Abundance of fin whales in West Greenland in 2007

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ABSTRACT

An aerial line transect survey of fin whales (*Balaenoptera physalus*) conducted off West Greenland in 2007 was used to estimate the current abundance of fin whales on the summer feeding ground. A total of 24 sightings of fin whale groups were collected during 8,632km of survey effort in sea states <5. Based on conventional distance sampling techniques an abundance of 4,359 whales (95% CI 1,879–10,114) was estimated. The survey was conducted as a double platform survey and mark recapture distance sampling techniques were used to correct for perception bias which resulted in an estimate of 4,468 whales (95% CI 1,343–14,871). Both estimates are negatively biased because no corrections were applied for whales that were submerged during the passage of the survey plane. The abundance estimate furthermore only represents the coastal areas of West Greenland. The sightings at the westernmost border of the strata suggest that the entire Baffin Bay-Davis Strait summer abundance of fin whales could be considerably larger. Based on comparison with previous surveys in West Greenland in 1987/88 and 2005 it appears that the fin whale abundance in West Greenland has increased.

KEY WORDS: FIN WHALE; ABUNDANCE ESTIMATE; SURVEY-AERIAL; WEST GREENLAND; NORTHERN HEMISPHERE

INTRODUCTION

Exploitation of fin whales (*Balaenoptera physalus*) in West Greenland began around 1919 with pelagic Norwegian whaling in the Davis Strait (Kapel, 1979). In 1924 coastal whaling along West Greenland was initiated and during 1919–39 approximately 1,200 fin whales were taken in West Greenland and the Davis Strait. Approximately 300 fin whales were taken during 1946–58, primarily along the coast of West Greenland. From 1959 to 1976 catches remained low with <2 catches per year and in 1977 the first quota was installed by the International Whaling Commission (IWC). Catches have remained stable at a mean of 12 per year for the period 1977–2007.

Fin whales are primarily hunted in West Greenland during summer and early autumn. Although their occurrence in West Greenland likely spans most of the year, West Greenland must still be considered a summer feeding ground for fin whales that generally spend the winter at more southern latitudes in the North Atlantic. The stock delineation of fin whales in the North Atlantic is unresolved but it is currently considered that fin whales in West Greenland comprise an isolated stock with limited exchange with the East Greenland-Iceland stock or the Newfoundland-Labrador stock even though genetic studies indicate a large exchange of individuals between areas (Bérubé *et al.*, 2006; IWC, 1992).

Despite many attempts between 1982 and 2007 only two surveys obtained enough sightings to allow for calculation of the abundance of fin whales in West Greenland. In 1987/88 fin whale abundance was estimated at 1,100 whales (95% CI 520–2,100) from an aerial cue counting survey (IWC, 1992). In 2005 the abundance was estimated at 3,218 whales (95% CI 1,431–7,240) from an aerial line transect survey with independent observers that allowed for correction of whales missed by the observers (Heide-Jørgensen *et al.*, 2008). A ship-based survey also conducted in 2005 gave a smaller abundance estimate (1,980, 95% CI 913–4,296) than the aerial survey (Heide-Jørgensen *et al.*, 2007).

In 2004, the IWC's Scientific Committee expressed concern that the available abundance estimates for fin whales in West Greenland were outdated and too imprecise to be used for generating advice on sustainable takes (IWC, 2005). For continued advice on the sustainability of the harvest in West Greenland it is important to determine if the abundance of fin whales in Baffin Bay-Davis Strait is stable, fluctuating in relation to climatic or ecological changes, or in a decline. A survey conducted at regular intervals is one way to update our knowledge on the status of fin whales in West Greenland. Here we report on an aerial survey of fin whales conducted off West Greenland in 2007 as part of the Trans North Atlantic Sightings Survey (TNASS; an international whale survey in 2007 that covered large parts of the Northern Atlantic).

METHODS

An aerial line transect survey of large whales in West Greenland was conducted between 25 August and 30 September 2007. The survey platform was a Twin Otter plane from Air Greenland, with long-range fuel tank and two independent pairs of observers all with bubble windows. Sightings and a log of the cruise track (recorded from the aircrafts GPS) were recorded on a Redhen msDVRs system that also allowed for continuous video recording of the trackline as well as vertical digital photographic recordings. The declination angle to sightings was measured with Suunto inclinometers when sighting was abeam (i.e. perpendicular to the trackline) and a time stamp (from the microphone switch) on the recordings was used to determine the moment when the sighting was abeam. Declination angles were

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converted to perpendicular distance of the animal to the trackline using an equation that adjusts for earth curvature (Buckland *et al.*, 2001). Target altitude and speed was 213m and 167km hr^{-1}, respectively.

