Estimates of large whale abundance in Greenland 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 200 m). The surveyed area comprised 81000 km^2 in East Greenland and 225000 km^2 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 (3140, 95% CI 940-10492) with lower abundances estimated for West Greenland (1847, 95% CI 855-3989). Sei whales, *Balaenoptera borealis*, were frequently encountered in the same areas as the fin whale, but the estimated abundance in East Greenland (729, 95% CI 226-2358) was lower than in West Greenland (1529, 95% CI 660-3540). Humpback whales, *Megaptera novaeangliae*, were found both in offshore and coastal areas of West Greenland (1316, 95% CI 592-2927) and in low numbers in East Greenland (329, 95% CI 45-2388). Finally, minke whale, *Balaenoptera acutorostrata*, abundance was estimated at 1686 (95% CI 179-15841) for East Greenland and 4086 (95% CI 1645-10150) for West Greenland. Sighting rates for minke whales were low, resulting in low abundance estimates with low precision. Inclusion of sightings of unidentified large baleen whales in West Greenland distributed in proportion to species sightings increased abundances estimates for fin, sea, and humpback whales by 29%, 12%, and 14% 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 Northwest 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. This should cause a particularly large negative bias especially for the estimates of minke whale abundance. Abundance estimates presented in this study provide the most up-to date and complete estimates for large whales in Greenland waters since 1993.

INTRODUCTION

Information on the abundance of large whales in Greenland waters, including minke whales, *Balaenoptera acutorostrata*, fin whales, *Balaenoptera physalus*, humpback whales, *Megaptera novaeangliae*, and sei whales, *Balaenoptera borealis,* is scarce and outdated. In 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 this survey and no abundance estimates were produced. After this, aerial surveys were instead used as the primary platform to increase survey coverage during the relatively small window of time when survey conditions are optimal in unstable and dark Greenland waters.

Between 1983 and 1993, visual aerial surveys of large cetaceans were conducted nine times in West Greenland. Only two times during this decade did these surveys provide useful abundance estimates of large whales (cue-counting surveys in 1987-88 and again in 1993) (Hiby *et al.* 1989, Larsen 1995, Larsen *et al.* 1989). From these surveys, fin whale abundance was estimated at 1,100 (95% CI 520-2100) in West Greenland in 1987-88 (IWC 1992). In 1993, another estimate of ~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 402-2392), similar to that obtained in 1987-88.

Abundances of minke whales were also obtained from the cue counting in 1993, and were estimated at 8371 (95% CI 2414-16929) whales in West Greenland (Larsen 1995). This estimate was slightly larger (but not significantly different) than the estimate obtained on the 1987-88 survey (3266 minke whales, 95% CI 1700-5710 (IWC 1990). The visual photographic survey in 2002 and 2004 resulted in an abundance of only 510 minke whales (95% CI 138-1889). This estimate was considered unrealistically low because the annual take in West Greenland (about 170 minke whales) has remained stable for the past 20 years. Sei whale abundance has never been estimated in Greenland.

Humpback whale abundance has been estimated in Greenland based on visual and photographic suryeys, as well as photo-identification techniques. Photo-identification 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 200 m 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 which resulted in an uncorrected estimate of 599 (95% CI 237-1512) (Kingsley and Witting 2003) as well as an estimate of 400 humpbacks based on sightings of 100 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).

The Scientific Committee of the International Whaling Committee has stated it is difficult to provide satisfactory advice on sustainable takes from Greenland stocks without recent and robust abundance estimates (IWC 2005). Available estimates of all large baleen whale abundance in West Greenland waters are either dated or unreliably low. There is an urgent need for abundance estimates in Greenland given that minke and fin whales are taken annually in Greenland waters, with removals in West Greenland between 1999-2004 averaging 172 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 utilizes bottom traps attached to surface buoys.

This manuscript reports on a ship-based survey of large cetaceans conducted in East and West Greenland in September 2005. Abundance estimates were developed for all large whale species where sufficient sightings were available. These are the most current abundance estimates for large cetaceans in Greenland waters and update knowledge on distribution and numbers on both coasts.

METHODS

The Icelandic fisheries research vessel *r/v* Bjarni Saemundsson RE 30 (length 56 m and

height to upper deck 7 m) was used as the platform for the sighting survey. The survey was conducted between 2nd September and 3rd 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: 180 cm, width: 226 cm, height of walls: 145 cm) 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 in a string around their neck. The length of the strings was such that one mm from the horizon, when measuring standing on the observation platform, corresponded to a declination angle of 0.1 degree. The eye height of the observers was approximately 10.3 m 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 – 1600 m 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 1000 m, both when estimated by eye and when measured with distance sticks. We believe that the underestimation of targets on far distances was diminished following 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 (sea state less than 6 and visibility more than 500 m).

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 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 100 km) to the shelf break. Transect lines were placed in an east-west direction and the survey started at the northern most 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 also used for whale sightings as weather permitted. The surveyed area was divided into 6 strata with one strata in East Greenland and five strata in West Greenland (Fig. 1). The Disko Bay area and the Nuuk Fjord were considered separate strata.

Analysis

Abundance of fin, sei, humpback and minke whales was estimated using Distance 4.1 (Thomas *et al.* 2001). Based on the minimum Akaike Information Criteria, the half-normal key, $k(y) = \exp(-y^2/(2*A^2))$, with cosine adjustments was chosen for fitting the detection functions of perpendicular sighting distances. Effort and sightings during sea states exceeding Beaufort 5 were excluded for fin, sei and humpback whales abundance estimations following Buckland *et al.* (1993) and Pike *et al.* (2005). For minke whales only sightings and effort at sea states below Beaufort 3 were included. Different right truncations were chosen for each species and common detection functions for all strata (including sightings outside strata) were derived. Due to lack of variation in pod sizes across strata an estimate of mean pod size was used. Confidence intervals were calculated following Burnham *et al.* (1987, p. 212) assuming the abundance estimates had a log-normal distribution.

RESULTS

A total of 222 hours of on-effort observations were made where approximately 1,622 nmi were covered in sea states less than 5 and 760 nmi were covered in sea states less than 3 (Fig. 1). During the survey 194 sightings of 531 individual whales were made, including 13

different species (Table 2).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). No ice was encountered in East or West Greenland.

The realised survey effort in West Greenland included lines that both went parallel and perpendicular to the coast and it was therefore decided to examine if there is a major effect of bathymetric contours on the abundance estimates.

