Final estimates of large whale abundance in West Greenland waters from an aerial survey in 2005

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ABSTRACT

An aerial line transect and cue counting survey of large whales in West Greenland was conducted in August and September 2005. The survey covered the area between Cape Farewell and Disko Island on the West Greenland coast out to the 200m depth contour. The surveyed area covered 163,574 km^2 and a total of 246 sightings of 9 cetacean species were obtained. Abundance estimates were developed for humpback whales, *Megaptera novaeangliae*, (21 sightings), fin whales, *Balaenoptera physalus*, (78 sigthings) and minke whales, *Balaenoptera acutorostrata*, (42 sightings). The mean group size of humpback whales was 3.30 but groups as large as 95 animals were seen. The mean group size of fin whales was 2.96 with groups as large as 50 seen. Minke whale group size was 1.1 with only one sighting of a group of 2 whales. Humpback whales were found both in offshore and coastal areas of West Greenland with the exception of Store Hellefiske Bank and the Cape Farewell offshore area. The line transect abundance estimate of humpback whales is 1,218 (cv=0.56), uncorrected for submerged whales and unsubmerged whales on the trackline that were missed by the observers. Fin whales were observed in all areas of the survey and the uncorrected line transect estimate was 1,652 (cv=0.37). When corrected for perception bias (missing animals on the trackline) the estimates increases to 3,218 fin whales (cv=0.43). Minke whales were found in almost equal densities in all strata except for the Cape Farewell offshore area, where none were seen. The cue-counting abundance estimate of minke whales was 4,856 (cv=0.49) for West Greenland using a cue rate of 46.3 cues per hour (cv=10.6). If the estimate is corrected for perception bias the minke whale abundance is estimated to be 10,792 whales (cv=0.59). Low coverage was attained in the northern area of West Greenland and this should cause an especially large negative bias for the estimates of fin whale abundance because the area is believed to have particularly large densities of fin whales.

INTRODUCTION

Most estimates of abundance of large baleen whales, including minke whales, *Balaenoptera acutorostrata*, fin whales, *Balaenoptera physalus*, humpback whales, *Megaptera novaeangliae*, in West Greenland waters are more than 10 yrs old. A series of aerial surveys of large baleen whales in West Greenland were conducted between 1983 and 1993 and abundance estimates were provided from cue counting techniques (cf. Hiby 1985) in 1987-88 and in 1993 (Hiby *et al.* 1989, Larsen 1995, Larsen *et al.* 1989). From these surveys, all conducted in July and August, fin whale abundance was estimated at 1,100 (95% CI 520-2,100) in West Greenland in 1987-88 (IWC 1992) and abundance of minke whales was estimated at 3,266 in 1987-88 (95% CI 1,700-5,710 (IWC 1990) and at 8,371 (95% CI 2,414-16,929) minke whales in 1993 (Larsen 1995).

Abundance of humpback whales in West Greenland was estimated from photo-identification surveys in July and August 1988-93, with a combined estimate over the five years of surveys of 360 humpback whales (95% CI 314-413) (Larsen and Hammond 2004). A line transect analysis of the aerial survey in July and August 1993 resulted in an uncorrected estimate of 599 (95% CI 237-1,512) (Kingsley and Witting 2003) and an aerial photographic survey in July through October 2002 and August through October 2004 provided an estimate of 400 humpback whales (cv=0.64) corrected for submergence about three quarter of the time.

In September 2005 a ship-based line transect survey was conducted in East and West Greenland covering the shelf areas out to the 200 depth contour (Heide-Jørgensen et al. In press). Fin whales were most abundant in East Greenland with an estimate of 3214 (95% CI 980-10,547) and a lower abundance 1,980 (95% CI 913-4,296) was estimated for West Greenland. Humpback whales were found both in offshore and coastal areas of West Greenland and abundance was estimated at 1,306 (95% CI 570-2,989). They occurred in low numbers in East Greenland with abundance estimated at 347 (95% CI 48-2,515). Finally, minke whale 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. These abundance estimates were considered negatively biased due to incomplete survey coverage and lack of correction factors for availability and perception bias.

The lack of up-to-date information on the abundance of large cetaceans in West Greenland has made it difficult for the Scientific Committee of the International Whaling Committee to provide advice on sustainable takes from especially minke whales and fin whales in West Greenland (IWC 2005). Given that the average annual removals during 1999-2004 of minke whales and fin whales were 172 and 9, respectively, it seems prudent to update abundance estimates for these two species.

This manuscript reports on an aerial survey of large cetaceans conducted in West Greenland in August-September 2005. Abundance estimates were developed for fin whales, humpback whales and minke whales and are presented here, with comparisons to the abundance estimates obtained during a ship based survey conducted simultaneously in 2005.

METHODS

Survey methods and design

The survey was conducted between 28 August and 23 September 2006. The survey platform was an Icelandic Partenavia Observer P-68 where two observers were located in the rear seats each with bubble windows. An additional observer/cruise leader was seated in the right front seat. Sightings and a log of the cruise track (recorded from the aircrafts GPS) were recorded on laptop computers. Declination angle to sightings was measured with Suunto inclinometers and lateral angle from the nose of the aircraft was estimated. No correction for drift of airplane was applied. Sightings with time stamps were entered on dictaphones and on a computer-based voice recording system that also logged the positions of the plane. Target altitude and speed was 750 feet (229 m) and 90 kts (167 km^{-1}), respectively.

A cue was defined as a dive for minke whales and a blow for fin and humpback whales, and all cues were reported unless the group size was so large that reporting was impossible. Declination and lateral angles, as well as time for each cue, was recorded together with information on number of whales in the group and the visual cue of the sighting.

Survey conditions were recorded at the start of the transect lines and whenever a change in sea state, horizontal visibility and glare occurred. 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 (i.e. the 200 m depth contour). Transect lines were placed in an east-west direction except for south Greenland where they were placed in a north-south direction. The surveyed area was divided into 6 strata (Fig. 1).

Analytical methods

<u>Humpback whales</u>

Humpback whales were found predominantly in groups, and the size of the groups was sometimes large: only 8% of detections were of single animals, 32% were of groups larger than 5 and the largest group was estimated to contain 95 animals. Due to this occurrence in large groups, the abundance of humpback whales was analyzed using standard line transect methods, assuming probability of detection on the line to be 1. Animal abundance is estimated by

$$\hat{N} = \frac{n}{2L}\hat{f}(0)\hat{E}[s]A$$

where n is the number of groups detected, L is the transect line length, $\hat{f}(0)$ is the intercept of the estimated probability density function of distances to detected groups, $\hat{E}[s]$ is estimated mean group size, and A is stratum area (see Buckland et al. 2001, for further details of estimation methods). Only effort and detections in sea states 4 and below were used in the analyses.

Half-normal and hazard-rate detection functions were fitted to the grouped data. Sample size is lower than desirable for line transect surveys (only 22 groups within the

truncation distance of 3 km); this precluded stratifying for estimation of the detection function and $f(0)$ and it precluded use of covariates in this estimation. Based on Akaike's Information Criterion (AIC), a half-normal detection function model with no adjustment terms was chosen (Fig. 2). The associated χ^2 goodness-of-fit statistic was not significant (p=0.63), indicating an adequate fit to the data.

A regression of log group size against estimated detection probability was used to estimate mean group size. Because of small sample size, a single mean group size was estimated over all strata.

Fin whales

Fin whale abundance was also estimated using line transect methods. Fin whale group sizes were not as variable and large as for humpback whales, but nevertheless, 44% of detections were of groups of 1 whale, 37% were in groups of 2 whales and 7% were in groups of 5 or more. The largest detected group was estimated to contain 50 animals. Only effort and detections in sea states 4 and below were used in the analyses.

Exploratory analysis suggested perpendicular distance truncation at 3km; this excluded 8% of detections (7 out of 84 detections). Estimation was therefore based on grouped distance data, using a regression of log school size on estimated detection probability to estimate mean group size. Because of small sample size, a single mean group size was estimated over all strata. Half-normal and hazard rate detection function forms were considered and a hazard rate function with no adjustment parameters was selected on the basis of AIC (Fig. 3). The associated χ^2 goodness-of-fit statistic was not significant (p=0.22), indicating an adequate fit to the data.

Duplicates between right front and right rear observers of sightings and cues were determined based on coincidence in timing, lateral angle and perpendicular distance.