Survey conditions were recorded at the start of the transect lines and whenever a change in sea state, horizontal visibility or glare occurred. For the analysis only effort in sea states <5 was included. The survey was designed to systematically cover the area between the coast of West Greenland and offshore (up to 100km) to the shelf break (i.e. the 200m depth contour, Fig. 1). Following previous survey designs transect lines were placed in an east-west direction except for South Greenland where they were placed in a north-south direction. This design ensured that the transects were perpendicular to the bathymetric gradients and did not follow depth contours. The surveyed area was divided into 11 strata plus several inshore strata that are not included here because of the absence of sightings (Fig. 2). The southern strata were planned to be covered first.

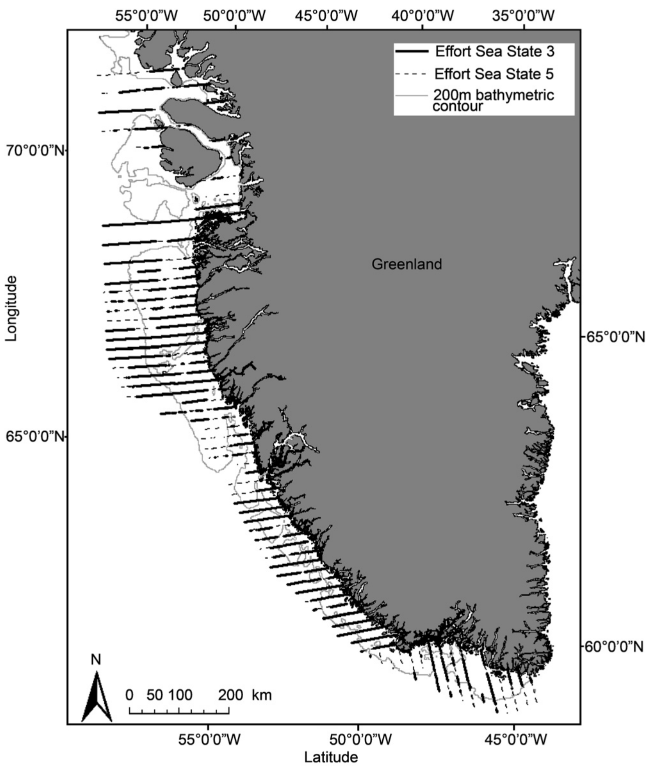

Fig. 1. Survey effort in sea states <3 and <5.

Conventional distance sampling abundance estimator

Using conventional distance sampling (CDS) methods, where detection on the trackline is assumed to be certain (denoted by $g(0) = 1$), animal abundance in each stratum was estimated by

$$\hat{N} = \frac{n}{2L\hat{\mu}} \hat{E}\,[s]\,A$$

where A is the area of the stratum, L is the total search effort in the stratum, n is the number of unique groups detected in the stratum by both set of observers, $\hat{\mu}$ was the estimated effective strip width of perpendicular distances to the midpoint of detected groups and $E[s]$ was the estimated mean