Distribution of whales

Six species of baleen whales were seen: Blue whales, fin whales, minke whales, sei whales, humpback whales, and right whales. 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 the fin whales. 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 2 blue whales were observed in East Greenland in the same area (65.1842N 29.9558W) on 3 September (Fig. 4).

Sightings of odontocetes included sperm whales, *Physeter catodon*, 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, *Ziphidae sp.*, was seen in a deep canyon between the coastal banks in southwest Greenland. Sperm whales were observed off the east coast of Greenland and once in coastal waters on the west coast. (Fig. 5)

Abundance estimates

The detection function showed a satisfactory fit to the distribution of the 46 perpendicular distances of fin whale sightings (Fig. 6, χ^2 goodness-of-fit statistic not significant, p=0.627) and the effective search half-width (*esw*=1018 m) could be estimated with low variance (*cv*=0.11, Table 3). There were no sightings of fin whales in Northwest Greenland and in

Disko Bay and the abundance was higher in East Greenland (N=3140 fin whales, *cv*=0.49) than in South Greenland (i.e. Centralwest and Southwest, N=1847 fin whales, *cv*=0.39). If the fin whale abundance is estimated only for the east-west going lines off West Greenland the abundance in Centralwest changes to 623 (0.87) and the total for West Greenland changes to 1659 (0.48).

The detection function for the 27 sei whales sightings alone (*esw*=978 m) was very similar to the detection function of the combined sightings of fin whales and sei whales (*esw*=979 m), except that the *cv* for the sei whales was more than twice (0.20) the *cv* for the combined data set (0.09). It was consequently decided to estimate the sei whale abundance utilizing both fin and sei whale distance estimates for deriving a common detection function (Fig. 7 and Table 3, χ^2 goodness-of-fit statistic not significant, p=0.624). The largest abundance of sei whales was estimated in the southernmost part of West Greenland (N=1529 sei whales, *cv*=0.42) and lower numbers were found in East Greenland (N=729 sei whales, *cv*=0.47). If the detection function for only sei whale sightings was used the *cv*s increased by 9% for East Greenland and 13% for West Greenland. If the sei whale abundance is estimated only for the east-west going lines off West Greenland the abundance in Centralwest changes to 212 (1.62) the total for West Greenland changes to 1534 (0.45).

Only 27 humpback whale sightings were available for estimating the detection function (Fig. 8). Right truncation of the sighting distances did not improve the fit of the model and an untruncated detection function provided an *esw* of 762 m (*cv*=0.12, χ^2 goodness-of-fit statistic not significant, p=0.204). Humpback whales were seen in all strata except for Northwest Greenland and the largest numbers were found in South Greenland (N=1316 humpback whales, *cv*=0.41) with lower numbers in East Greenland (N=329 humpback whales, *cv*=0.85, Table 3). A separate abundance estimate was developed for Nuuk Fjord based on 106 nmi zig-zag coverage of the main fjord (Fig. 3) and 10 sightings of humpback whales which revealed an abundance of 138 whales (*cv*=0.38). If the humpback whale abundance is estimated only for the east-west going lines off West Greenland the abundance in Centralwest changes to 0 and the total for West Greenland changes to 1082 (0.45).

Only 12 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* (0.22) for determination of the *esw* (237 m, χ^2 goodness-of-fit statistic not significant, p=0.467). Nevertheless it was possible to estimate minke whale abundance for the three areas with available sightings in Greenland. The largest numbers of minke whales were in the southern part of West Greenland (4086 minke whales, *cv*=0.44) with fewer on the east coast (Table 3). If the minke whale abundance is estimated only for the east-west going lines off West Greenland the abundance in Centralwest changes to 1868 (0.48) and the total for West Greenland changes to 4842 (0.41).

A total of 35 sightings of blows of unidentified large baleen whales were recorded. In order to include these in alternative abundance estimated these sightings were attributed to the three possible species (fin, humpback and sei whales) in proportion to their occurrence in each stratum (Table 4). The inclusion of unidentified sightings resulted in a 29% increase in the abundance estimate for fin whales in West Greenland (raised to 2382, 95% CI 1137-4992). The sei whale abundance increased by 12 % with a slightly improved precision, and the humpback whale abundance estimate increased in West Greenland (by 14%) with lower precision yet declined in East Greenland due to the change in *esw*.

DISCUSSION

The sampling design during this survey was not optimal for a cetacean survey and the realised survey was restrained by inclement weather conditions. It can specifically be argued that transect lines running parallel to the coast might follow density gradients of whales. However, this did not seem to have a major impact on the abundance estimates which only changed slightly when effort and sightings on the latitudinal transects were removed. This is probably explained by the fact that the bathymetry in West Greenland does not follow simple east-west gradients but is characterised by deep trenches intersecting banks (Fig. 1). Also, the distribution of the whales is not a simple function of bathymetry but rather is determined by complex oceanographic features including areas of upwelling that potentially can be found in many areas across the strata.

The abundance estimates for large cetaceans obtained during this survey provide the most up to date and complete picture of large baleen whale occurrence and abundance in late

summer off the east and west coasts of Greenland. These abundance estimates 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 in prep), suggest abundances are considerably larger than previously reported.

Abundance of fin whales

No fin whales were sighted in the northern survey strata (Northwest and in Disko Bay) despite good conditions and considerable effort in the area. Fin whales have frequently been observed in these areas (Kapel 1979, Kapel 1984, Kapel 1985, Kapel and Larsen 1981, Kapel and Larsen 1982, Heide-Jørgensen *et al.* 2003, 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 Centralwest (812) and Southwest Greenland (1035) as well as in East Greenland (3140). The survey in East Greenland only covered parts of the distribution of fin whales between the coast and Iceland, where an estimated abundance of 29 900 fin whales was obtained in 2001 (Pike *et al.* in prep.). The abundance of fin whales in West Greenland (1847 95% CI 855-3989) was larger, although not significantly higher, than the estimate from the aerial surveys in 1987 and 1988 (IWC 1992).

