platform for the sighting survey. The survey was conducted between 2 September and 3 October 2005 during a systematic acoustic survey targeting capelin, *Mallotus villosus*, on the West and East Greenland shelf.

Observations were made from a wooden box (length: 180cm, width: 226cm, height of walls: 145cm) built with an effective windshield on the roof of the bridge. Four cetacean observers scanned in pairs from the main platform, each covering 90 degrees in front of the vessel. Observers had an angle board mounted in front of them and a distance stick on a string around their neck. The length of the strings was such that one mm from the horizon corresponded to a declination angle of 0.1 degree, when measuring standing on the observation platform. The eye height of the observers was approximately 10.3m above sea level. When a whale or a cue of a whale was observed, the observer immediately measured the angle to the sighting with the angle board and the distance from the horizon to the sighting with the distance stick, which was later converted into distance from the boat to the whale. When the horizon was not visible or in the instances when a sighting was too brief for the observer to measure both angle and distance, the observer would estimate the distance by eye.

The observers were trained to estimate distances through distance estimation experiments, where a zodiac with a radar reflector was placed at distances between 100-1,600m to the boat (within the survey field). The observers estimated the distance by eye and then measured the distance using distance sticks. The real distance to the zodiac was measured with a laser rangefinder (Zeiss, Halem II) and the radar of the ship by the captain. Initially all observers' slightly underestimated distances exceeding 1,000m, both when estimated by eye and when measured with distance sticks. This underestimation was likely to have been reduced after the distance training, as the observers became aware of the bias. A second distance estimation experiment was scheduled to test this, but it could not be carried out due to low visibility and bad weather.

The observers only used binoculars for species identification after recording a whale sighting. On-effort observations were carried out during all hours of daylight and when weather conditions permitted (Beaufort sea state <6 and visibility >500m).

Measurements of angle and distance were noted in a sighting log together with date, time, position, group size and composition, swimming direction and surface behaviour. An effort log was kept every half hour or less if observation conditions changed. The effort log contained information about the date, time, location, bearing of the ship, weather and visibility. Positional information was obtained with a handheld Global Positioning System (GPS) or from instruments on the bridge.

The survey was designed to systematically cover the area between the coast of West Greenland and offshore (up to 100km) to the shelf break. Transect lines were placed in an east-west direction and the survey started at the northernmost lines. Some fjord areas including Vaigat, Disko Bay and Nuuk Fjord were also covered. Ferry time between Iceland and the surveyed area in West Greenland was used for whale sightings as weather permitted. Based on expected densities of whales the surveyed area was divided into 6 strata, with 1 stratum in East Greenland and 5 strata in West Greenland (Fig. 1). The Disko Bay area and the Nuuk Fjord were considered separate strata.

Analysis

Abundances of fin, sei, humpback and common minke whales were estimated using *Distance* 4.1 (Thomas *et al.*, 2001). Based on the minimum Akaike Information Criteria (AIC), the half-normal key, $k(y) = \exp(-y^2/(2\times A^2))$, with one cosine adjustment was chosen separately for each species for fitting the detection functions of grouped, perpendicular sighting distances. Effort (L) and sightings (n) during sea states of < Beaufort 6 were included for fin, sei and humpback whales abundance estimations following Buckland *et al.* (1992) and Víkingsson *et al.* (In Press). Only sightings and effort at sea states of < Beaufort 3 were included in the calculation of common minke whale abundance. Different right truncations were chosen for each species and common detection functions for all strata were derived. On-effort sightings in standard survey mode outside strata were included in the detection functions and in pod size estimates, but not in encounter rates (Table 1). Except for common minke whales, where all sightings were of individual whales, pod sizes combined for all strata were estimated by regression of *ln*(pod size) against the estimated probability of detection (Buckland *et al.*, 2001). Encounter rate, n/L, and the empirical variance was estimated and used to derive standard errors following Buckland *et al.* (2001). Confidence intervals were calculated following Burnham *et al.* (1987, p.212), assuming the abundance estimates had a log-normal distribution.

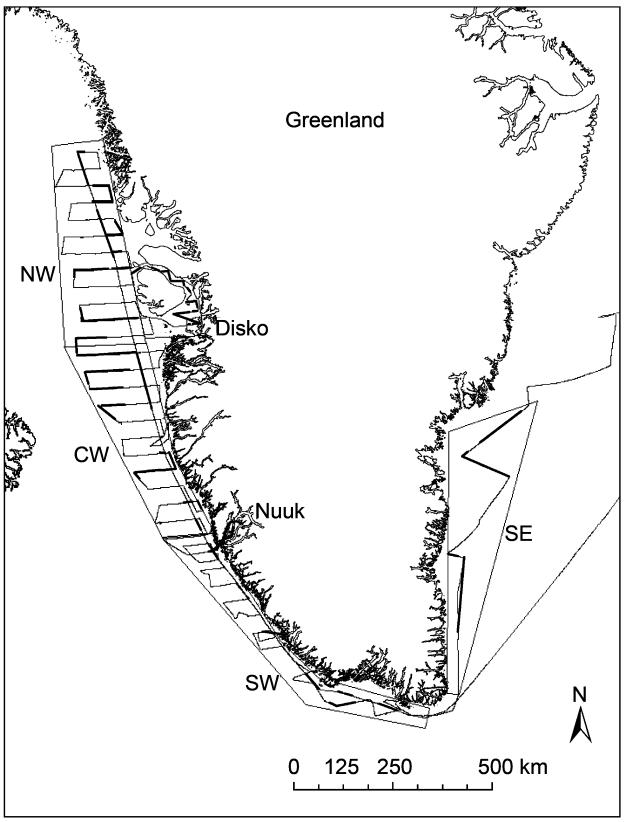

Fig. 1. Survey transect lines (thin lines), realised survey effort (thick lines) and delineation of strata for the ship-based survey of large cetaceans in Greenland in September 2005 in Beaufort sea states <6.

RESULTS

A total of 222 hours of on-effort observations were made where approximately 1,622 n.miles were covered in sea states < Beaufort 5 and 760 n.miles were covered in sea states of <3 (Fig. 1). During the survey, 194 sightings of 531 individual whales were made, including 13 different species (Table 1). The largest species diversity was observed in the Denmark Strait and off East Greenland's coast, where 11 of the 13 cetacean species were seen. No cetaceans were observed north of the Disko Bay in West Greenland (Fig. 1).