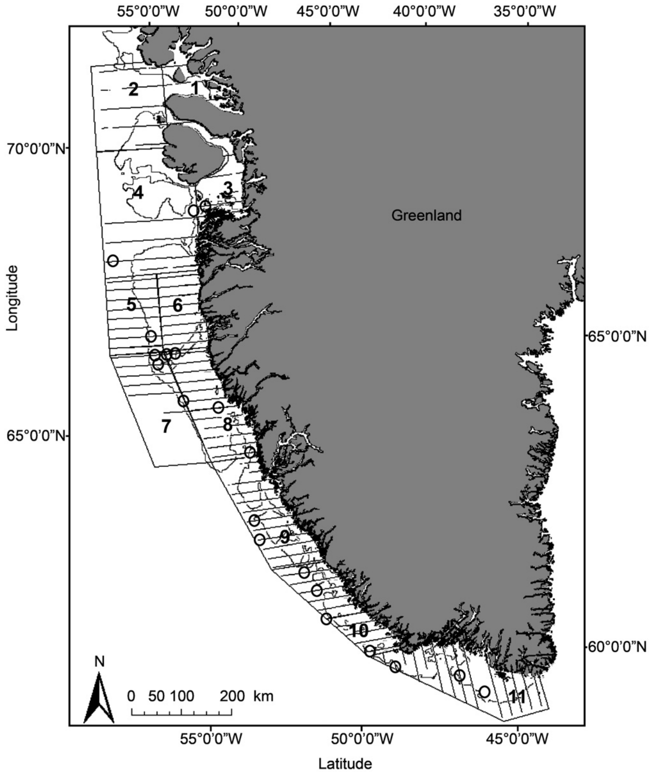

Fig. 2. Strata and transect lines and sightings of fin whales during the 2007 aerial survey.

group size using a regression of log group size against estimated detection probability (Buckland *et al.*, 2001).

Correction for perception bias

In this survey mark-recapture (MR) and DS methods were used which allowed detection on the trackline to be estimated and thus abundance could be estimated without assuming that $g(0) = 1$. However, this method of analysis (point independence) relies on having enough sightings to be able to estimate the parameters in the fitted models.

The search method used an independent observer configuration where the primary observers in the front seats acted independently of the secondary observers in the rear seats. Detections of animals by the primary observers serve as a set of binary trials in which a success corresponds to a detection of the same group by secondary observers. The converse is also true because the observers are acting independently; detections by the secondary observers serve as trials for the primary observers. Analysis of the detection histories using logistic regression allows the probability that an animal on the trackline is detected by an observer to be estimated, and thus, abundance can be estimated without assuming $g(0)$ is one (Buckland *et al.*, 2001).

Abundance of groups was estimated in each stratum using

$$\hat{N}_G = \frac{A}{2wL} \sum_{i=1}^{n} \frac{1}{\hat{p}_i}$$

where w is the truncation distance, and $\hat{p}_i$ is the estimated probability of detecting group i obtained from the fitted mark-recapture distance sampling (MRDS) model. Individual animal abundance is given by

$$\hat{N} = \frac{A}{2wL} \sum_{i=1}^{n} \frac{s_i}{\hat{p}_i}$$

where s_i is the size of the group i. The estimated group size in the stratum is given by

$$\hat{E}[s] = \frac{\hat{N}}{\hat{N}_G}$$

RESULTS

The total survey effort in sea states <5 was 8,632km of which 66% was in sea states <3 (Fig. 1). Although the southern strata were planned to be covered first, the actual succession of the effort was weather dependent and the effort had to be allocated to strata with sufficiently low sea states. Therefore, strata 3, 5, 6 and 8 had some coverage between 25 August and 1 September, strata 4, 5, 7, 8, 9, 11 were partially covered during 4–11 September, strata 1, 2, 3, 4, 6, 8, 9 and 10 had some effort during 11–24 September and some transects in strata 8, 10, 11 were also flown during 28–29 September.

A total of 24 fin whale sightings in nine strata were obtained (Fig. 2, Table 1). One duplicate sighting had a missing declination angle and was assigned the same angle as the other record in the duplicate pair. The observers searched independently and for some duplicate sightings, the observers recorded different declination angles or group sizes. There did not appear to be any systematic bias between duplicate pairs of perpendicular distance or school size. Thus the mean perpendicular distance and mean group size of the duplicate pairs was used.

One large school of fin whales detected at 36m from the trackline in stratum 9 was estimated by the primary observer to consist of 15 whales and by the secondary observer to be 25 whales and the average was used for analysis. Shortly after, an additional 8 whales (at 770m) and 3 whales (at 2m) were seen by observers on either side of the plane. A video sequence obtained off effort of this fin whale aggregation confirmed that about 50 whales were present in 8 smaller groups at that location (63°332'N 52°707'W). Aside from this aggregation, the vast majority of sightings were single animals.

The distribution of perpendicular distances of sightings (Fig. 3) shows that there were a large number of sightings close to the trackline indicating that there was not a blind spot for observers beneath the plane. To fit the CDS methods both hazard rate and half normal functional forms were

Table 1

Summary of strata information including size of strata, number of transects (k), total length of transects and total number of sightings (without truncation).