Abundance of sei whales

The high number of sightings and large 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. However, an aerial survey conducted simultaneously with the ship-based survey also confirmed many sei whales in West Greenland in 2005 (Heide-Jørgensen unpubl. data) and there is little doubt that this species was indeed present in large numbers. Kapel (1985) summarized 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 1924-1957, 18 sei whales were confirmed caught and a similar number of catches are unconfirmed of which only four seems 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 1316 humpback whales (cv=0.41, 95% CI 592-2927) in West Greenland and 329 humpback whales in East Greenland (cv=0.85, 95% CI 45-2388) is approximately three times larger than any previous estimates of this species in Greenland waters. Photo-identification surveys of humpback whales conducted off West Greenland during the 1990s resulted in an estimate of 360 humpbacks (*cv* = 0.07) in West Greenland in summer (Larsen and Hammond 2004). Three concentration areas were identified: an area off Nuuk, an area at c. 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 was recently been revealed by satellite tracking studies (Heide-Jørgensen unpubl. data) 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. Sigurjonsson and Gunnlaugsson (1990) observed an increase of humpback whales around Iceland of 11.2 % per year between 1970 and 1988. Pike et al (2005) observed an even higher growth rate for humpback whales around Iceland from the NASS surveys. 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 2000 whales. This is within the confidence limits of the present abundance estimates.

The estimate of 138 humpback whales in the Nuuk Fjord alone initially seems high. Satellite tracking studies demonstrate that this species uses the entire fjord as delineated by the stratum (Fig. 3, Heide-Jørgensen unpubl. data), and therefore it is not unreasonable to extrapolate sightings made on the periphery or mouth of the fjord to the whole area. Although the course of the survey vessel should have covered all gradients in the fjord it still occasionally approached the coast closer than the effective search half-width. However, inclusion of these minor fractions of effort close to the coast only add to the negative bias of the estimate. In any case, the estimate from the Nuuk Fjord only contributes ~10% of the total abundance estimate of humpback whales in West Greenland.

Abundance of minke whales

The relatively low number of sightings of 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 minke whale abundances estimates is 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 minke whale estimate is to deploy 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 minke whales occur in high densities. A large proportion of the minke whale sightings were missed by the primary platform ($g(0)$=0.56, SE=0.07) and applying this correction factor gives partially corrected abundance estimates for West Greenland of 7297 minke whale (*cv*=0.46, 95% CI 2842-18732). If only the east-west going transects in West Greenland are included then the corrected (for g0)) abundance of minke whale in West Greenland is 8646 (0.43). The $g(0)$ estimate was developed on a different survey platform with different observers and in an area with high densities of minke whales where whale spotters presumably are more efficient (Øien 1990). Also, the correction does not include whales that were diving during the passage of the survey platform. In any case the corrected estimate provides both a conservative and a more realistic figure of the actual abundance of minke whales in West Greenland in late autumn 2005 than in the uncorrected estimate.

Very few sightings of minke whales were made on the offshore banks of West Greenland, an area they used to be frequently encountered (cf. Kapel and Larsen 1982). The explanation for the lack of sightings cannot be harvest. There has been no hunting of minke whales in this offshore area since the ban on commercial whaling in 1985. It is well known that minke whales travel extensively, and recent satellite tracking studies off Iceland show that this species can travel 1000 km in just two months, reaching as far south as the Cape Verdes Isles from Icelandic waters in 60 days It is highly possible that minke whales inhabiting Greenlandic waters are a temporary population that move in and out of important areas as has been 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 than the whaling ground known by the whalers as the "Cape Farewell whaling ground" used by American whalers during 1868-1898 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 and there seem to be more typical fish eaters in East Greenland compared to more whales feeding on zooplankton in West Greenland.

Biases

If the distance to whale sightings was underestimated, density of whales would be overestimated. It was not possible to test if distances (particularly long ones) were underestimated after the initial trials and training of observers. In any case the right truncation of the detection functions eliminated several of the long distance measurements. Furthermore, this bias does not apply to estimates for minke whales because all sightings were at short distances (within 540 m) except for one which was at 1186 m.

All the abundance estimates presented in this manuscript are negatively biased for at least four primary 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 minke whales which are smaller and less conspicuous. Correction for whales missed by the observers also leads to considerably larger abundance estimates for minke whales. Ship avoidance by minke whales was not considered here (Palka and Hammond 2001). Secondly, the survey did not cover the entire stock area of any of the whales in either East or West Greenland. The survey covered the banks of both areas, but there were whales at the borderlines of the strata indicating a connection to a larger area. Third, the survey was conducted late in the season. No whales were seen in the northernmost strata along the 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. . Finally, a large number of sightings of large baleen whales could not be determined to species. If these 35 undetermined sightings were included in the abundance estimates in proportion to the sightings of the four target species, then the abundance estimates increase as much as 29% for fin whales resulting in a revised estimate of 2382 fin whales (95% CI 1137-4992). Similarly the abundance estimates for sei and humpback whales increase by 12 and 14%, respectively. The combination of all these factors have a large negative affect on the survey results and the estimates presented here should clearly be considered minimum abundance estimates for Greenland in September 2005.

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Table 1. Akaike Information Criteria values for different selections of detection functions.

Akaike Information Criteria values for detection function selection	Minke whales	Humpback whales	Fin whales
Half-normal key, k(y) = Exp(-y**2/(2*A(1)**2))	139.182	385.730	892.545
Cosine adjustments of order(s) : 2	139.659	386.518	894.057
Hermite polynomial adjustments of order(s) : 4	141.162	387.713	894.517
Simple polynomial adjustments of order(s) : 2	140.515		
Hazard Rate key, k(y) = 1 - Exp(-(y/A(1))**-A(2))	139.866	385.369	893.613
Cosine adjustments of order(s) : 2	141.059	387.366	894.460
Hermite polynomial adjustments of order(s) : 4	141.865	387.369	
Simple polynomial adjustments of order(s) : 4	141.287		
Uniform key, k(y) = 1/W	138.062	399.865	906.520
Cosine adjustments of order(s) : 1	138.489	386.162	891.381
Cosine adjustments of order(s) : 2			892.690
Negative Exponential key, k(y) = Exp(-y/A(1))	138.525	384.768	891.072
Cosine adjustments of order(s) : 1	140.387	386.311	892.800
Simple polynomial adjustments of order(s) : 2	140.388		

Table 2. The total numbers of observations of each of the different species of marine mammals observed during the survey. Observations are included from sea states and areas that are not included in the abundance estimations.

Species	Number of sightings	Number of individuals
Blue whale	2	2
Fin whale	54	87
Sei whale	21	33
Humpback whale	30	46
Unidentified large cetacean	39	48
Northern right whale	1	1
Minke whale	14	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 dolphins	2	100
Harbour porpoise	2	3
Seal	14	79

Table 3A. Summary statistics for abundance estimates of fin whales and sei whales. For both species only effort during sea states less than 6 was included.