Minke whales

With the exception of one group of two whales, all minke whale detections were of solitary animals. Standard cue-counting methods (assuming probability of detection at zero radial distance is 1) were used in the first instance to estimate the abundance of minke whales, as follows:

$$\hat{N} = \frac{n}{\phi T \hat{\eta}} \hat{h}(0) A$$

Here A is the survey area; n is the number of detected cues; T is the total time spent searching; $\phi/(2\pi)$ is the fraction of a full circle searched (taken to be 0.5 here since the region ahead of abeam on both sides of the aircraft was searched); $\hat{h}(0)$ is the estimated slope of the probability density function of radial distances to detections, evaluated at distance zero; $\hat{\eta}$ is the estimated cue rate of animals. See Buckland et al. (2001, pp 191-193) for further details. Only effort and detections in sea states 3 and below were used in analysis.

$h(0)$ was estimated by fitting half-normal and hazard-rate functional forms to grouped radial distance data truncated at 1.6 km. This led to 7 detections (17% or the

distances) being discarded. A hazard-rate detection function form with no adjustment terms was selected on the basis of AIC. The resulting detection function and fit of the pdf of radial distances to the observed radial distance distribution are shown in Figures 4 and 5. The associated χ^2 goodness-of-fit statistic was not significant (p=0.47), indicating an adequate fit to the data.

Because substantial random errors in measuring distance can lead to substantial positive bias (see Borchers et al., 2003), the data were examined for evidence of measurement error, and methods which take account of measurement errors were considered.

Although the sample size is small (only 4 duplicates from 32 sightings), we also estimated the probability of detecting a cue at the closest distance and estimate abundance using a "point independence" method (Borchers et al., 2006) without the assumption of certain detection at distance zero.

RESULTS

The survey covered the coast of West Greenland between northern Disko Island (70°45`N) south to Cape Farewell (60°N). Six strata were covered: Disko Bay, Store Hellefiske Bank, Central West Greenland, South West Greenland, South Greenland and an offshore Cape Farewell stratum. All survey effort in Disko Bay and on Store Hellefiske Bank was completed before the 12th September. After this, between the 11th September and 20th September, the survey was primarily concentrated in the southwest and south Greenland and after the 20th of September, effort was concentrated in the two strata in south Greenland. A total of 246 sightings were made during the survey of which 54 sightings were not determined to species but most of these were of unidentified dolphins (Table 1).

Distribution of sightings

Large baleen whale sightings were made in all strata (Fig. 6). Sightings of fin whales were heavily concentrated in the Central West Greenland strata in an offshore area at approximately 66°N 56°W, although additional sightings were made all along the West Greenland coast generally around the 200 m depth contour. Sightings of humpback whales and sei whales were also found in the same concentration area in Central West Greenland, yet sightings of humpback whales in both the South West and South strata were also made closer to the coast at depths <100 m. A few sei whale sightings were made outside of the high density region in Central West Greenland. Minke whale sightings were distributed along the entire coast and no apparent concentration areas were detected. Minke sightings were generally made at <200 m depths.

Large to medium sized toothed whales were also detected (Fig. 6). Pilot whales were seen in all strata and sightings were generally far offshore beyond 400-600 m depths. Two sightings of sperm whales occurred south of Cape Farewell in offshore waters. Several sightings of smaller toothed whales, particularly white-beaked dolphins and white-sided dolphins were made. All sightings of these dolphins were concentrated in the South West and South strata and none were seen north of Nuuk (64°N). The many sightings of unidentified dolphins (n=44) were in the same areas where the sightings of white-beaked dolphin and white-sided dolphins were made. Two unidentified small

dolphins were seen in Disko Bay and these sightings were likely of harbour porpoises: additional sightings of this species were south of Nuuk Fjord.

Humpback whale abundance estimates

There were no duplicate sightings of humpback whales so perception bias and measurement error could not be estimated.

Detection function and abundance estimates

Estimates of the key components of the line transect estimator are shown in Table 2, together with summaries of stratum areas, effort and estimated density and abundance. Total abundance was estimate to be 1,218 humpback whales (cv=0.57) with log-based 95% confidence interval (423; 3,508) and log-based 90% confidence interval (501; 2,960).

Fin whale abundance estimates

Measurement errors

Although the sample size is small, there appears to be little difference between the estimates of perpendicular distances from the two platforms at distances less than about 1.5 km (Fig. 7). The level of distance "binning" used in analysis (see Fig. 3) should make the line transect estimates of fin whale abundance insensitive to both the small errors there appear to be at distances less than 1.5 km and the more substantial errors at larger distances. The apparent lack of substantial errors at smaller distances indicates that little, if anything, would be gained by incorporating a measurement error model in estimation. Borchers *et al.* (in prep) found that random, unbiased measurement errors on line transect surveys introduced little bias when measurement error cv was less than 10% and introduced less than 10% bias even when the cv was as large as 30%. In addition, estimating the measurement error process parameters from such a small sample size may add substantially to the variance of the resulting density and abundance estimates. We therefore dealt with measurement errors only by using binned distance data in estimation.

Probability of detection at distance zero

We used sightings only on the right side of the plane (where there were two independent observers) to estimate g(0). Conditional detection functions for each observer (conditional on detection by the other observer) were estimated using the iterative logistic regression, as implemented in Distance 5.0, release 2 (Thomas et al., 2006). After truncating at 2.5 km to remove an influential observation at 3 km which led to conditional detection functions which increased slightly with distance, there remained 27 detections by the rear observer, 20 by the front observer and 6 duplicates. Fig. 8 shows the distribution of detections and duplicate proportions (proportion of each observer's detections which were seen by the other observer) as a function of distance, together with each observer's estimated conditional detection function (conditional on detection by the other observer). Models were selected using AIC and a model with radial distance and observer as explanatory variables was found to be best on this basis.

The probability of detecting a whale on the trackline was estimated to be 0.34 (cv=0.29) for the rear observer, 0.26 (cv=0.32) for the front observer and 0.51 (cv=0.21)

for both observers combined. As noted above, the sample size for this analysis is small and as a result, the reliability of these estimates is somewhat uncertain.

Detection function and abundance estimates

Estimates of the key components of the line transect estimator are shown in Table 3, together with summaries of stratum areas, effort and estimated density and abundance. Total fin whale abundance was estimated to be 1,652 animals (cv=0.37) and log-based 95% confidence interval (811; 3,367) and log-based 90% confidence interval (910; 3,000).

To correct for g(0)<1, we divided the above estimates by the estimated g(0) for both observers combined and used the Delta Method to calculate the cv of the estimate. This resulted in an abundance estimate of 3,218 animals (cv=0.43), log-based 95% confidence interval (1,431; 7,240) and log-based 90% confidence interval (1,630; 6,355). This point estimate of abundance is likely negatively biased because g(0) for the left side of the aircraft is likely to be lower than the combined g(0) for the right side – because the left side had only one observer.

An alternative approach that takes into account diving whales is the cue counting technique. Cue-counting methods were applied to estimate the abundance of solitary fin whales and to compare with line transect abundance of solitary fin whales. Using a cue rate of 50 cues per hour (Heide-Jørgensen and Simon submitted), a cue counting abundance estimate of 8,889 (n=50, cv=0.68) solitary fin whales was achieved. This estimate is ~10 times bigger than a similar line transect calculated solely for solitary fin whales (719, cv=0.40). However, the detection function to the observed radial distance distribution in the cue counting estimate showed a somewhat unrealistic rapid drop off close to the origin (Fig. 11) and cue counting estimates were not developed any further for fin whales.

Minke whale abundance estimates

Measurement errors

The sample size of four minke whale cues detected by both front and rear observers (minke duplicates) in the right side of plane is too small to estimate the distance measurement error process reliably. However, comparison of measurement of cues from both minke and fin whales suggest that the difference in measurement error between the two platforms within about 1.5 km is negligible (Fig. 9) and we did not attempt to incorporate distance measurement error in the abundance estimation. It is not possible to estimate bias in estimating distance by either platform from these data.

Probability of detection at distance zero

Independent observer data were available only for the right side of the aircraft. These were used to estimate probability of detection at the closest radial distance used in analysis. Because the front observer did not have a clear view of distance zero (because there was no bubble window in this position), and no detections were made within 0.2 km of the aircraft, data were left-truncated at 0.2 km before analysis. Fig. 10 shows the duplicate proportions (proportion of each observer's detections which were seen by the other observer) as a function of distance, together with each observer's estimated conditional detection function (conditional on detection by the other observer). Conditional detection functions were estimated using the iterative logistic regression, as

implemented in Distance 5.0, release 2 (Thomas et al., 2006). Models were selected using AIC and a model with radial distance, observer and Beaufort sea state as explanatory variables was found to be best on this basis.