Stratum	Area (km^2)	k	Length (km)	Fin whale sightings	Number of fin whales
1	8,404	3	191		
2	22,631	5	508		
3	14,653	9	532	1	2
4	34,272	4	545	3	3
5	16,226	9	863	1	1
6	14,902	9	973	1	1
7	22,085	6	551	2	2
8	20,264	12	1,345	5	8
9	20,334	12	998	5	37
10	15,950	10	932	3	6
11	24,085	16	1,194	3	3
Total	213,806	95	8,632	24	63

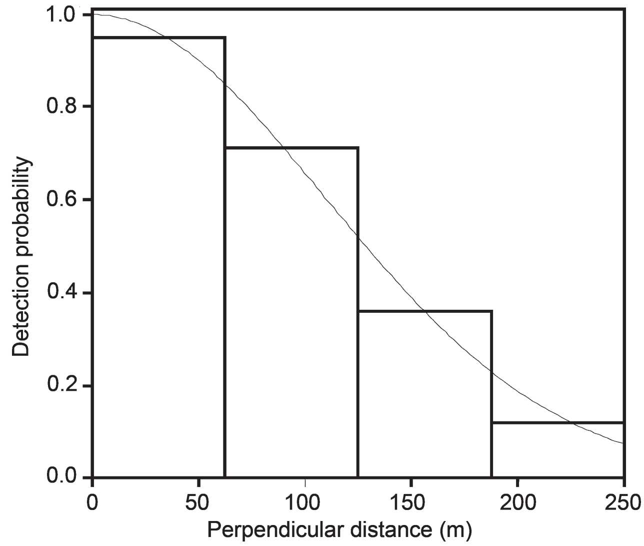

Fig. 3. Perpendicular distance distribution and fitted detection probability model fitted using CDS methodology to the fin whale sightings. Note that the histogram bars are scaled in order to place them on a comparable scale with the detection function.

considered and a half-normal model was chosen on the basis of AIC (Fig. 3, Table 2). A truncation at 250m was chosen to avoid the long tail in the distribution of sightings and based on the remaining 18 sightings, an effective search half-width of 134m (CV 0.21) was estimated. The mean group size across all strata was 2.3 (CV 0.21) and the abundance of fin whales was 4,359 animals (CV 0.45; 95% CI 1,879–10,114).

Stratum 4 contributed 37% of the total abundance but this stratum had a considerably lower coverage than the other strata (Fig. 1 and Table 1). In order to assess if the overall estimate was affected by the low coverage of stratum 4, a CDS analysis that treated all of West Greenland as one stratum was conducted. The abundance attained from this alternative analysis was 3,556 whales (CV 0.34) or 800 whales less than the stratified estimate. The coverage in stratum 4 was biased towards the southern portion and given that the neighbouring stratum 2 to the north had no sightings it seemed appropriate to limit the stratum to the area where transects were flown (i.e. 50% of the stratum). This reduced the CDS estimate by 19%. Stratum 7 also suffered from biased coverage but there were sightings both south and east of the stratum and it only contributes 16% of the total abundance, so no corrections were applied here.

There were 18 detections by the primary observers, 15 by the secondary and 9 by both observers (Table 3). The explanatory variables available to be included in the MRDS models were, in addition to perpendicular distance to sightings; group size, Beaufort sea state (as a factor variable with 4 levels) and observer (2 levels). The final model (Fig. 4) included distance and was chosen based on AIC (Table 4).

The final MRDS model indicated that the primary and secondary observers had similar probabilities of detection on the trackline; 0.62 (CV 0.17) and that the estimate for both observers combined was 0.86 (CV 0.09, Fig. 4). In the MRDS analysis, the data were truncated at 800m excluding one duplicate sighting that was seen >2km away – leaving 23 sightings and 9 duplicates for analysis. A further

Table 2

Abundance estimates using CDS methodology showing the encounter rate (n/L), effective strip half-width (esw) and estimates for group size $E[s]$, group density D_G, group abundance N_G , animal density D, and animal abundance N. Strata without sightings are not shown although the total densities take all strata into account. CVs are given in parentheses. Portion (a) shows the preferred analysis whereas portion (b) shows the analysis with group size estimates for each strata with both the preferred CDS left truncation at 250m and a left truncation at 800m that is compatible with the MRDS analysis.