Species:	Fin whale					Sei whale				
Effective Search half-Width n cv	1018m 46 observations, 5% right truncation 0.11					Fin and sei observations: 979 m 65 observations, 5% right truncation 0.09				
Stratum:	NW	DB	CW	SW	SE	NW	DB	CW	SW	SE
Sightings (n)	0	0	12	8	22	0	0	3	10	5
Effort (L) nmi	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) cv	0	0	0.03 0.53	0.05 0.52	0.09 0.47	0	0	0.01 1.06	0.06 0.44	0.02 0.45
Density of pods cv	0	0	0.01 0.54	0.01 0.53	0.02 0.48	0	0	0.01 1.06	0.02 0.45	0.01 0.46
Mean pod size cv	0	0	1.7 0.08	1.7 0.08	1.7 0.08	0	0	1.6 0.07	1.6 0.07	1.6 0.07
Density of whales cv	0	0	0.01 0.55	0.02 0.53	0.04 0.49	0	0	0.01 1.06	0.02 0.45	0.01 0.47
Abundance cv	0	0	812 0.55	1035 0.53	3140 0.49	0	0	207 1.06	1322 0.45	729 0.47
Total West Greenland	1847 (cv=0.39, 95% CI 855-3989)					1529 (cv=0.42, 95% CI 660-3540)				
Total East Greenland	3140 (cv=0.49, 95% CI 940-10492)					729 (cv=0.47, 95% CI 226-2358)				

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

Species:	Humpback whale						Minke whale				
Effective Search half-Width n cv	762 m 27, no right truncation 0.12						237 m 12, 10% right truncation 0.22				
Stratum:	NW	DB	CW	NF	SW	SE	NW	DB	CW	SW	SE
Sightings (n)	0	1	3	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) cv	0	0.01 1.17	0.01 0.75	0.10 0.34	0.03 0.50	0.01 0.83	0	0	0.01 0.49	0.05 0.49	0.02 1.21
Density of pods cv	0	0.01 1.18	0.01 0.76	0.03 0.36	0.01 0.51	0.01 0.84	0	0	0.02 0.54	0.06 0.54	0.02 1.23
Mean pod size cv	0	1.4 0.12	1.4 0.12	1.4 0.12	1.4 0.12	1.4 0.12	0	0	1	1	1
Density of whales cv	0	0.01 1.18	0.01 0.77	0.05 0.38	0.01 0.53	0.01 0.85	0	0	0.01 0.54	0.06 0.54	0.02 1.23
Abundance cv	0	49 1.18	234 0.77	138 0.38	895 0.53	329 0.85	0	0	1112 0.54	2974 0.54	1686 1.23
Total West Greenland	1316 (cv=0.41, 95% CI 592-2927)						4086 (cv=0.44, 95% CI 1645-10150)				
Total East Greenland	329 (cv=0.85, 95% CI 45-2388)						1686 (cv=1.23, 95% CI 179-15841)				

Table 4. Summary statistics on abundance estimates of fin whales and sei whales including unidentified sightings. For both species only effort during sea states less than 6 was included.

Species:	Fin whale			Sei whale			Humpback whale				
Effective Search half-Width n cv	1129m 60 observations, 5% right truncation 0.10			Fin and sei observations: 1096 m 84 observations, 5% right truncation 0.09			846 m 30 observations, no right truncation 0.13				
Stratum:	CW	SW	SE	CW	SW	SE	DB	CW	NF	SW	SE
Sightings (n)	19	11	26	4	13	6	1	4	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) cv	0.04 0.52	0.06 0.50	0.10 0.49	0.01 0.87	0.07 0.39	0.02 0.39	0.01 1.17	0.01 0.75	0.10 0.34	0.05 0.62	0.01 0.83
Density of pods cv	0.10 0.52	0.02 0.51	0.03 0.50	0.01 0.87	0.021 0.40	0.01 0.40	0.01 1.18	0.01 0.76	0.03 0.37	0.01 0.63	0.01 0.84
Mean pod size cv	1.6 0.08	1.6 0.08	1.6 0.08	1.6 0.07	1.6 0.07	1.6 0.07	1.4 0.11	1.4 0.11	1.4 0.11	1.4 0.11	1.4 0.11
Density of whales cv	0.02 0.53	0.02 0.51	0.04 0.51	0.01 0.88	0.01 0.41	0.01 0.41	0.01 1.18	0.01 0.77	0.04 0.38	0.02 0.64	0.01 0.85
Abundance cv	1131 0.53	1251 0.51	3265 0.51	238 0.88	1477 0.41	752 0.41	44 1.18	278 0.77	123 0.38	1065 0.64	294 0.85
Total West Greenland	2382 (cv=0.38, 95% CI 1137-4992)			1714 (cv=0.37, 95% CI 809-3635)			1510 (cv=49, 95% CI 576-3955)				
Total East Greenland	3265 (cv=0.51, 95% CI 923-11545)			742 (cv=0.41, 95% CI 267-2119)			294 (cv=0.85, 95% CI 41-2129)				