Distribution of whales

Six species of baleen whales were seen: blue whales (*Balaenoptera musculus*); fin whales; common minke whales; sei whales; humpback whales; and right whales (*Eubalaena glacialis*). Fin whales were most often found in dense aggregations in offshore areas, particularly along the East Greenland coast and southwest of Disko Bay. Sei whales did not extend as far north, but were otherwise found in the same areas as fin whales. Common minke whales were observed in the same areas as fin whales but in lower numbers. The humpback whale was the only species observed both offshore and inshore (Figs 2 and 3). One northern right whale and two blue whales were observed in East Greenland in the same area (65.1842°N 29.9558°W) on 3 September (Fig. 4).

Sightings of odontocetes included sperm whales, *Physeter macrocephalus*, pilot whales, *Globicephala melas*, white-sided dolphins, *Lagenorhynchus acutus*, white-beaked dolphins, *Lagenorhynchus albirostris*, killer whales, *Orcinus orca* and an unidentified beaked whale. Most odontocetes were seen in East Greenland (Fig. 5). White beaked dolphins were seen close to Cape Farewell and the one unidentified beaked whale, *Ziphiidae sp.*, was seen in a deep canyon between the coastal banks in South West Greenland. Sperm whales were observed off the east coast of Greenland and once in coastal waters on the west coast (Fig. 5).

Abundance estimates

Fin whales were detected at distances of up to 2km and sei whales at distances of up to 2.5km. Sightings were truncated at 1,800m to reduce the effect of measurement error on distant sightings. Both fin and sei whales had a high detection probability up to ~800m from the platform and there was a peak between 50 and 150m close to the trackline. The reason for this peak was not known. The detection function showed a satisfactory fit to the distribution of the 45 perpendicular distances of fin whale sightings (Fig. 6, χ^2 goodness-of-fit statistic not significant, p=0.53) and the effective search half-width (*esw*=944m) could be estimated with low variance (CV=0.12, Table 2). There were no sightings of fin whales in North West Greenland and in Disko Bay and the abundance was higher

Table 1

Sightings of different species of marine mammals during the survey. Observations are included from all Beaufort sea states and areas that are not included in the abundance estimation. In parenthesis are the unidentified sightings apportioned to species.

	Number of sightings				
Species	Total	Used in detection function	Used in abundance estimation	Outside survey region	Number of individuals
Blue whale	2	-	-	-	2
Fin whale	54	45 (57)	41 (53)	4 (4)	87
Sei whale	21	64 (81)	18 (23)	1 (1)	33
Humpback whale	30	26 (29)	21 (24)	5 (5)	46
Unidentified large cetacean	39	-	-	-	48
Northern right whale	1	-	-	-	1
Minke whale	14	12	10	2	14
Sperm whale	10	-	-	-	13
Beaked whale	1	-	-	-	1
Killer whale	2	-	-	-	8
Long-finned pilot whale	2	-	-	-	11
White-beaked dolphin	4	-	-	-	18
Atlantic white-sided dolphin	4	-	-	-	140
Unidentified dolphin	2	-	-	-	100
Harbour porpoise	2	-	-	-	3
Seal	14	-	-	-	79

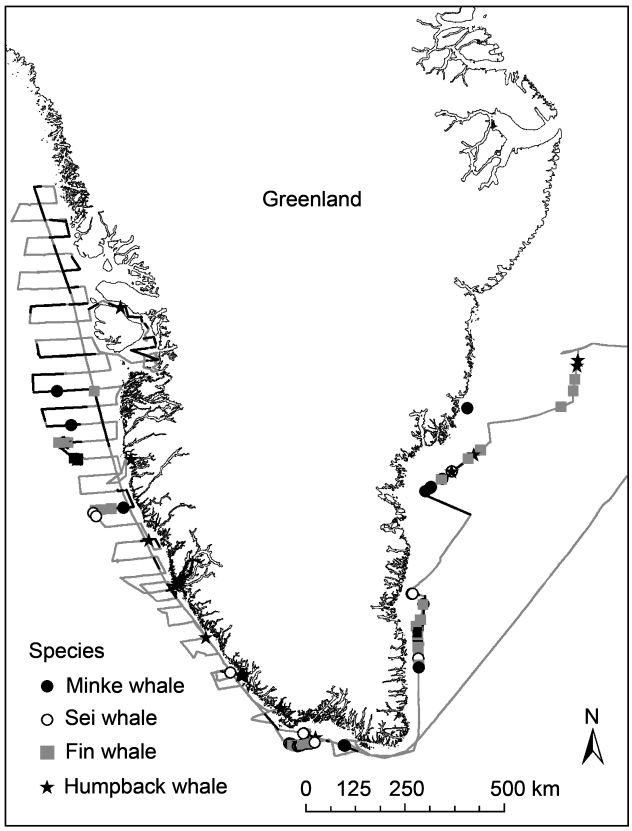

Fig. 2. Sightings of the four large cetaceans targeted in the ship based survey in Greenland September 2005. On-effort sections of transect lines (thick lines) are shown together with the sightings. [●]=common minke whales, [○]=sei whales, [■]=fin whales and [★]=humpback whales.

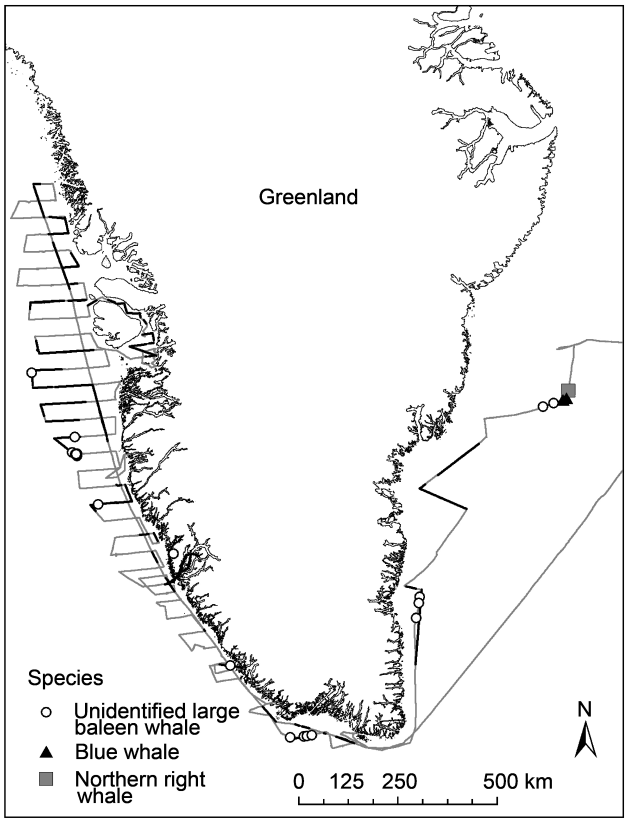

Fig. 4. Sightings of blue whales [▲], northern right whale [■] and unidentified large baleen whales [○].