The probability of detecting a cue at distance 0.2 km was estimated to be 0.36 (cv=0.39) for the rear observer, 0.22 (cv=0.42) for the front observer and 0.45 (cv=0.33) for both observers combined. As noted above, the sample size for this analysis is small (21 detections by the rear observer, 11 by the front observer, with 4 duplicates) and as a result, the reliability of these estimates is somewhat uncertain.

Detection function and abundance estimates

Estimates of the key components of the cue-counting estimator are shown in Table 4, together with summaries of stratum areas, effort and estimated density and abundance. Cue densities were converted to animal densities by dividing by an estimated cue rate of 46.3 cues per hour (cv=10.6, Heide-Jørgensen and Simon submitted). If detection at distance 0.2 km (called "$g(0)$" in the table) is assumed to be certain, total minke whale abundance is estimated to be 4,856 animals (cv=0.49) and log-based 95% confidence interval (1,910; 12,348) and log-based 90% confidence interval (2,219; 10,628). If detection at distance 0.2 km is estimated as above, total minke whale abundance is estimated to be 10,792 animals (cv=0.59) and log-based 95% confidence interval (3,594; 32,407) and log-based 90% confidence interval (4,289; 27,156). In obtaining this estimate it is assumed that the observer on the left side of the aircraft has the same probability of detecting a cue at 0.2 km as the two observers on the right side of the plane.

DISCUSSION

Due to inclement weather conditions the survey failed to cover areas west of Disko Island, the western part of the northern edge of Store Hellefiske Bank and a large part of the Central West Greenland strata. This lack of coverage, especially in the latter area, may cause a negative bias on the estimate of fin whale abundance in West Greenland, since large concentrations of fin whales are known to occur in this region. Further evidence of this bias is that the ship-based survey in September 2005 found large numbers of fin whales around 67°N 57°W, the area not covered in the present survey and that locations from fin whales tracked by satellite tracking and observations from Norwegian minke whalers indicate that fin whales occur in this area in conspicuous numbers (Heide-Jørgensen et al. 2003; Heide-Jørgensen et al. in press). No survey coverage was attained in offshore areas west of the 200 m depth contour south of 64°N and this may cause additional bias to the estimates of abundance of fin whales and minke whales in West Greenland.

The line transect estimate of humpback whale abundance in this study (1,218; 95%CI 423-3,508) was very similar to the estimate from the simultaneous shipbased survey (1,306; 95% CI 570-2,989). However, the estimate from the aerial survey is negatively biased because some animals will have been underwater and hence undetectable as the plane flew over them and no corrections were attempted for whales missed by the observers. If estimates of the percentage of time humpback whales are visible from the air were available, this bias might be reduced substantially. Hedley and Bannister (2001) estimated the surface detection probabilities for aerial surveys of southern hemisphere humpback whales to range within 0.25 and 0.41. Satellite-linked

time-depth-recorders deployed on five humpback whales off Central West Greenland (Fyllas Bank) in June-July 2000 has shown that these whales spend between 29.7 and 43.6% of their time at the surface above 4 m with an average of 36% (Dietz et al. 2002). If it is assumed that humpback whales can be seen at depths down to 4 m the estimates will need to be multiplied by a factor that takes into account the time the whales are visible (above a certain depth) to be seen by the observers. This will in any case lead to a substantially larger abundance estimate of humpback whales in West Greenland.

Previously the abundance of humpback whales in West Greenland has been estimated to about 360 humpback whales (95% CI 314-413) for 1988-1993 (Larsen and Hammond 2004), 599 (95% CI 237-1,512) in 1993 (Kingsley and Witting 2003) and 400 (*cv*=0.64) in 2002 and 2004 (Witting and Kingsley 2005). The uncorrected aerial and the ship based surveys in 2005 both confirm that the current abundance of humpback whales in West Greenland is substantially larger than what was estimated in the surveys in the 1990s. This may be due to both a severe underestimation of abundance in previous surveys, growth in population size and/or increased affinity to the West Greenland feeding ground. The timing of the surveys in 2005 was one month later than the surveys conducted in the 1990s. Humpback whales arriving late on the West Greenland feeding ground could have contributed to the larger abundance estimates in 2005. The observations of unprecedented large groups of humpback whales (up to 95 individuals), often with reddish defecation trailing behind, could be interpreted as a fall feeding migration to West Greenland, but could also be a result of aggregation of whales before the fall migration out of Greenlandic waters.

Comparison of cue counting and line transect estimates for solitary fin whales resulted in a cue counting estimate that was ~10 times the line transect estimate. This suggests that the availability bias in line transect estimates may be large and that the fin whale abundance estimate presented here (based on a line transect analysis of all schools) may be substantially negatively biased. Several circumstances made the cue counting estimate less attractive; the direction of the bias, if any, is unknown, the cue counting method can not deal with large group sizes, and the detection function showed an implausible drop near the origin.

The line transect estimate of fin whale abundance (1,652; 95 % CI 811-3,367) was similar to the estimate obtained from the simultaneous ship-based survey (1,980; 95% CI 913-4,296). Both estimates are negatively biased to an unknown degree by incomplete coverage, lack of correction for submerged whales and especially for the aerial survey, by the lack of correction for whales missed by the observers. Correcting the aerial survey for availability bias increases the abundance estimate to 3,218 whales (95% CI 1,431-7,240). However, all three estimates confirm that the likely magnitude of the fin whale abundance off West Greenland in September is in the low thousands. The 1987-88 estimate of 1,100 (95% CI 520-2,100) fin whales in West Greenland (IWC 1992) was a cue counting estimate and is therefore not directly comparable to the current abundance estimates. However, considering that the current but uncorrected estimates are larger than the earlier estimates corrected for availability bias (by the cue counting techniques) it seems likely that the abundance of fin whales in West Greenland has increased. Additional evidence that fin whale abundance has increased in West Greenland comes from a simple comparison of encounter rate. About 3 times as many whales were seen (per unit effort) in the 2005 survey than in the 1987 survey. The later timing of the aerial survey in 2005 could be partially responsible and included fin whales arriving late on the West Greenland feeding ground. However, like humpback whales, fin whales were also

seen in large groups of up to 50 whales. These group sizes were not seen on previous surveys, and could be interpreted as a fall aggregation before the initiation of the southward migration.

The cue counting estimate of minke whale abundance (4,856; 95 % CI 1,910-12,348) was close to the estimate obtained from the simultaneous ship-based survey (4,479, 95% CI 1,760-11,394). The two estimates are however not directly comparable since the aerial survey estimate correct for availability bias (cue counting technique) and the ship based survey estimate assumes that all minke whales are at the surface to be seen during the passage of the survey platform. The cue counting minke whale abundance estimate from this survey is also not significantly different from previous estimates from West Greenland, but when corrected for perception bias or g(0) it is considerably larger than previous estimates although not statistically different. The data that are used for estimating the perception bias are based on a small sample size from just one side of plane and the estimate of g(0) is similarly relatively imprecise (cv=0.59). However, the few duplicate sightings between front and rear observer indicate that a considerable number of minke whales are not detected. In comparison with perception bias of other species of marine mammals in aerial surveys minke whales are clearly among the most difficult animals to detect and the low estimate of g(0) (=high estimated perception bias) determined in this study is not unexpected (Table 5). Minke whales are hard to detect because they are inconspicuous and spent short time at the surface, but it could also be because of the rather demanding data collection from each cue of a whale. Finally the fact that the survey targets whales close to the plane (i.e. minke whales) as well as those farther away (fin and humpback whales) might add to perception bias for minke whales. It is therefore recommended that future minke whale surveys should use a full double platform setup in both sides of the plane, preferably flying at a slower speed to allow more time for data collection and to concentrate on collection of data on the minke whale sightings near the survey platform. However, this will be in conflict with using the survey platform for abundance estimation of large cetaceans as well.