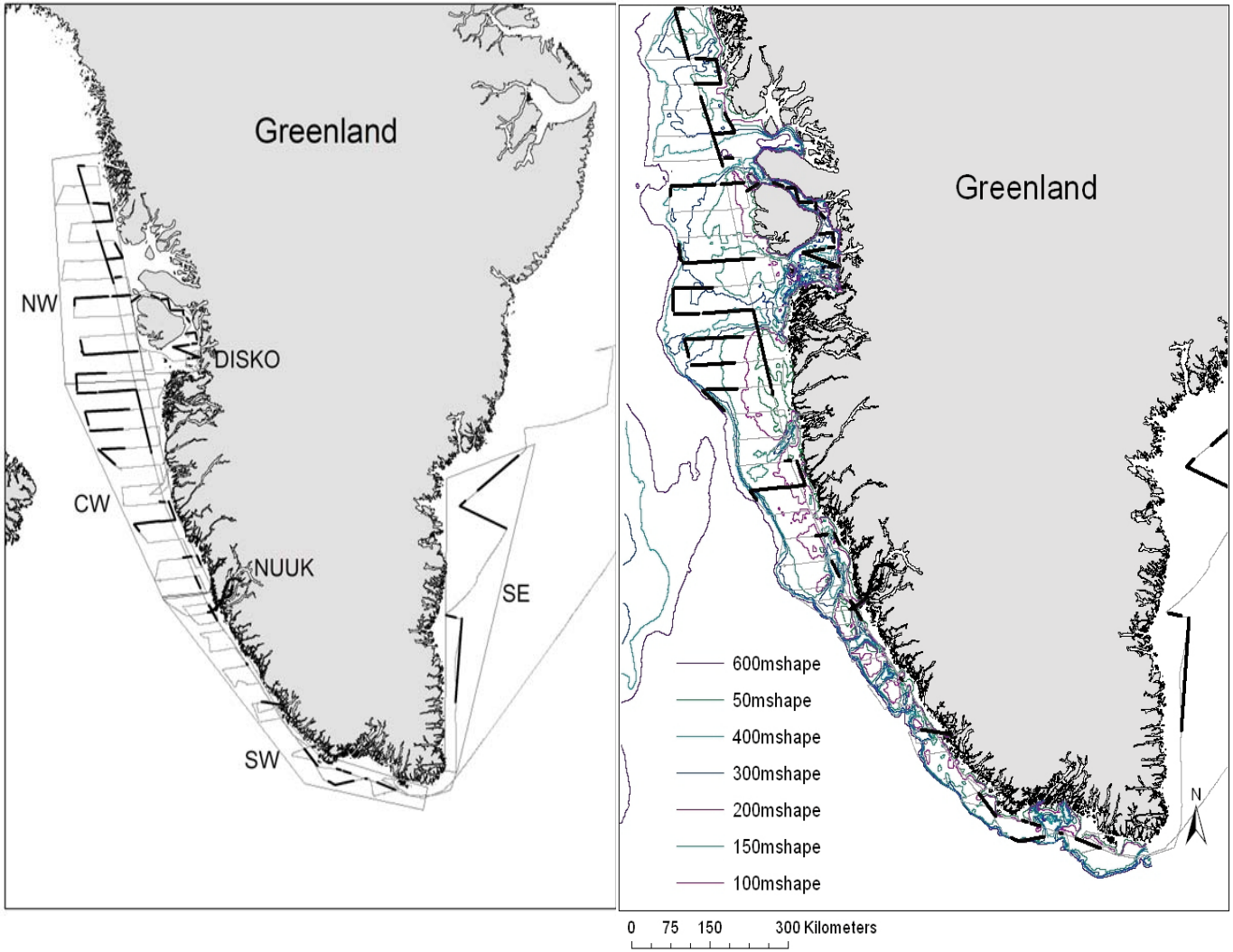

Fig. 1. Survey transect lines, delineation of strata for the ship-based survey of large cetaceans in West Greenland in September 2005 (left) and transect lines shown on top of bathymetry for West Greenland . The area of the strata was calculated as 82,518 km^2 for the North West (NW) strata, 15,780 km^2 for Disko Bay (DISKO) strata, 72,342 km^2 for the Central West (CW) strata, 2843 for Nuuk (NUUK) Fjord strata, 51,684 km^2 for the South West (SW) strata and 81,065 km^2 for the South East (SE) strata.

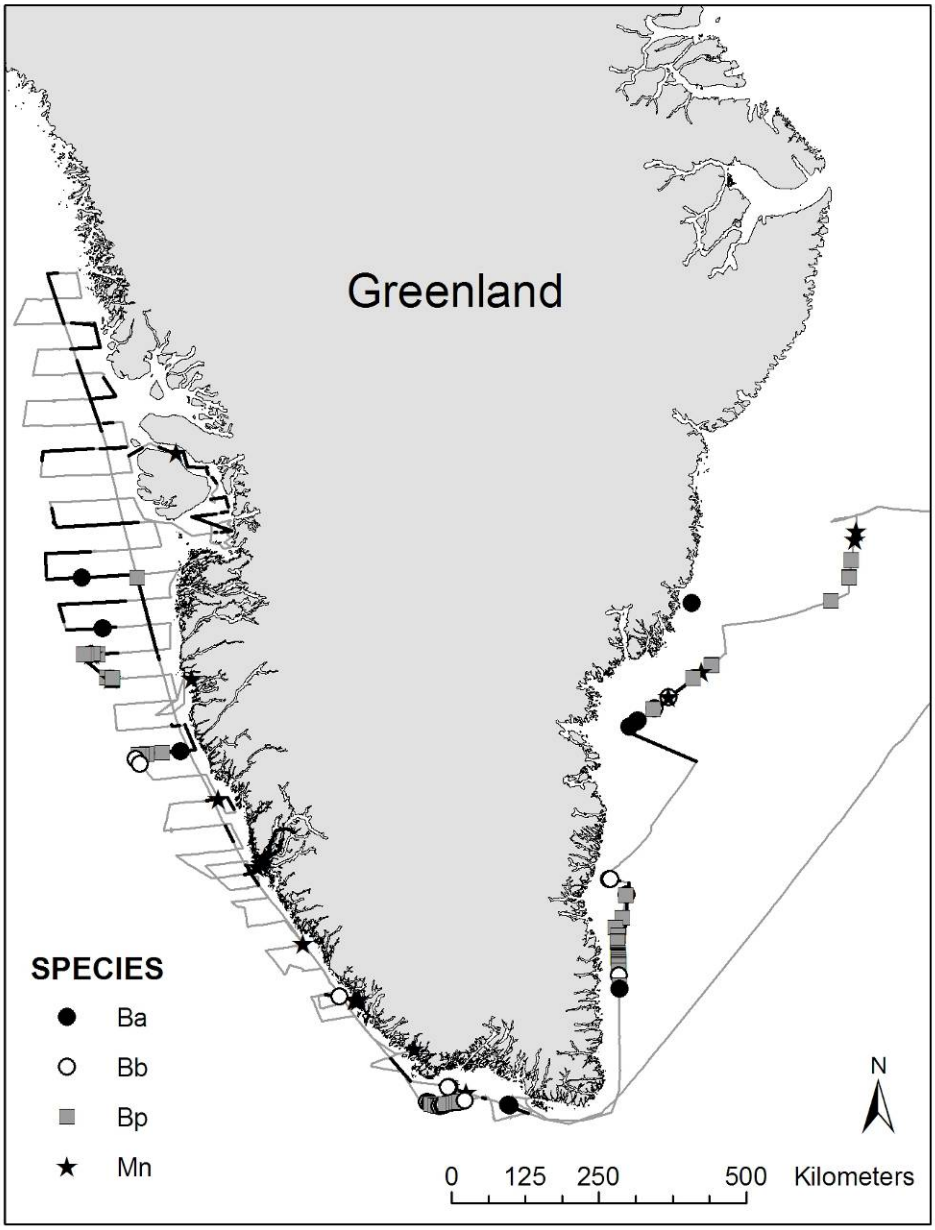

Fig. 2. Sightings of the four large cetaceans targeted in the ship based survey off West Greenland September 2005. On-effort sections of transect lines are shown together with the sightings. Ba = minke whales, Bb = sei whales, Bp = fin whales , and Mn = humpbacks.