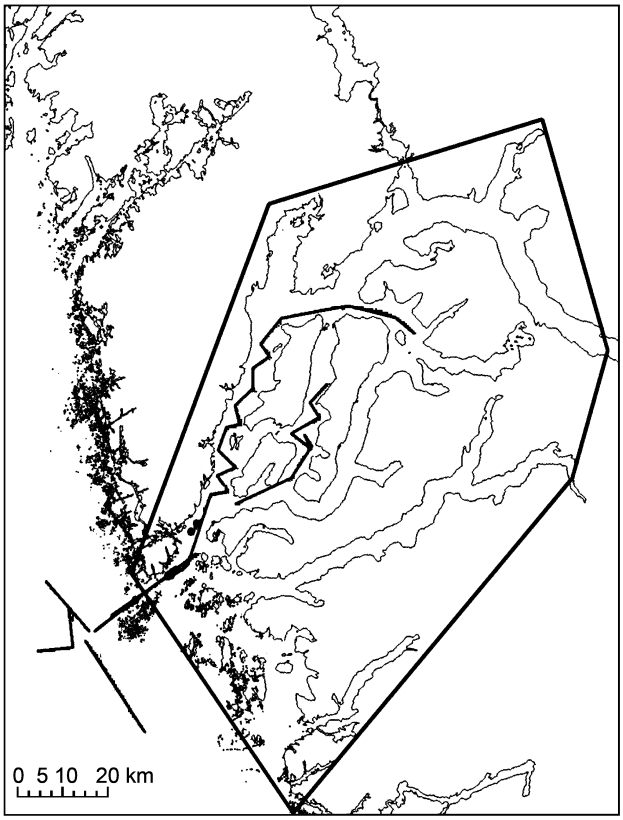

Fig. 3. Effort and sightings of humpback whales inside Nuuk Fjord. The polygon shows the stratum area used for extrapolating the density estimate.

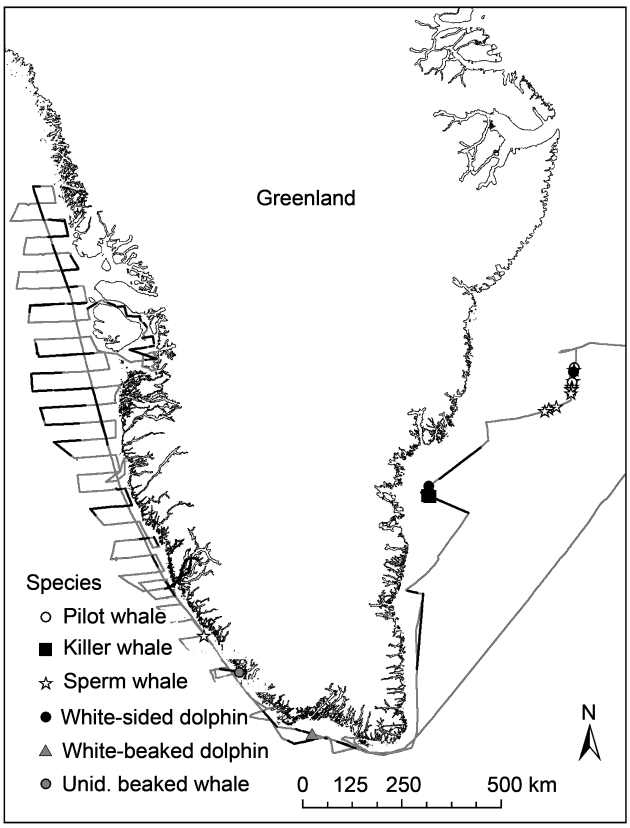

Fig. 5. Sightings of sperm whales [☆], pilot whales [○], white-sided dolphins [●], white-beaked dolphins [△], killer whales [■] and unidentified beaked whale [◍].

in East Greenland (n=3,214 fin whales, CV=0.48) than in South Greenland (i.e. Centralwest and Southwest, n=1,980 fin whales, CV=0.38).

The detection function for the 18 sei whales sightings alone (esw=978m) was very similar to the detection function of the combined sightings of fin whales and sei whales (esw=927m), except that the CV for the sei whales was twice (0.20) the CV for the combined data set (0.10). It was consequently decided to estimate the sei whale abundance utilising both fin and sei whale distance estimates for deriving a common detection function (Fig. 7 and Table 2, χ^2 goodness-of-fit statistic not significant, p=0.62). The largest abundance of sei whales was estimated in the southernmost part of West Greenland (n=1,599 sei whales, CV=0.42) and lower numbers were found in East Greenland (n=763 sei whales, CV=0.47).

Only 27 humpback whale sightings were available for estimating the detection function (Fig. 8) and the detection function provided an esw of 622m (CV=0.15, χ^2 goodness-of-fit statistic not significant, p=0.72). Humpback whales were seen in all strata except for North West Greenland and the largest numbers were found in South Greenland (n=944 humpback whales, CV=0.53) with lower numbers in East Greenland (n=347 humpback whales, CV=0.85, Table 2). A separate abundance estimate was developed for Nuuk Fjord based on 106 n.miles zig-zag coverage of 4.3% of the area of the fjord complex (Fig. 3) and 10 sightings of humpback whales which revealed an abundance of 145 whales (CV=0.38). However, all areas of the fjord were not evenly sampled and the abundance therefore should be used with caution (see Discussion).

Table 2A

Summary statistics for abundance estimates of fin whales and sei whales. For both species only effort during Beaufort sea states <6 was included.