This study demonstrates the amount of data that can be obtained from an aerial survey effort of the shelf area off West Greenland in a year with reasonably good weather conditions. Other years where surveys were attempted have had much more severe weather conditions and the timing of the present survey (late August and September) may have improved the likelihood of experiencing fair weather. The trade off is that the southward migration of baleen whales out of the Greenland shelf areas might already have started which also negatively affects the abundance estimates. Víkingsson and Heide-Jørgensen (2005) showed that some minke whales tagged with satellite transmitters left the Icelandic shelf areas in mid September when they initiated their southbound migration.

This study has also brought to light the difficulties of applying the cue counting method to other species besides solitary minke whales. Fin whales and humpback whales occur in groups and some of these groups are up to 50 fin whales and 95 humpback whales. It is not a simple or practical task to count cues from tens of animals simultaneously, and it becomes increasingly complicated with increasing pod size of whales. Also, because there is a considerable range in fin whale group sizes, some of them large, the fin whale cue counting estimates will be fairly sensitive to whether or not animals in groups cue at the same rate as the observed individuals from which cue rate estimates were obtained.

The question remains if the cue counting method is the most efficient and accurate way to obtain abundance estimates of large cetaceans in West Greenland. Alternative methods include sight-resight methods applied to aerial line-transect survey (e.g. Innes et al. 2002) that will include correction for perception bias from double platform experiments, but this requires telemetry data on species specific surface times to correct for availability bias.

In summary, the abundance estimates presented in this study are likely underestimates of the actual abundance of large whales in West Greenland because of incomplete coverage, no correction for perception bias in the case of humpbacks, and lack of correction for availability bias for fin whales and humpback whales. Furthermore, the survey was conducted late in the summer season and it can be expected that the southbound autumn migration was already initiated by that time.

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Table 1. 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**	**Mean group size**	**Maximum group size**	**Minimum group size**
Fin whale	78	231	2.96	50	1
Sei whale	4	13	3.30	10	1
Humpback whale	21	350	16.70	95	1
Sperm whale	2	2	1.00	1	1
Unidentified large whale	12	15	1.25	3	1
Minke whale	42	43	1.10	2	1
Pilot whale	10	181	18.20	50	1
Unidentified small whale	10	16	1.60	5	1
White-beaked dolphin	12	62	5.20	13	1
White-sided dolphin	3	27	9.00	20	3
Harbour porpoise	8	19	2.40	6	1
Unidentified dolphin	44	406	9.20	45	1

Table 2. Humpback whale data summary and estimates. K is number of transects; a is area (km^2); L is transect length (km); n is number of groups detected within 3 km; n/L is encounter rate (groups per 1,000 km); $\hat{E}[s]$ is estimated mean group size; $\hat{D}$ is estimated animal density (animals per 1,000 km^2); $\hat{N}$ is estimated animal abundance. Percentage coefficients of variation (%CVs) are in brackets.

Stratum	area	K	L	n	n/L	$\hat{f}(0)$	$\hat{E}[s]$	$\hat{D}$	$\hat{N}$
CF	11,523	4	293	0	0.0			0	0
CW	74,798	30	1,958	4	2.04 (91%)			5.63 (100%)	421 (100%)
DB	12,312	12	556	1	1.80 (178%)	0.664 (12%)	8.3 (38%)	4.95 (182%)	61 (182%)
SG	19,491	19	1,106	4	3.62 (46%)			9.97 (62%)	194 (62%)
SH	15,669	7	577	0	0			0	0
SW	29,781	31	1,968	12	6.61 (42%)			18.2 (60%)	542 (60%)
Total	163,574							19.1 (57%)	1,218 (57%)

Table 3. Fin whale data summary and estimates. K is number of transects; a is area (km^2); L is transect length (km); n is number of groups detected within 3 km; n/L is encounter rate (groups per 1,000 km); $\hat{E}[s]$ is estimated mean group size; $\hat{D}$ is estimated animal density (animals per 1,000 km^2); $\hat{N}$ is estimated animal abundance. Percentage coefficients of variation (%CVs) are in brackets.

Stratum	area	K	L	n	n/L	$\hat{f}(0)$	$\hat{E}[s]$	$\hat{D}$	$\hat{N}$
CF	11,523	4	293	2	6.8 (209%)			5.10 (210%)	59 (210%)
CW	74,798	30	1,958	38	19.4 (41%)			14.48 (46%)	1,083 (46%)
DB	12,312	12	556	1	1.80 (67%)	0.939 (21%)	1.59 (9%)	1.34 (71%)	17 (71%)
SG	19,491	19	1,106	18	16.3 (28%)			12.14 (36%)	237 (36%)
SH	15,669	6	577	6	10.4 (114%)			7.76 (117%)	122 (117%)
SW	29,781	31	1,968	12	6.1 (31%)			4.55 (39%)	135 (39%)
Total	163,574							10.10 (37%)	1,652 (37%)

Table 4. Minke whale data summary and estimates. K is number of transects; a is area (km^2); T is time spent searching (hours); n is number of cues detected within 1.6 km; n/T is encounter rate (cues per hour); $\hat{D}_c$ is estimated cue density (cues per 10^3 km^2); $\hat{D}$ is estimated animal density (animals per 10^6 km^2); $\hat{N}$ is estimated animal abundance. Percentage coefficients of variation (cv's) are in brackets. Estimated cue rate of $\hat{\eta}$ =46.3 cues per hour (cv=0.11) was used to convert cue density to whale density. Estimates in columns headed "estimated *g*(0)" are those in columns headed "*g*(0)=1" divided by the estimated *g*(0) of 0.45 (cv=0.33).

Stratum	area	K	T	n	n/T	$\hat{h}(0)$	*g*(0)=1		estimated *g*(0)	
							$\hat{D}$	$\hat{N}$	$\hat{D}$	$\hat{N}$
CF	11,523	3	1.26	0	0		0	0	0	0
CW	74,798	27	11.47	12	1.047		34.35	2,569	76.32	5,709
					(0.45)		(0.61)	(0.61)	(0.70)	(0.70)
DB	12,312	11	3.02	2	0.663	4.77	21.76	268	48.35	595
					(0.45)	(0.40)	(0.61)	(0.61)	(0.69)	(0.69)
SG	19,491	19	7.09	8	1.129		37.04	722	82.30	1,604
					(0.38)		(0.56)	(0.56)	(0.65)	(0.65)
SH	15,669	6	3.52	3	0.853		28.00	439	62.22	975
					(0.55)		(0.69)	(0.69)	(0.76)	(0.76)
SW	29,781	29	11.38	10	0.879		28.84	859	64.08	1,908
					(0.47)		(0.62)	(0.62)	(0.70)	(0.70)
Total	163,574						29.69	4,856	65.97	10,792
							(0.49)	(0.49)	(0.59)	(0.59)

Table 5. Estimates of perception bias for aerial surveys of different marine mammals in West Greenland and characterization of the main features of the sighting process.

Species	Survey platform	Mean pod size	Detection of cue's	Percep-tion bias	Estimation method	Ref.
Narwhal *Monodon monoceros*	Twin Otter	1.7	Dark but mostly in leads	0.86 (0.13)	Mark-recapture	GINR
Beluga *Delphinapterus leucas*	Twin Otter	3.0	White moving groups	0.77 (0.10)	Mark-recapture	GINR
Bowhead whale *Balaena mysticetus*	Twin Otter	1	Big black body, blows, in leads	0.62 (0.19)	Mark-recapture	GINR
Walrus *Odobenus rosmarus*	Twin Otter	1-2	Small brown body	0.51 (0.25)	Mark-recapture	GINR
Fin whale *Balaenoptera physalus*	Partenavia	3.0	Large blows	0.51 (0.21)	Line transect	This survey
Minke whale *Balaenoptera acutorostrata*	Partenavia	1.1	Inconspicuous blows	0.45 (0.33)	Cue counting, point independence	This survey