Stratum	n/L (groups/km)	esw (km) 250m truncation	$E[s]$	D_G (groups/km^2)	N_G (groups)	D (animals/km^2)	N (animals)	Percentage contribution to the variance of N: esw	n/L	$E[s]$
(a)										
3	0.0019 (0.76)			0.0070 (0.79)	103 (0.79)	0.0169 (0.82)	232 (0.82)	6.5	87.1	6.4
4	0.0055 (0.81)			0.0206 (0.84)	706 (0.84)	0.0496 (0.86)	1,592 (0.86)	5.8	88.4	5.8
5	0.0012 (0.98)			0.0043 (1.00)	70 (1.00)	0.0105 (1.02)	159 (1.02)	4.1	91.8	4.1
6	0.0010 (0.90)			0.0038 (0.92)	57 (0.92)	0.0093 (0.95)	129 (0.95)	4.8	90.4	4.8
7	0.0036 (0.59)	0.134	2.256	0.0136 (0.63)	300 (0.63)	0.0327 (0.66)	676 (0.66)	9.8	80.4	9.8
8	0.0015 (0.52)	(0.21)	(0.21)	0.0056 (0.56)	113 (0.56)	0.0134 (0.60)	254 (0.60)	12.1	75.8	12.0
9	0.0040 (0.72)			0.0150 (0.75)	305 (0.75)	0.0338 (0.78)	687 (0.78)	7.1	85.9	7.0
10	0.0021 (0.58)			0.0080 (0.62)	128 (0.62)	0.0193 (0.65)	289 (0.65)	10.1	79.9	10.0
11	0.0017 (0.51)			0.0063 (0.55)	151 (0.55)	0.0151 (0.59)	340 (0.59)	12.6	74.9	12.5
Total	0.0019 (0.18)			0.0088 (0.40)	1,933 (0.40)	0.0211 (0.45)	4,359 (0.45)	8.1	74.9	12.5

Stratum	esw (km) 250m truncation	$E[s]$	N (animals)	esw (km) 800m truncation	N (animals)
(b)					
3		2.0 (0.0)	206 (1.00)		158 (1.03)
4		1.0 (0.0	706 (0.96)		541 (0.99)
5		1.0 (0.0)	70 (1.03)		54 (1.06)
6		1.0 (0.0)	57 (1.00)		44 (1.03)
7	0.134 (0.21)	1.0 (0.0)	300 (0.65)	0.175 (0.34)	230 (0.70)
8		1.0 (0.0)	113 (0.64)		259 (0.70)
9		6.25 (0.74)	1,904 (1.08)		1,926 (1.02)
10		1.0 (0.0)	128 (0.65)		147 (0.57)
11		1.0 (0.0)	151 (0.67)		173 (0.63)
Total			3,635 (0.63)		3,532 (0.65)

truncation at 500m excluded one additional sighting but resulted in practically no difference in the abundance estimate. The additional truncation would have reduced the number of duplicates which was already small.

The abundance of fin whales was 4,468 animals (CV 0.68; 95% CI 1,343–14,871) using MRDS methods with a right truncation at 800m (Table 5). The contribution from stratum 4 with the biased coverage was only 14% and a correction for the unsurveyed northern part of the stratum similar to the CDS analysis above reduced the MRDS estimate by 7%. The large aggregations of fin whales in stratum 9 made up half the estimate from the MRDS analysis and similarly for the CDS estimates with stratum specific group sizes (Table 2b).

Table 3

Number of sightings seen by the primary and secondary observers and the number of duplicates (seen by both). The Total column reports number of sightings seen by observer 1 plus observer 2 minus sightings seen by both.

Group size	Primary observer	Secondary observer	Seen by both	Total
1	15	10	7	18
2	1	2	1	2
3	1	1		2
8		1		1
25	1	1	1	1
Total	18	15	9	24

Table 4

MRDS models fitted to the data for fin whales truncated at 800m. D is distance to sightings and O is observer.

Distance sampling model	Mark recapture model	Akaike Information Criteria	ΔAIC
Half Normal: D	D	343.92	5.81
Hazard rate: D	D	338.11	0.00
Hazard rate: D	$D + O$	338.95	0.85

The data in the CDS estimator was truncated at 250m and so the encounter rates are slightly lower than the MRDS estimate. However, the average expected school size used in the CDS estimator is higher than the average school size in the MRDS estimator and this resulted in higher animal abundance in most strata (see Tables 2 and 5). If for the comparison a truncation at 800m and mean group sizes for each stratum were used in the CDS analyses, a total of 3,532 (0.65) fin whales were obtained which is compatible with a perception bias of approximately 0.86 in the MRDS analyses (Table 2).