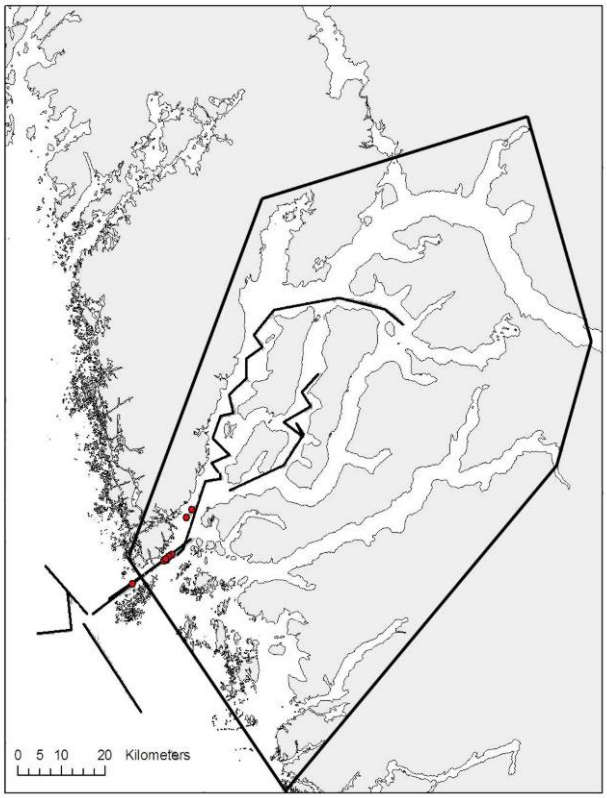

Fig. 3. Effort and sightings of humpback whales inside Nuuk Fjord.

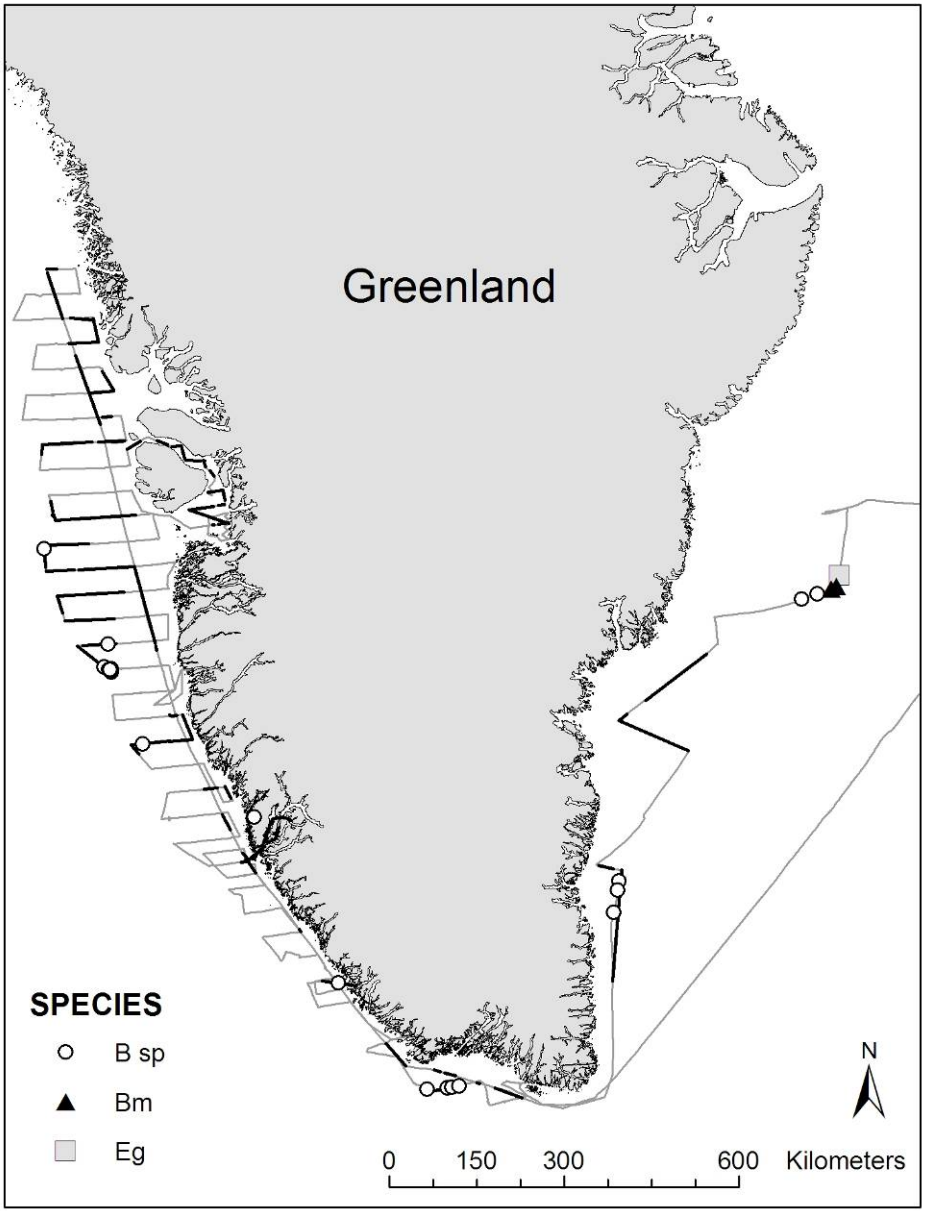

Fig. 4. Sightings of blue whales (Bm), northern right whale (Eg) and unidentified large whales (B sp.).