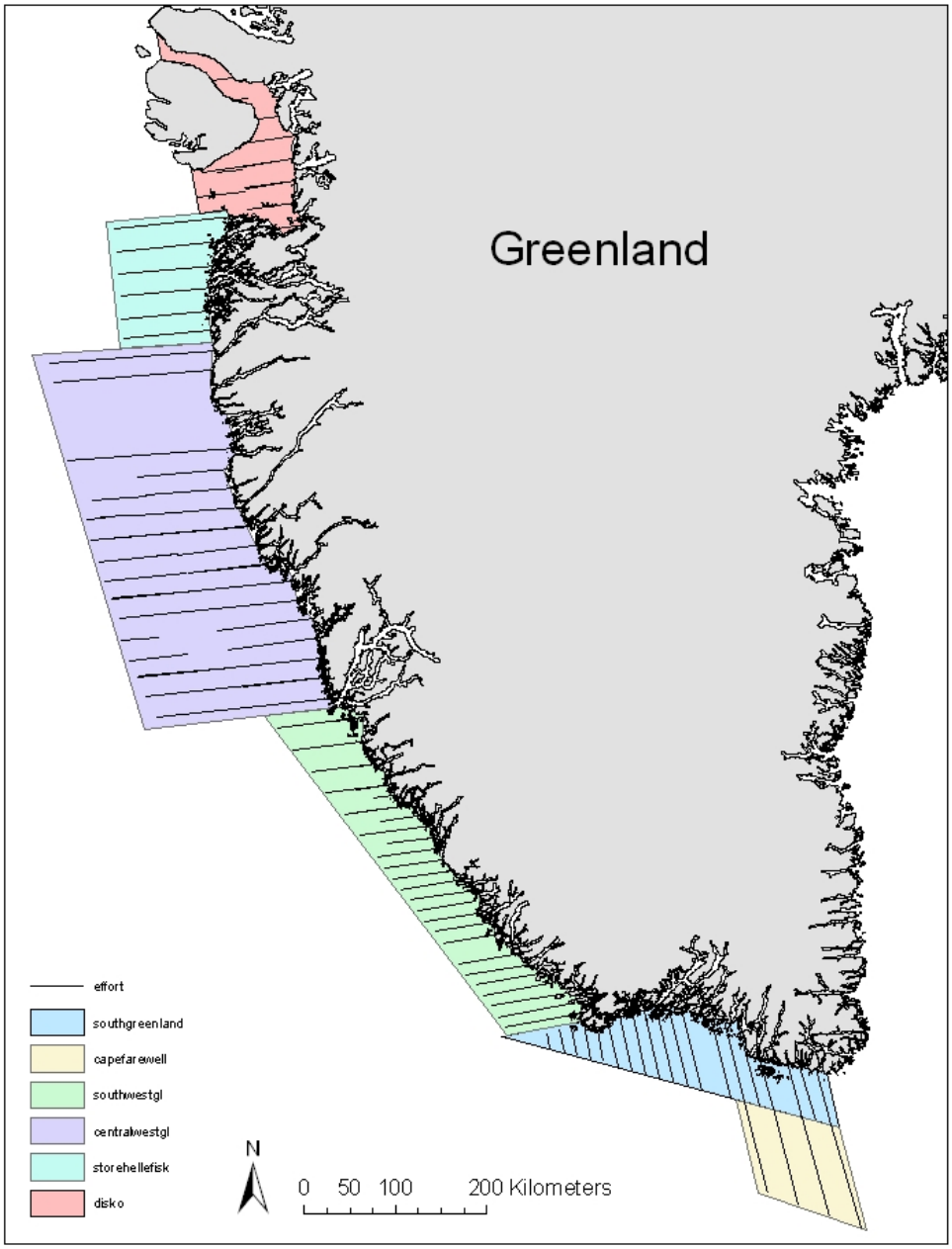

Fig. 1. Survey transect lines and delineation of strata for the aerial survey of large cetaceans in West Greenland in September 2005. The area of the strata was calculated as 12,312 km^2 for the Disko Bay strata, 15,669 km^2 for the Store Hellefiske Bank strata, 74,798 km^2 for the central West Greenland strata, 29781 for the southwest Greenland strata, 11,523 km^2 for the Cape Farewell strata and 19,491 km^2 for the South Greenland strata.

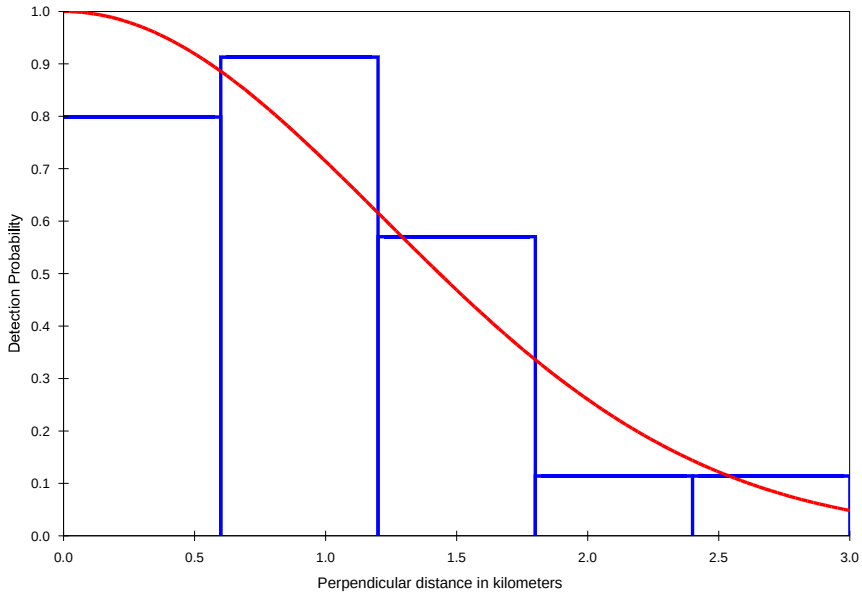

Fig. 2. Perpendicular distance histogram and fitted half-normal probability density function for humpback whale line transect data.

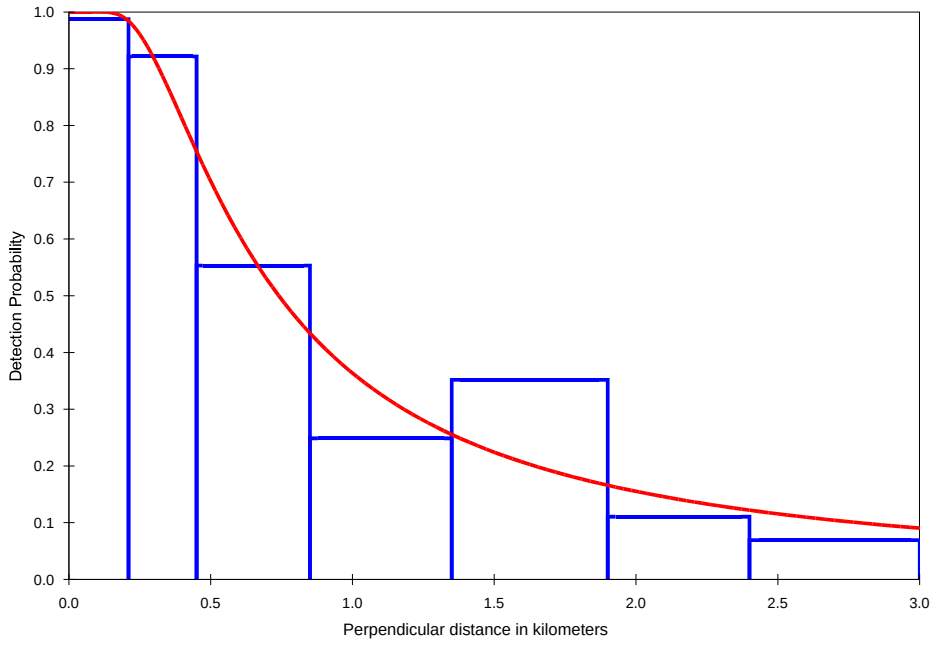

Fig. 3. Perpendicular distance histogram and fitted hazard rate probability density function for fin whale line transect data.