DISCUSSION

The estimate of fin whale abundance provided here only covered the coastal areas of West Greenland and must be considered an absolute minimum for the abundance in Baffin Bay and Davis Strait. The main reason for this is that fin whales were observed at the westernmost point of the transects several times and the survey strata clearly did not cover the entire fin whale summer distribution in Baffin Bay and Davis Strait. Satellite tracking of fin whales has also demonstrated their capacity to move from the coastal areas

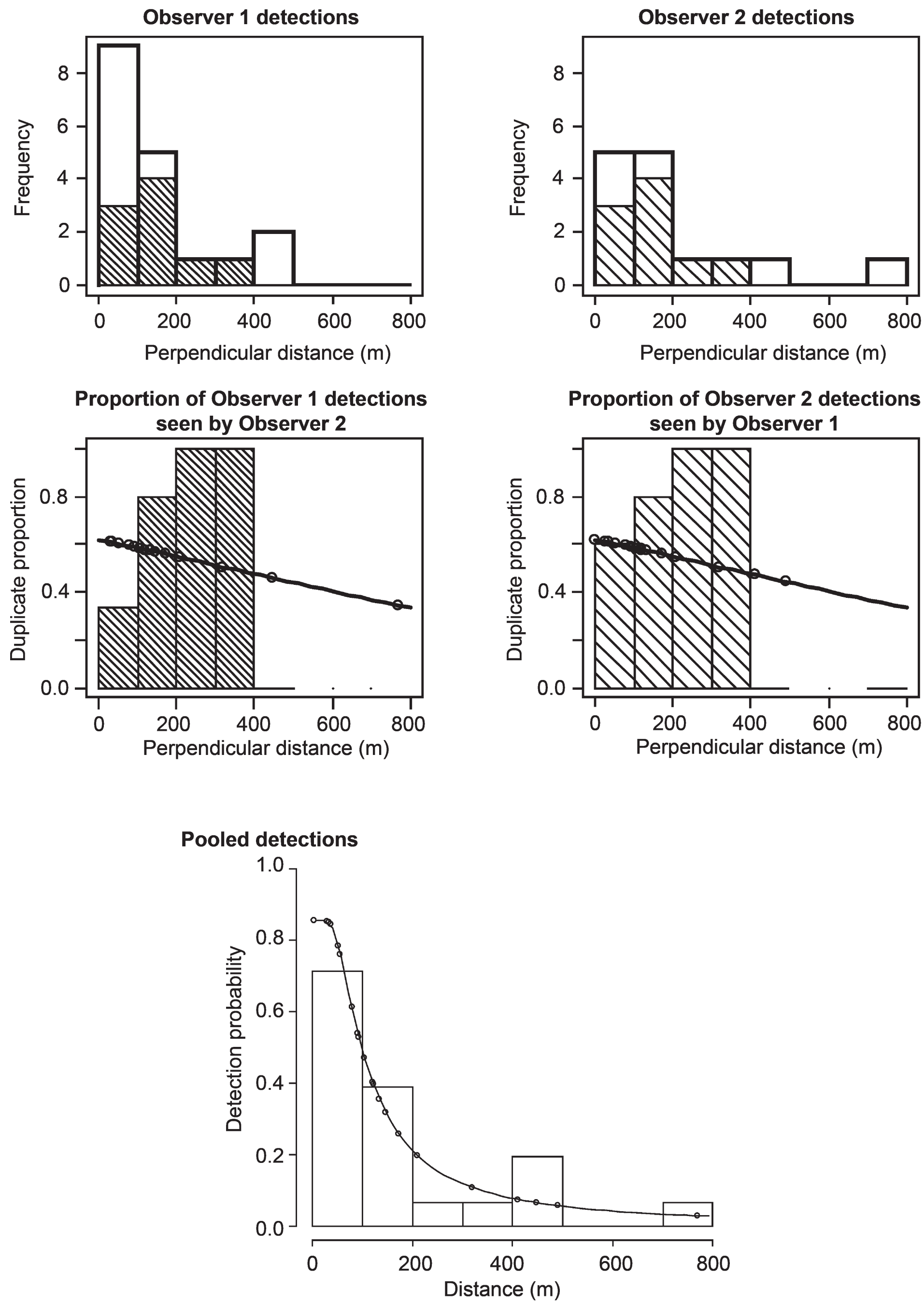

Fig. 4. Detection function plots for the MRDS analyses. Duplicate detections are indicated in the shaded areas; as a number in the top plots and as a proportion in the middle plots. The points are the probability of detection for each sighting given its perpendicular distance and the lines are the fitted models. In the pooled detection plot, the line is the fitted detection function.

of West Greenland to offshore areas west of the range of the surveys (Heide-Jørgensen *et al.*, 2003).

Large aggregations of fin whales were detected in stratum 9 and similar large groups were also detected in an aerial survey in 2005 (Heide-Jørgensen *et al.*, 2008). Stratum 9 contributed about half the total abundance when using stratum-specific mean group size estimates, but only 16% of the total abundance when averaging group sizes across all strata. However, it seems reasonable to restrict the effect of the large group sizes to stratum 9 since mostly solitary whales were detected in the other strata. The reason for the large congregations of fin whales in recent years in West Greenland is likely due to large concentrations of krill (*Meganyctiphanes norvegica* and *Thysanoessa sp.*) stimulated by increased advection and warmer sea temperatures in West Greenland (Laidre *et al.*, 2010). Schooling fin whales have been shown to feed on these krill concentrations in West Greenland (Laidre *et al.*, 2010).