	Fin whale					Sei whale				
Effective search half-width	944m					Fin and sei observations: 927m				
n	45 observations, right truncation >1,800					64 observations, right truncation >1,800				
CV	0.12					0.10				
Stratum	NW	DB	CW	SW	SE	NW	DB	CW	SW	SE
Area of stratum (km^2)	82,518	15,780	72,342	51,684	81,065	82,518	15,780	72,342	51,684	81,065
Sightings (*n*)	0	0	12	8	21	0	0	3	10	5
Effort (*L*) n.miles	449	163	475	177	252	449	163	475	177	252
Transects	18	16	20	15	5	18	16	20	15	5
Sighting rate (*n/L*)	0	0	0.03	0.05	0.08	0	0	0.01	0.06	0.02
CV			0.53	0.52	0.46			1.06	0.44	0.45
Density of pods	0	0	0.01	0.01	0.02	0	0	0.01	0.02	0.01
CV			0.54	0.53	0.48			1.06	0.45	0.46
Expected pod size	0	0	1.7	1.7	1.7	0	0	1.6	1.6	1.6
CV			0.08	0.08	0.08			0.06	0.06	0.06
Density of whales	0	0	0.01	0.02	0.04	0	0	0.01	0.03	0.01
CV			0.55	0.53	0.48			1.06	0.45	0.47
Abundance	0	0	871	1,109	3,214	0	0	217	1,382	726
CV			0.55	0.54	0.48			1.06	0.45	0.47
Total West Greenland	1,980 (CV=0.38, 95% CI=913-4,296)					1,599 (CV=0.42, 95% CI=690-3,705)				
Total East Greenland	3,214 (CV=0.48, 95% CI=980-10,547)					763 (CV=0.47, 95% CI=236-2,465)				

Table 2B

Summary statistics for abundance estimates of humpback whales and minke whales. For humpback whales only effort during Beaufort sea states <6 was included and for minke whales effort was restricted to sea states less than 3.

	Humpback whale						Minke whale				
Effective search half-width	622m						216m				
n	26, right truncation >1,600						12, right truncation >350m				
CV	0.15						0.25				
Stratum	NW	DB	CW	NF	SW	SE	NW	DB	CW	SW	SE
Area of stratum (km^2)	82,518	15,780	72,342	2,843	51,684	81,065	82,518	15,780	72,342	51,684	81,065
Sightings (*n*)	0	1	2	10	6	2	0	0	2	3	5
Effort (*L*)	449	163	475	106	177	252	217	60	149	60	274
Transects	18	16	20	31	15	5	12	8	9	7	8
Sighting rate (*n/L*)	0	0.01	0.01	0.10	0.03	0.01	0	0	0.01	0.05	0.02
CV		1.17	0.89	0.34	0.50	0.83			0.49	0.49	1.21
Density of pods	0	0.01	0.01	0.04	0.01	0.01	0	0	0.02	0.06	0.02
CV		1.18	0.89	0.37	0.52	0.84			0.55	0.55	1.24
Expected pod size	0	1.3	1.3	1.3	1.3	1.3	0	0	1	1	1
CV		0.09	0.09	0.09	0.09	0.09					
Density of whales	0	0.01	0.01	0.05	0.02	0.01	0	0	0.01	0.06	0.02
CV		1.18	0.90	0.38	0.53	0.85			0.55	0.55	1.24
Abundance	0	52	165	145	944	347	0	0	1,219	3,260	1,848
CV		1.18	0.90	0.38	0.53	0.85			0.55	0.55	1.24
Total West Greenland	1,306 (CV=0.42, 95% CI=570-2,989)						4479 (CV=0.46, 95% CI=1,760-11,394)				
Total East Greenland	347 (CV=0.85, 95% CI=48-2,515)						1848 (CV=1.24, 95% CI=197-17,348)				

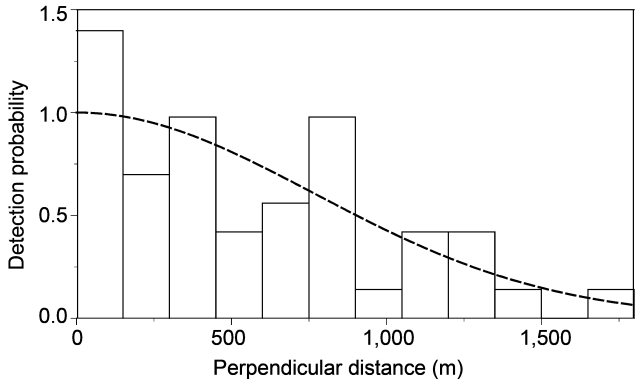

Fig. 6. Detection function for fin whales grouped in 150m intervals (*n*=45).

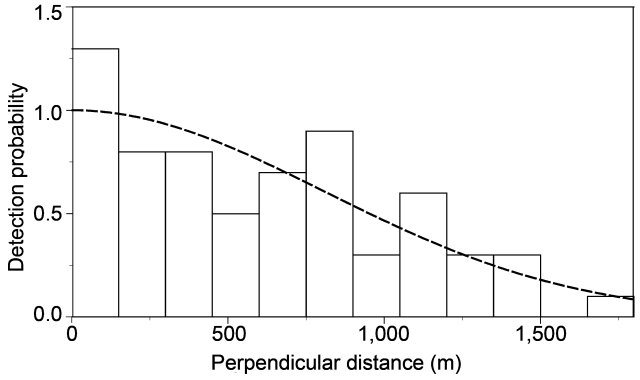

Fig. 7. Detection function for fin and sei whales combined grouped in 150m intervals (*n*=66).

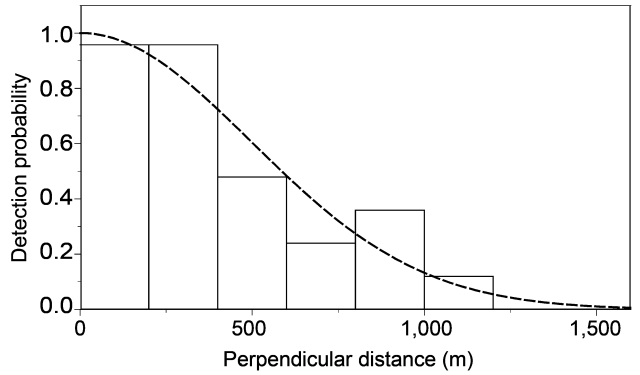

Fig. 8. Detection function for humpback whales grouped in 200m intervals (*n*=26).

Only 12 common minke whales were sighted, including sightings outside strata *en route* to and from Iceland. This low number does not provide sufficient data for a robust estimation of the detection function (Fig. 9). This is also reflected in the relatively large CV (0.25) for determination of the *esw* (216m, χ^2 goodness-of-fit statistic not significant, p=0.65). The low *esw* for common minke whales probably reflects the difficulty in detecting this species. Nevertheless estimates of common minke whale abundance were developed for the three areas where sightings occurred and with effort in sea states of < Beaufort 3 (Fig. 10). The largest numbers of common minke whales were in the southern part of West Greenland (4,479 common minke whales, CV=0.46) with fewer on the east coast (Table 2).