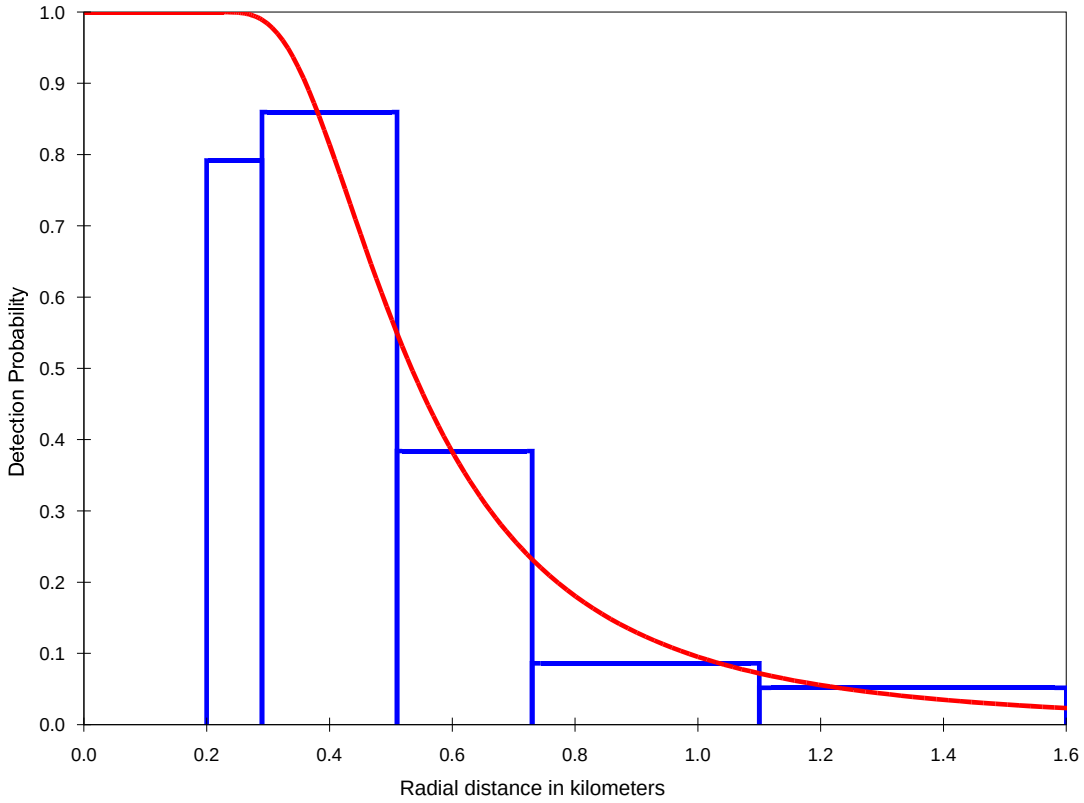

Fig. 4. Radial distance histogram and fitted hazard-rate probability detection function for minke whale cue-counting data. (Note that the histogram bar heights have been scaled in inverse proportion to their mean radial distance, in order to place them on a comparable scale to the detection function curve.)

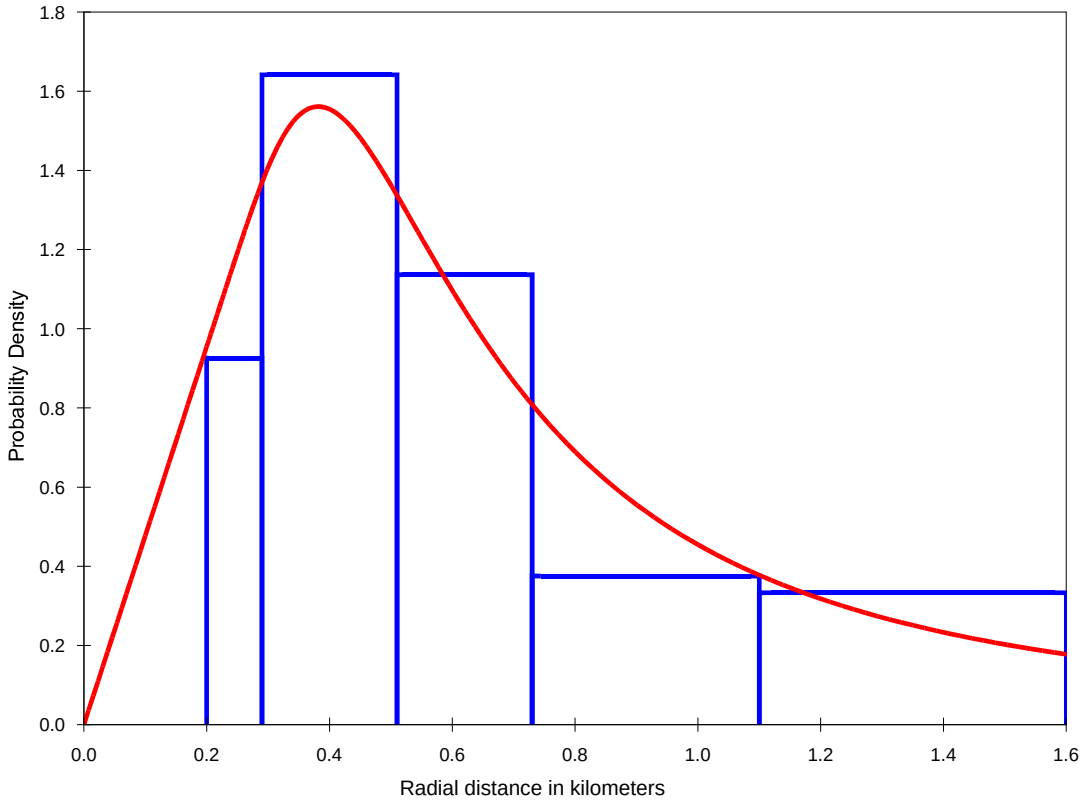

Fig. 5. Radial distance histogram and fitted hazard-rate probability density function for minke whale cue-counting data.

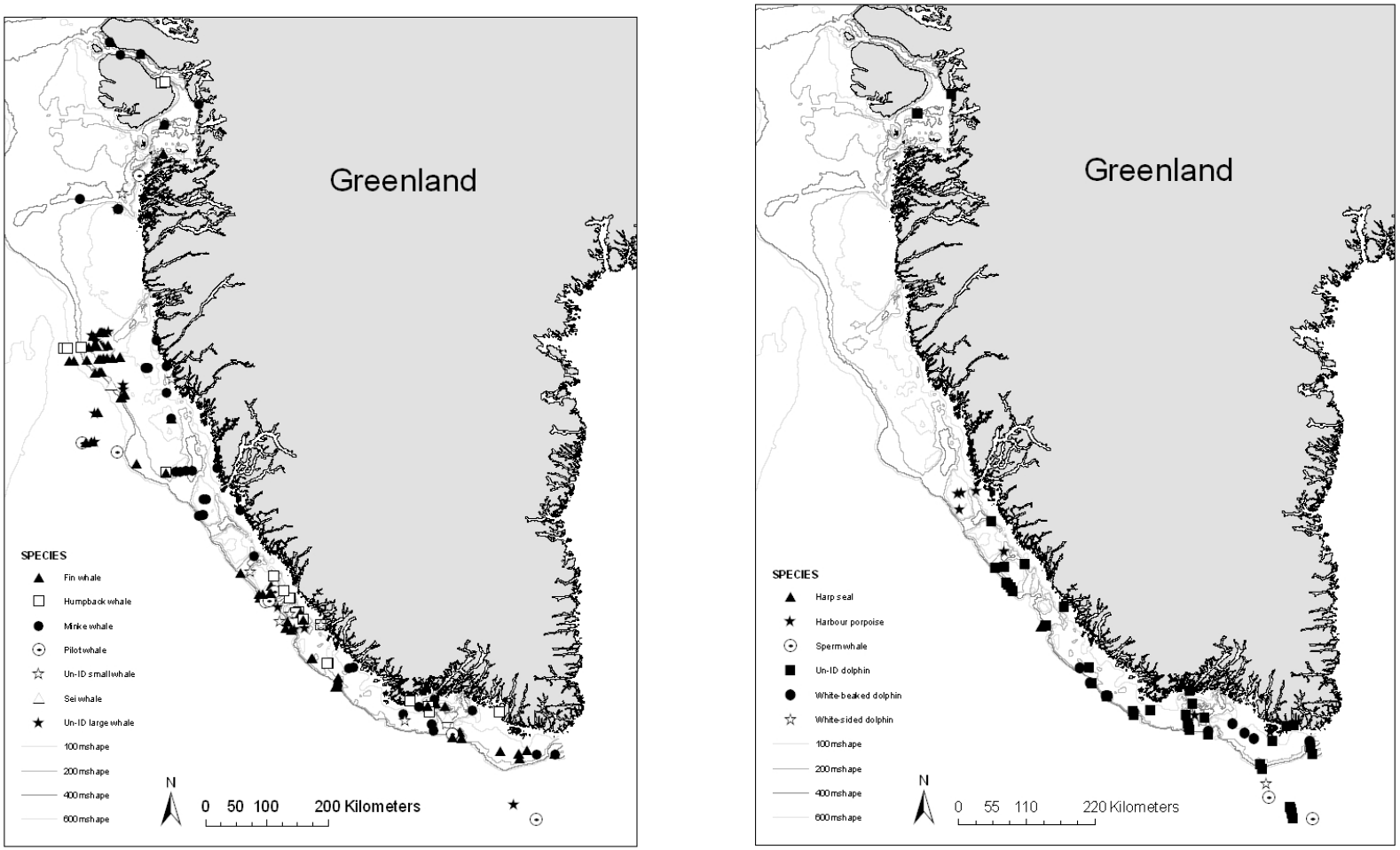

Fig. 6. Sightings of fin whales, humpback whales, minke whales, sei whales, pilot whales, sperm whales, harbour porpoises, white-beaked and white-sided dolphin and harp seals during the aerial survey off West Greenland September 2005.