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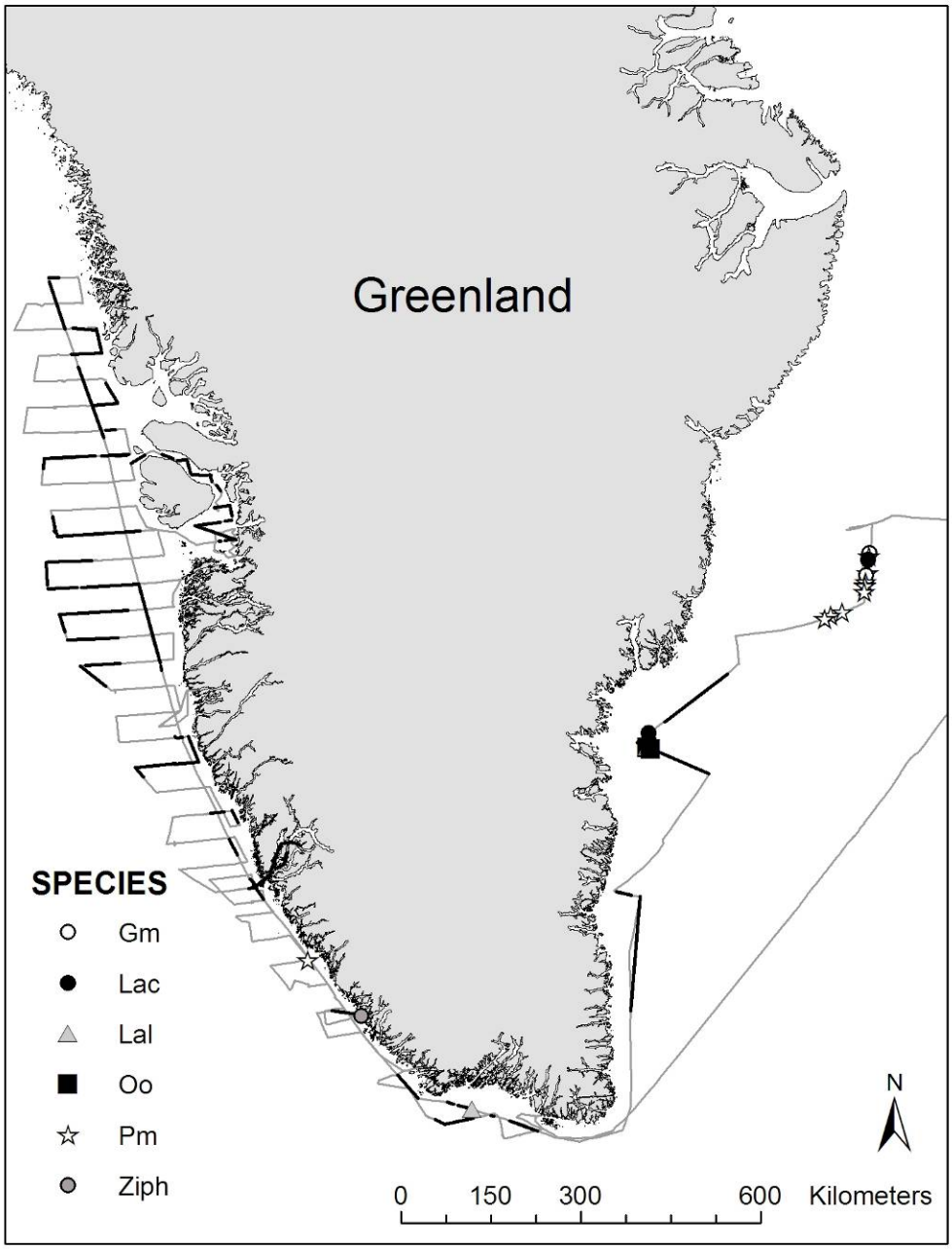

5 Fig. 5. Sightings of sperm whales (Pm, pilot whales (Gm), white-sided dolphins (Lac), white-beaked dolphins (Lal), killer whales (Oo) and unidentified beaked whale (Ziph).

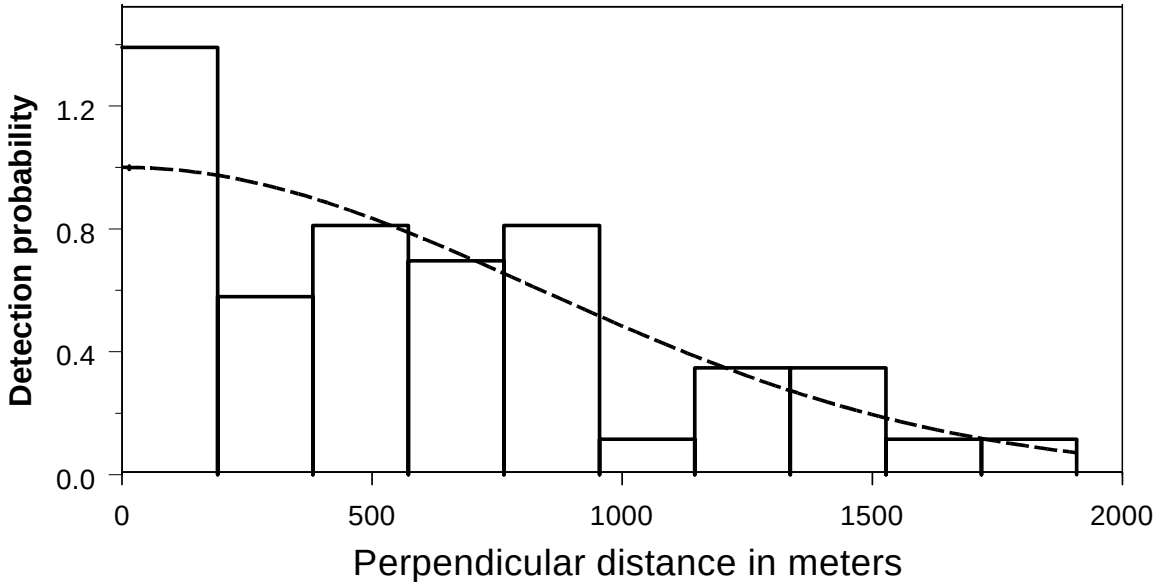

Fig. 6. Detection function for fin whales (n=46).