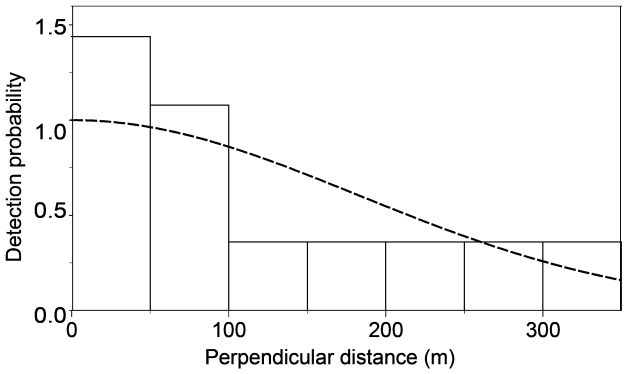

Fig. 9. Detection function for common minke whales grouped in 50m intervals (*n*=12).

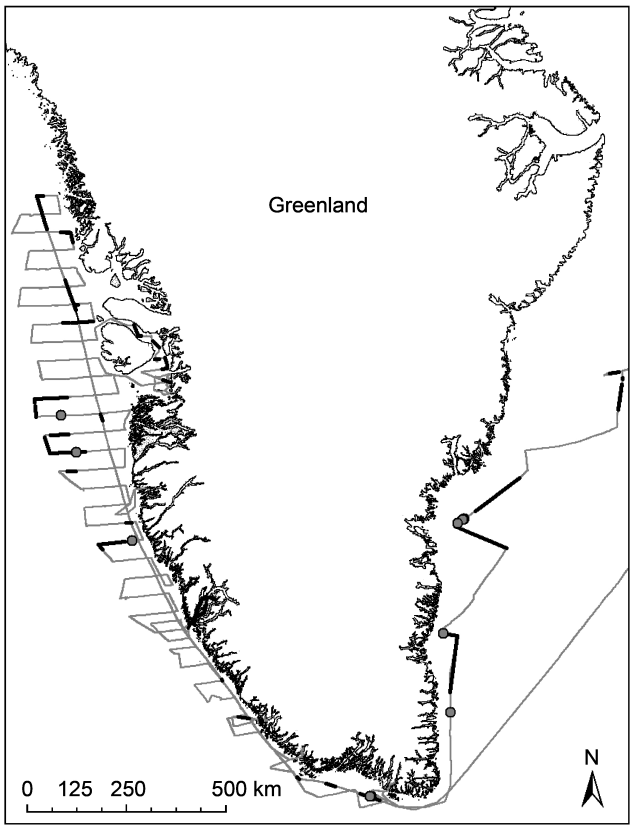

Fig. 10. Survey transect lines (thin lines), realized survey effort (thick lines) in Beaufort sea state <3 and common minke whale sightings.

A total of 35 sightings of blows of unidentified large baleen whales were recorded. In order to include these in more complete abundance estimates, the sightings were attributed to the three possible species (fin, humpback and sei whales, Table 3). The unidentified blows were apportioned to the six strata in proportion to the occurrence of each species in each stratum and the associated distance measurements were apportioned randomly to the three species. Thus, both new encounter rate estimates and new detection functions including variance estimates were derived. The inclusion of unidentified sightings resulted in a 43% increase in the abundance estimate for fin whales in West Greenland (raised to 2,824 fin whales, CV=0.38). The sei whale abundance increased by 26% with a slightly improved precision and the humpback whale abundance estimate increased in West Greenland (by 16%) with lower precision yet declined in East Greenland due to the change in *esw*.

Table 3

Summary statistics for abundance estimates of fin, sei, and humpback whales including unidentified sightings. For both species only effort during Beaufort sea states <6 was included.

	Fin whale			Sei whale			Humpback whale				
Effective search half-width	960m			Fin and sei observations: 982m			718m				
n	57 observ., right truncation >1,800			81 observ., right truncation >1,800			29, right truncation >1,600				
CV	0.11			0.09			0.14				
Stratum	CW	SW	SE	CW	SW	SE	DB	CW	NF	SW	SE
Area of stratum (km^2)	72,342	51,684	81,065	72,342	51,684	81,065	15,780	72,342	2,843	51,684	81,065
Sightings (*n*)	17	11	25	4	13	6	1	3	10	8	2
Effort (*L*) nmi	475	177	252	475	177	252	163	475	106	177	252
Transects	20	15	5	20	15	5	16	20	31	15	5
Sighting rate (*n/L*)	0.01	0.06	0.10	0.01	0.07	0.02	0.01	0.01	0.10	0.05	0.01
CV	0.52	0.50	0.48	0.87	0.39	0.39	1.17	0.89	0.34	0.62	0.83
Density of pods	0.10	0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.01
CV	0.52	0.51	0.50	0.88	0.40	0.41	1.18	0.90	0.37	0.64	0.84
Expected pod size	1.7	1.7	1.7	1.6	1.6	1.6	1.3	1.3	1.3	1.3	1.3
CV	0.07	0.07	0.07	0.06	0.06	0.06	0.09	0.09	0.09	0.09	0.09
Density of whales	0.02	0.03	0.05	0.01	0.03	0.01	0.01	0.01	0.05	0.02	0.01
CV	0.52	0.51	0.50	0.88	0.41	0.41	1.18	0.90	0.38	0.64	0.85
Abundance	1,263	1,562	3,917	279 0.88	1,731	882	46	219	129	1,119	309
CV	0.52	0.51	0.50		0.41	0.41	1.18	0.90	0.38	0.64	0.85
Total West Greenland	2,824 (CV=0.38, 95% CI=1,346-5,925)			2,009 (CV=0.37, 95% CI=948-4,260)			1,514 (CV=0.51, 95% CI=560-4,089)				
Total East Greenland	3,917 (CV=0.50, 95% CI=1,122-13,672)			882 (CV=0.41, 95% CI=313-2,484)			309 (CV=0.85, 95% CI=43-2,240)				

DISCUSSION

Biases and problems with survey design

The sampling design used in this survey was not optimal for a cetacean survey and the realised survey effort was restricted by inclement weather conditions. It can specifically be argued that the South West strata in West Greenland had particularly uneven and poor coverage and that transect lines running parallel to the coast might follow density gradients of whales. One option is to eliminate the part of South West strata with poor coverage from the abundance estimates which reduces the abundance to about 2/3 for both estimates based on identified blows and those where unidentified blows were apportioned to species and strata (Table 4). This, however, leaves a large uncovered area in West Greenland where there are high densities of whales.