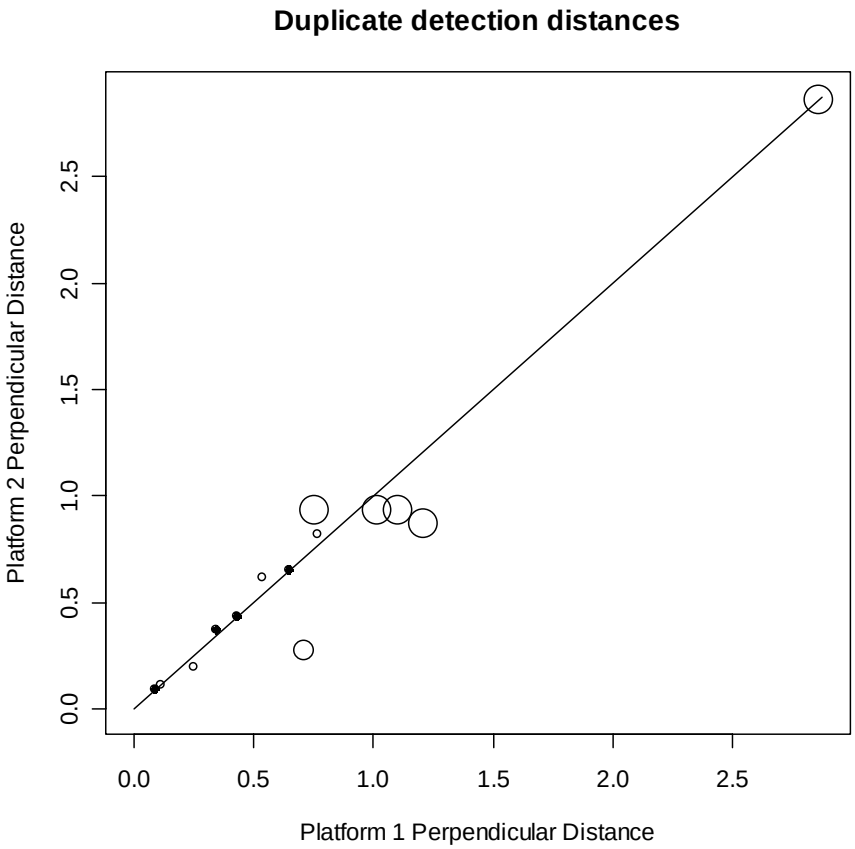

Fig. 7. Perpendicular distance estimates (in km) from duplicates (minke=solid dots, fin=circles; dots are proportional to group size (1, 2 or 3)). The line corresponds to platform 1 (front observer) and platform 2 (rear observer) estimated distances being equal.

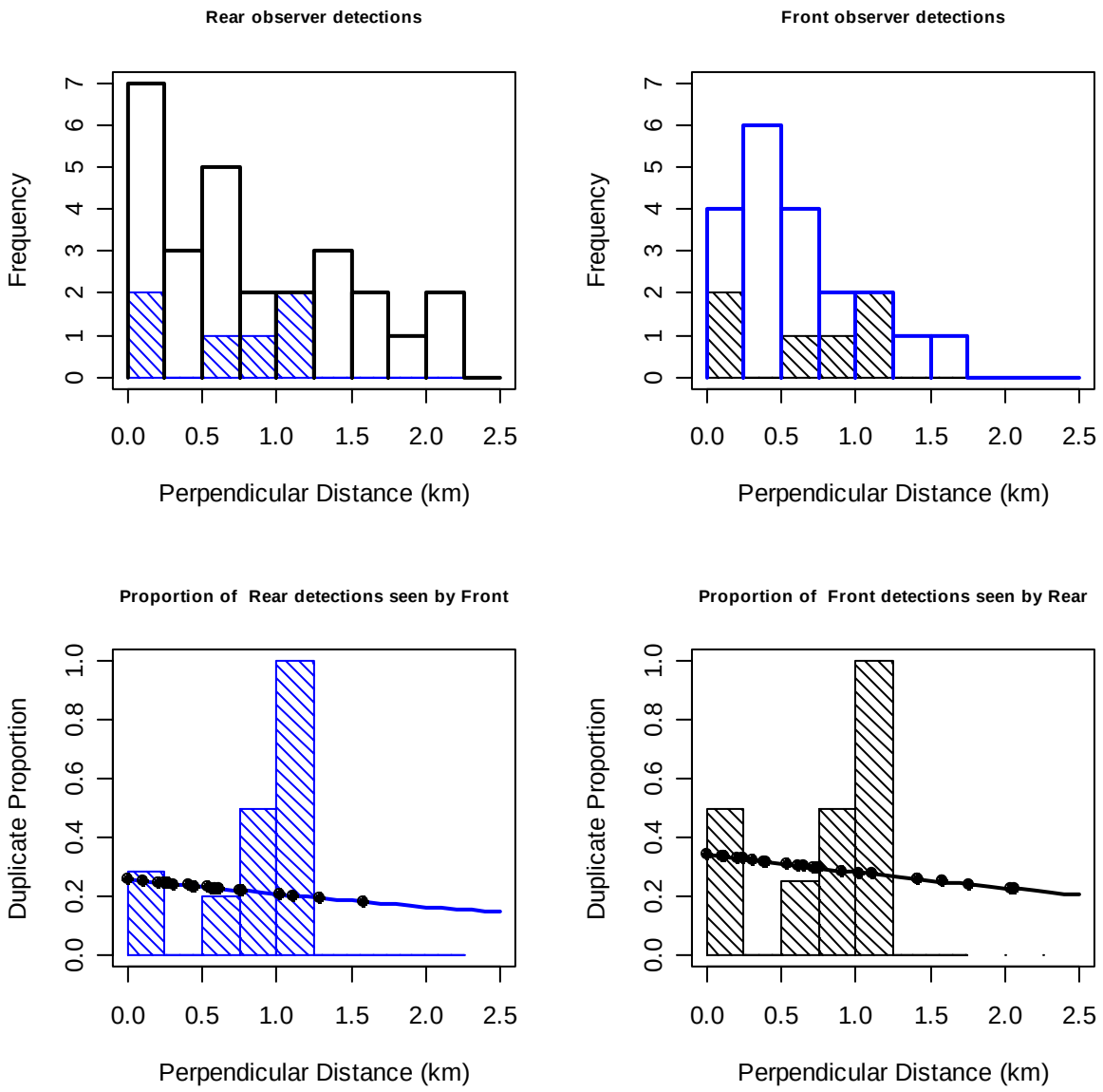

Fig. 8. Duplicate proportions and estimated conditional detection functions for fin whales. All data and estimates are for the right hand side of the aircraft only. The top row of plots shows the number of detections by each observer, with the numbers of these that were detected by the other observer (the duplicates) shaded. The bottom row of plots shows the duplicate proportions, together with fitted detection function (smooth curve) and estimated detection probability for individual detections made by the observer in question.