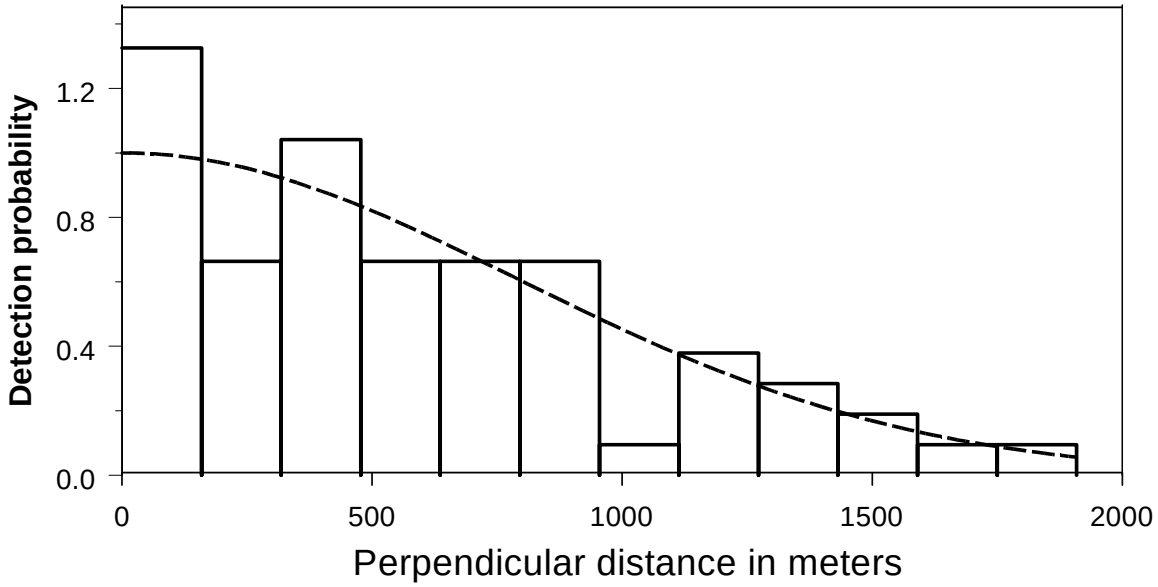

Fig. 7. Detection function for fin and sei whales combined (n=65).

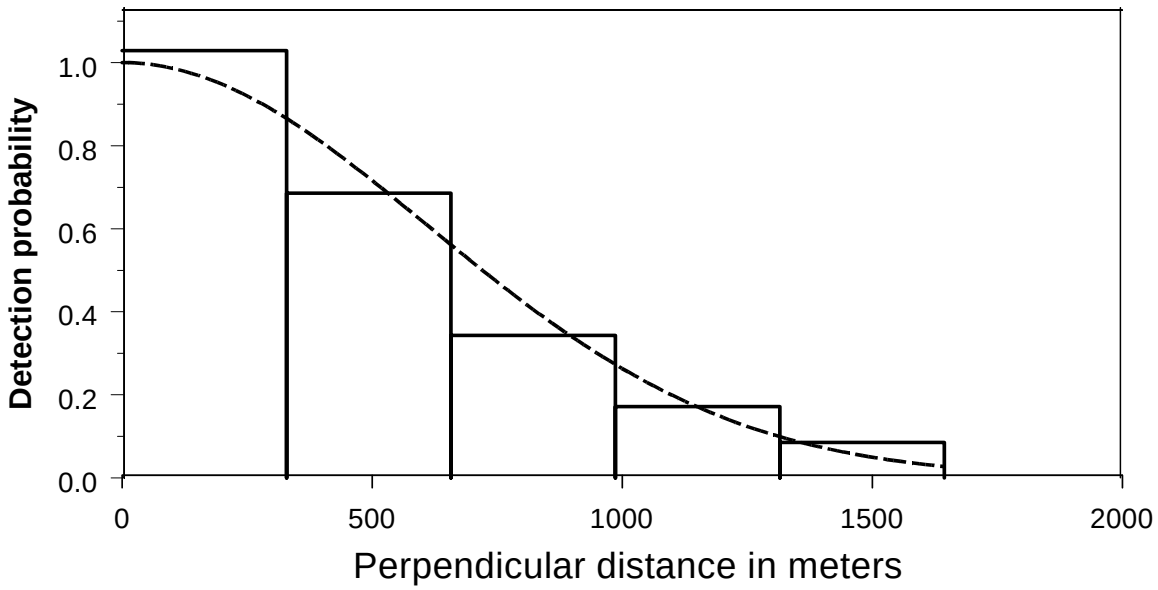

Fig. 8. Detection function for humpback whales (n=27).

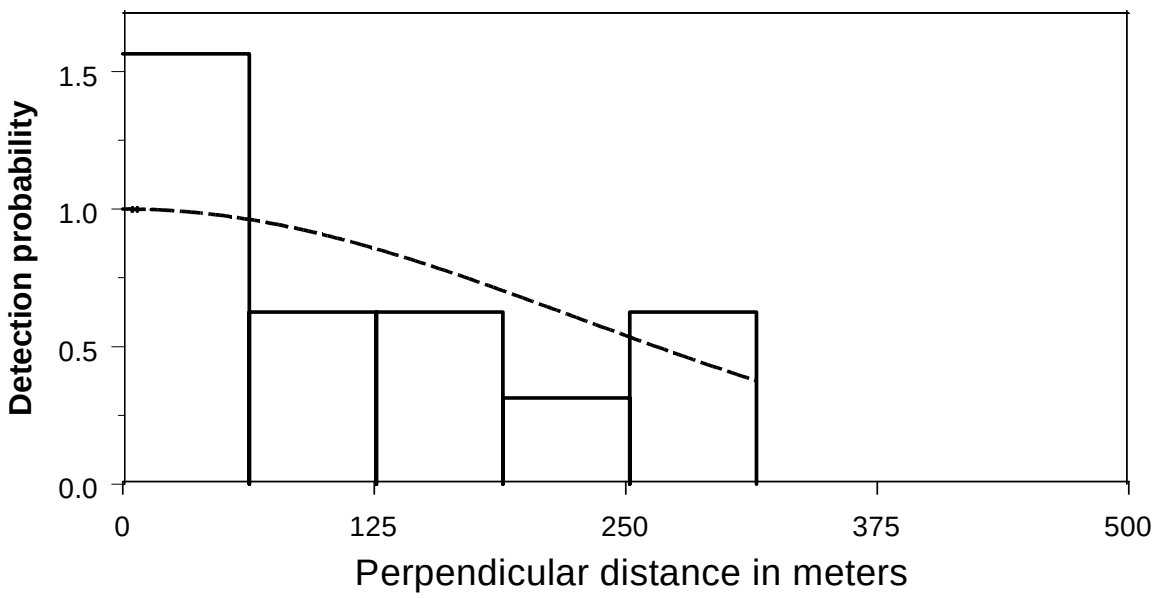

Fig. 9. Detection function for minke whales (n=12).