One option for eliminating the potential problem of transects running parallel to the coast is to include only east-west transects in the abundance estimates. However, this does not have a major impact on the abundance estimates, as a recalculation with only east-west transects only slightly changed the abundance estimates (Table 4). This is probably due to the fact that the bathymetry in West Greenland does not follow simple east-west gradients but is characterised by deep trenches with intersecting banks (Fig. 1). In addition, the distribution of whales is not a simple function of bathymetry in this region but rather is determined by complex oceanographic features, including areas of upwelling that potentially can be found in many areas across several strata.

The estimate of 145 humpback whales in the Nuuk Fjord alone initially seems high. Clearly the ship-based survey did not provide random or uniform coverage of the entire fjord

Table 4

Summary statistics for abundance estimates for fin, sei, humpback and minke whales under alternative assumptions for West Greenland. Approximately half of the South West Greenland stratum was removed when the area with poor coverage was removed from that stratum. CVs indicated in parenthesis.

Estimation options			Species			
Sightings	Transects	Coverage	Fin whale	Sei whale	Humpback whale	Minke whale
Identified blows	East-west going	Areas with poor coverage in SW Greenland and Nuuk Fjord eliminated	na	na	509 (0.49)	na
Identified blows	East-west going	Area with poor coverage in SW Greenland eliminated	1,317 (0.54)	1,031 (0.53)	663 (0.37)	4,068 (0.40)
Identified blows	East-west going	Continuous	1,777 (0.48)	1,604 (0.45)	1,141 (0.45)	5,307 (0.43)
Identified blows	All	Area with poor coverage in SW Greenland eliminated	1,520 (0.41)	1,026 (0.45)	829 (0.36)	3,239 (0.41)
Identified blows	All	Continuous	1,980 (0.38)	1,599 (0.42)	1,306 (0.42)	4,479 (0.46)
Unidentified blows apportioned to species and strata	All	Area with poor coverage in SW Greenland eliminated	2,115 (0.40)	1,291 (0.40)	926 (0.34)	na
Unidentified blows apportioned to species and strata	All	Continuous	2,824 (0.38)	2,009 (0.37)	1,514 (0.51)	na
Correction for perception bias *g*(0)=0.56, SE=0.07	All	Continuous	na	na	na	7,998 0.47

na = not applicable.

complex. Only about one fifth of the fjord was sampled and the density was extrapolated to other unsurveyed parts of the fjord under the unproven assumption of uniform density. If the estimated density is only applied to the sampled area then a conservative estimate of 29 whales, three times the number of sightings, is obtained. This however leaves 80% of the area without an abundance estimate. Satellite tracking studies and local observations demonstrate that humpback whales use the entire Nuuk Fjord as delineated by the stratum (Heide-Jørgensen and Laidre, 2007), (Fig. 3, GINR unpublished data), and therefore it is not unreasonable to extrapolate samples collected in the northern part of the mouth and in two fjord arms to the entire area shown in Fig. 3. In any case, the estimate from the Nuuk Fjord only contributes ~10% of the total abundance estimate for humpback whales in West Greenland.

Many sightings of large baleen whales could not be assigned to a species. If these 35 undetermined sightings were included in the abundance estimates in proportion to the correctly identified sightings of the four target species, then the abundance estimates increase as much as 43% for fin whales (resulting in a revised estimate of 2,824 fin whales, 95% CI=1,346-5,925). Similarly the abundance estimates for sei and humpback whales increase by 26% and 16%, respectively (Table 4).

All the abundance estimates presented in this manuscript are likely negatively biased for at least two reasons. First, no corrections have been made for whales submerged during the passage of the survey vessel or whales missed by the observers. This may be less of a problem for fin and sei whales, which can be seen at long distances from the vessel, but is certainly of concern for common minke whales, which are smaller and less conspicuous. Common minke whales in West Greenland are hunted intensively and considering the skittish behaviour of common minke whales in West Greenland, attraction to ships seems unlikely. The issue of ship avoidance (Palka and Hammond, 2001) was not addressed in this study. Secondly, the survey did not cover the entire stock area used by any of the whales in either East or West Greenland. The survey covered the banks of both areas, but whales were sighted at the borderlines of several strata indicating a connection to a larger unsurveyed area.

Abundance of fin whales

No fin whales were sighted in the northern survey strata (North West and in Disko Bay) despite good conditions and considerable effort. Fin whales have frequently been observed in these areas (Heide-Jørgensen *et al.*, 2003; Kapel, 1979;1984;1985; Kapel and Larsen, 1982;1983; Larsen, 1981) and the lack of sightings might be due to the late seasonal coverage. Fin whales were however estimated to occur in large numbers in Central West (1,263) and South West Greenland (1,562) as well as in East Greenland (3,917). The survey in East Greenland only covered parts of the distribution of fin whales between the coast and Iceland, where an estimated abundance of 24,000 fin whales was obtained in 2001 (Víkingsson *et al.*, In Press). The abundance of fin whales in West Greenland (1,980 95% CI=913-4,296) estimated by using only identified blows was larger, although not significantly higher, than the estimate from the aerial surveys in 1987 and 1988 (IWC, 1992) and lower than the estimate from the 2005 autumn aerial survey accepted by the IWC Scientific Committee (Heide-Jørgensen *et al.*, 2007; IWC, In press) of 3,200 (95% CI 1,400-7,200).

Abundance of sei whales

The high number of sightings and high abundance of sei whales in West Greenland was somewhat surprising. Sei whales are traditionally believed to occupy more southern areas of the North Atlantic (Cattanach *et al.*, 1993) and have not been found often in West Greenland. Kapel (1985) summarised observations and catches of sei whales in West Greenland waters in the 18th, 19th and 20th Centuries. The first confirmed sighting of a sei whale in Greenland was from Norwegian catches in 1924. During 1924-57, 18 sei whales were confirmed caught and a similar number of catches are unconfirmed, of which only four seem to be plausible sei whales. Kapel (1985) report that the erratic occurrence of sei whales in West Greenland waters may be related to the sea surface temperature, especially the influx of warm Irminger water to the southern part of Davis Strait. In 2005 the warmest sea surface temperatures were observed in West Greenland since 1876 (GINR unpublished data), and these warm temperatures may be related to the large abundance of sei whales in the area.