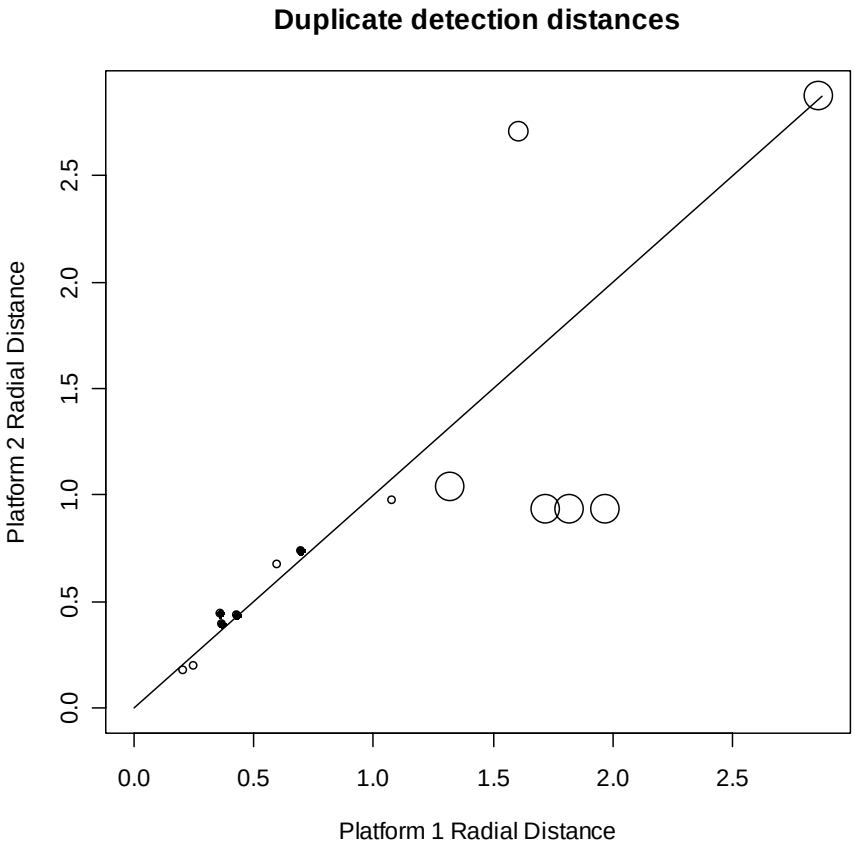

Fig. 9. Radial distance (in km) estimates from duplicates (minke=solid dots, fin=circles; dots are proportional to group size (1, 2 or 3)). The line corresponds to platform 1 (front observer) and platform 2 (rear observer) estimated distances being equal.

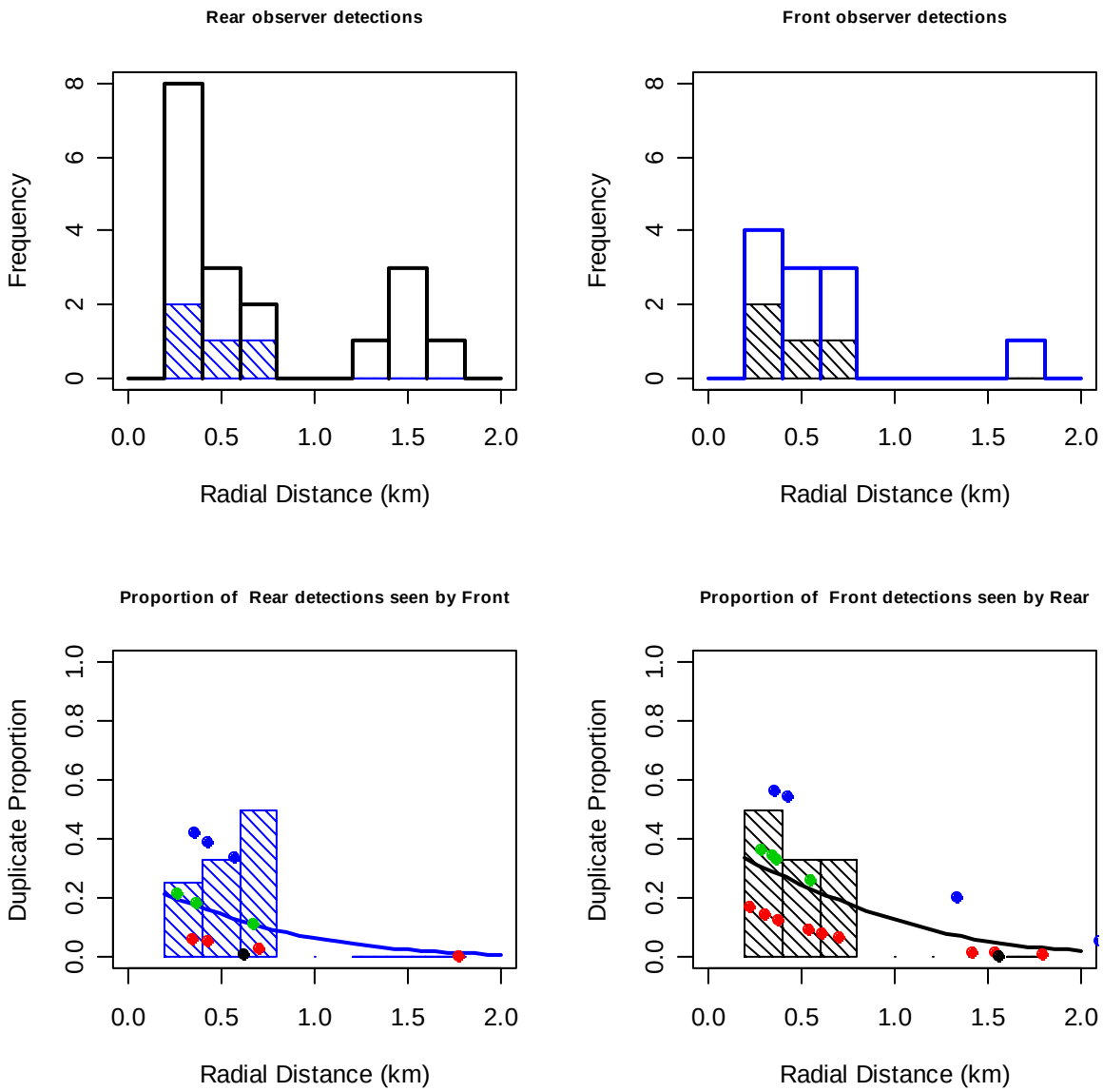

Fig. 10. Duplicate proportions and estimated conditional detection functions for minke whales. All data and estimates are for the right hand side of the aircraft only. The top row of plots shows the number of detections by each observer, with the numbers of these that were detected by the other observer (the duplicates) shaded. The bottom row of plots shows the duplicate proportions, together with fitted detection function (smooth curve) and estimated detection probability for individual detections made by the observer in question. Dot colour encodes Beaufort sea state: 0, 1, 2, and 3 are plotted in blue, green, red and black respectively.

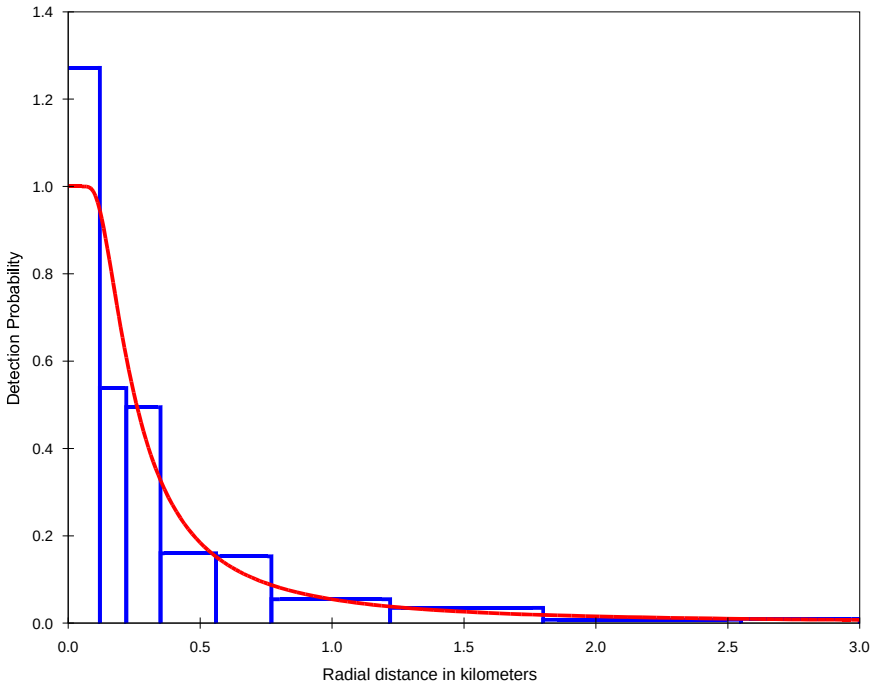

Fig. 11. Radial distance histogram and fitted hazard-rate probability detection function for fin whale cue-counting data.