Abundance of humpback whales

An estimated abundance of 1,306 humpback whales (CV=0.42, 95% CI=570-2,989) from identified blows in West Greenland and 347 humpback whales in East Greenland (CV=0.85, 95% CI=48-2,515) is approximately three times larger than any previous estimates of this species in Greenland waters. Photo-ID surveys of humpback whales conducted off West Greenland during the 1990s resulted in an estimate of 360 humpback whales (CV=0.07) in West Greenland in summer (Larsen and Hammond, 2004). At that time three concentration areas were identified: an area off Nuuk, an area at approximately 63°30'N, and an area off Paamiut. This survey did not intensely cover any of these three areas, yet still resulted in a significantly larger abundance estimate than in the past, suggesting the present estimates may even be low. This survey covered a wider range of the humpback whale distribution in West Greenland than any previous surveys and thus has a more complete, although less intense, coverage of the humpback whale distribution in West Greenland. The long-distance movements and broad use of the West Greenland coast has recently been revealed by satellite tracking studies (Heide-Jørgensen and Laidre, 2007), suggesting humpback whales use a large area of West Greenland and have a broad distribution. Part of the difference in present and past abundances of humpback whales may be explained by a growth in the abundance of humpback whales in West Greenland, which is not unreasonable to assume given observations in other areas of the North Atlantic. Sigurjónsson and Gunnlaugsson (1990) observed an increase in humpback whale numbers around Iceland of 11.2% per annum between 1970 and 1988. Pike *et al*. (2005) observed an even higher growth rate for humpback whales around Iceland from the North Atlantic Sighting Surveys (NASS). Based on an assumed growth of 10% per year since 1990 and a presumed abundance of 500 humpback whales in West Greenland in 1990, a present-day (2005) abundance should be on the order of approximately 2,000 whales. This is within the confidence limits of the present abundance estimates.

Abundance of common minke whales

The relatively low number of sightings of common minke whales severely reduced the precision of the abundance estimates in this study. Estimation of a detection function

was only possible through inclusion of sightings *en route* to and from Iceland. The variance on the common minke whale abundance estimates was very high, but it is important to note that correction for whales that were submerged during the passage of the survey platform and whales missed by the observers would raise the lower confidence limit of the estimate substantially.

One option for improving the accuracy of the common minke whale estimate is to use a correction factor for whales missed by the observer ($g(0)$) developed in a different survey. Øien (1990) used a double platform design to estimate $g(0)$ in an area west of Svalbard, where common minke whales occur in high densities. A large proportion of the common minke whale sightings were missed by the primary platform ($g(0)$=0.56, SE=0.07) and applying this correction factor gives a partially corrected abundance estimate for West Greenland of 7,998 common minke whales (CV=0.47, 95% CI=3,048-20,988). The $g(0)$ estimate was developed on a different survey platform with different observers and in an area with high densities of common minke whales where whale spotters presumably are more efficient (Øien, 1990). In addition, the correction does not include whales that were diving during the passage of the survey platform. In any case we believe that the corrected estimate probably provides an abundance estimate that is closer to the actual abundance of common minke whales in West Greenland in late autumn 2005. These estimates are not ~~sufficiently~~ different from the estimate accepted by the IWC Scientific Committee from an autumn 2005 aerial survey (Heide-Jørgensen *et al.*, 2007; IWC, In press) of 10,800 (95% CI 3,600-32,400).

Few sightings of common minke whales were made on the offshore banks of West Greenland, an area where they used to be frequently encountered (Kapel and Larsen, 1982). There has been no hunting of common minke whales in this offshore area since the ban on commercial whaling in 1985 and the lack of whales in this region cannot be attributed to harvest. It is well known that common minke whales travel extensively, and recent satellite tracking studies off Iceland show that this species can move 1,000km in just two months, reaching the Cape Verdes Isles from Icelandic waters in just 60 days. It is highly possible that common minke whales inhabiting Greenlandic waters are a temporary population that move in and out of important areas, as observed in Iceland (Heide-Jørgensen *et al.*, 2001; Víkingsson and Heide-Jørgensen, 2005). This makes it difficult to relate the present abundance estimate to any actual stock size.

Other species

Species diversity in cetacean sightings was much higher in East Greenland but abundance estimates could not be derived for all species. One northern right whale was sighted east of Greenland in an area slightly north and east of the whaling ground known by the whalers as the 'Cape Farewell whaling ground' used by American whalers during 1868-98 for finding right whales (Reeves and Mitchell, 1986). This is also the area where right whales have been sighted in recent years (Reeves *et al.*, 2004). Few odontocete whales were seen in West Greenland, these fish eaters seem to be sighted more typically in East Greenland in contrast to the many baleen whales sighted feeding on zooplankton in West Greenland.

CONCLUSIONS

The ship-based survey presented here provides a somewhat sporadic effort along East and especially South West Greenland. In some cases the patchy effort also leads to questionable extrapolations of densities to unsurveyed areas. The survey however provides insight into what can be accomplished by a ship-based cetacean survey effort in Greenland.

The abundance estimates for large cetaceans obtained during this survey are in some cases larger than expected and confirm that the waters of Greenland support large numbers of baleen whales during this season. The extensive ship survey coverage, coupled with the verification of high numbers of sightings and large group sizes by a concurrent aerial survey (Heide-Jørgensen *et al.*, 2007), suggest abundances are considerably larger than previously reported.

This survey was conducted late in the season. No whales were seen in the northernmost strata along West Greenland and only humpback whales were sighted in Disko Bay. Presumably most large whales were on their southbound exodus from Greenland by September (Heide-Jørgensen *et al.*, 2001; Víkingsson and Heide-Jørgensen, 2005) and this may have resulted in a reduced abundance relative to that which would have been estimated earlier in the summer.

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REFERENCES

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*. Oxford University Press, Oxford, UK. vi+xv+432pp.

Buckland, S.T., Cattanach, K.L. and Gunnlaugsson, T. 1992. Fin whale abundance in the North Atlantic, estimated from Icelandic and Faroese NASS-87 and NASS-89 data. *Rep. int. Whal. Commn* 42: 645-51.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C. and Pollock, K.H. 1987. *Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture*. No. 5 vols, *American Fisheries Society Monographs*. American Fisheries Society, Bethesda, Maryland. x+437pp.

Cattanach, K.L., Sigurjónsson, J., Buckland, S.T. and Gunnlaugsson, T. 1993. Sei whale abundance in the North Atlantic, estimated from NASS-87 and NASS-89 data. *Rep. int. Whal. Commn* 43: 315-21.

Heide-Jørgensen, M.P., Borchers, D., Witting, L., Simon, M., Laidre, K., Rosing-Asvid, A. and Pike, D.G. 2007. Final estimates of large whale abundance in West Greenland waters from an aerial survey in 2005. *J. Cetacean Res. Manage* Submitted.

Heide-Jørgensen, M.P. and Laidre, K. 2007. Autumn space-use-patterns of humpback whale (*Megaptera novaeangliae*) in West Greenland. *J. Cetacean Res. Manage.* Submitted.

Heide-Jørgensen, M.P., Nordoy, E.S., Øien, N., Folkow, L.P., Kleivane, L., Blix, A.S., Jensen, M.V. and Laidre, K.L. 2001. Satellite tracking of minke whales (*Balaenoptera acutorostrata*) off the coast of northern Norway. *J. Cetacean Res. Manage.* 3(2): 175-78.

Heide-Jørgensen, M.P., Witting, L. and Jensen, M.V. 2003. Inshore-offshore movements of two fin whales *Balaenoptera physalus*

tracked by satellite off West Greenland. *J. Cetacean Res. Manage.* 5(3): 214-45.
Hiby, A.R. and Hammond, P.S. 1989. Survey techniques for estimating abundance of cetaceans. *Rep. int. Whal. Commn (special issue)* 11: 47-80.
International Whaling Commission. 1990. Report of the Scientific Committee. *Rep. int. Whal. Commn* 40:39-79.
International Whaling Commission. 1992. Report of the Comprehensive Assessment Special Meeting on North Atlantic Fin Whales, Reykjavík, 25 February-1 March 1991. *Rep. int. Whal. Commn* 42:595-644.
International Whaling Commission. 2005. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 7:1-62.
International Whaling Commission. 2006. Report of the Scientific Committee. Annex E. Report of the Standing Working Group (SWG) on the Development of an Aboriginal Whaling Management Procedure (AWMP). *J. Cetacean Res. Manage. (Suppl.)* 8:91-109.
International Whaling Commission. In press. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 10.
Kapel, F.O. 1979. Exploitation of large whales in West Greenland in the twentieth century. *Rep. int. Whal. Commn* 29: 197-214.
Kapel, F.O. 1984. Whale observations off West Greenland in June-September 1982. *Rep. int. Whal. Commn* 34: 621-27.
Kapel, F.O. 1985. On the occurrence of sei whales (*Balaenoptera borealis*) in West Greenland waters. *Rep. int. Whal. Commn* 35: 349-52.
Kapel, F.O. and Larsen, F. 1982. Whale sightings from a Norwegian small-type whaling vessel off West Greenland, June-August 1980. *Rep. int. Whal. Commn* 32: 521-30.
Kapel, F.O. and Larsen, F. 1983. Whale sightings off West Greenland in June-September 1981. *Rep. int. Whal. Commn* 33: 657-66.
Kingsley, M.C.S. and Witting, L. 2001. A preliminary analysis of aerial survey observations of humpback whales in Greenland waters. Paper SC/53/NAH23 presented to the IWC Scientific Committee, July 2001, London (unpublished). 51pp. [Paper available from the Office of this Journal].
Larsen, F. 1981. Observations of large whales off West Greenland, 1979. *Rep. int. Whal. Commn* 31: 617-23.
Larsen, F. 1995. Abundance of minke and fin whales off West Greenland, 1993. *Rep. int. Whal. Commn* 45: 365-70.
Larsen, F. and Hammond, P.S. 2004. Distribution and abundance of West Greenland humpback whales *Megaptera novaeangliae*. *J. Zool., London.* 263: 343-58.
Larsen, F., Martin, A.R. and Nielsen, P.B. 1989. North Atlantic Sightings Survey 1987: report of the West Greenland aerial survey. *Rep. int. Whal. Commn* 39: 443-46.
Øien, N. 1990. Estimates of $g(0)$ for minke whales based on an independent observer experiment during the Norwegian sightings surveys in July 1988. *Rep. int. Whal. Commn* 40: 331-35.
Palka, D.L. and Hammond, P.S. 2001. Accounting for responsive movement in line transect estimates of abundance. *Can. J. Fish. Aquat. Sci.* 58: 777-87.
Pike, D.G., Paxton, C.G.M., Gunnlaugsson, T. and Víkingsson, G.A. 2005. Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters 1986-2001. *NAMMCO Sci. Pub.* 6. [Paper NAMMCO SC/12/11].
Reeves, R.R., Josephson, E. and Smith, T.D. 2004. Putative historical occurrence of North Atlantic right whales in mid-latitude offshore waters: 'Maury's Smear' is likely apocryphal. *Marine Ecology. Progress Series* 282: 295-305.
Reeves, R.R. and Mitchell, E. 1986. American pelagic whaling for right whales in the North Atlantic. *Rep. int. Whal. Commn (special issue)* 10: 221-54.
Sigurjónsson, J. and Gunnlaugsson, T. 1990. Recent trends in abundance of blue (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) off west and southwest Iceland, with a note on occurrence of other cetacean species. *Rep. int. Whal. Commn* 40: 537-51.
Thomas, L., Strindberg, S., Marques, F.F.C., Borchers, D.L., Buckland, S.T., Anderson, D.R., Burnham, K.P., Hedley, S.L. and Pollard, J.H. 2001. Distance 4.0. Beta 4. Research Unit for Wildlife Population Assessment, University of St Andrews, UK. [Available at: *http://www.ruwpa.st-and.ac.uk/distance/*].
Víkingsson, G.A. and Heide-Jørgensen, M.P. 2005. A note on the movements of minke whales tracked by satellite in Icelandic waters in 2001-2004. Paper SC/57/O9 presented to the IWC Scientific Committee, June 2005, Ulsan, Korea (unpublished). 3pp. [Paper available from the Office of this Journal].
Víkingsson, G.A., Pike, D.G., Desportes, G., Øien, N. and Gunnlaugson, T. In Press. Distribution and abundance of fin whales (*Balaenoptera physalus*) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987-2001. *NAMMCO Sci. Publ.* 7.
Witting, L. and Kingsley, M. 2005. Abundance of marine mammals off West Greenland, 2002-2004. Paper SC/57/AWMP3 presented to the IWC Scientific Committee, June 2005, Ulsan, Korea (unpublished). 13pp. [Paper available from the Office of this Journal].

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