Both the MRDS and the CDS analysis are negatively biased due to the lack of correction for whales that were submerged and therefore invisible to the observers. The relatively low number of primary sightings prevented the use of cue counting techniques that could correct for whales that were submerged during the passage of the survey plane. It must be assumed that only a fraction of the fin whales were available for detection at the surface. No availability factors

Table 5

Abundance estimates using MRDS methodology showing the encounter rate (n/L), effective strip width (esw) and estimates for group size $E[s]$, group density D_G, group abundance N_G, animal density D and animal abundance N. Strata without sightings are not shown although the total densities take all strata into account. CVs are given in parentheses.

Stratum	n/L (groups/km)	D_G (groups/km^2)	N_G (groups)	D (animals/km^2)	N (animals)	$E[s]$	Percentage contribution to the variance of N			
							esw	n/L	$E[s]$	$\hat{p}$
3	0.0019 (0.98)	0.0063 (1.04)	92 (1.04)	0.0126 (1.04)	185 (1.04)	2.00 (0.87)	16.4	81.9	0	1.2
4	0.0055 (0.94)	0.0184 (1.00)	632 (1.00)	0.0184 (1.00)	632 (1.00)	1.00 (0.66)	14.9	84.7	0	1.1
5	0.0012 (1.00)	0.0039 (1.06)	63 (1.06)	0.0039 (1.06)	63 (1.06)	1.00 (0.30)	10.5	88.9	0	0.7
6	0.0010 (0.98)	0.0034 (1.04)	51 (1.04)	0.0034 (1.04)	51 (1.04)	1.00 (0.54)	12.3	86.0	0	0.9
7	0.0036 (0.61)	0.0122 (0.70)	268 (0.70)	0.0122 (0.70)	268 (0.70)	1.00 (0.21)	24.3	73.1	0	1.7
8	0.0030 (0.51)	0.0100 (0.62)	202 (0.62)	0.0149 (0.64)	303 (0.64)	1.50 (0.41)	28.3	52.7	21.9	2.1
9	0.0050 (0.80)	0.0168 (0.87)	341 (0.87)	0.1107 (1.03)	2,592 (1.03)	7.60 (0.45)	12.0	70.0	9.4	0.9
10	0.0032 (0.46)	0.0108 (0.58)	172 (0.58)	0.0108 (0.58)	172 (0.58)	1.00 (0.12)	35.6	65.1	0	2.5
11	0.0025 (0.54)	0.0084 (0.64)	203 (0.64)	0.0084 (0.64)	203 (0.64)	1.00 (0.00)	14.3	85.1	0	1.0
Total	0.0024 (0.26)	0.0092 (0.49)	2,024 (0.49)	0.0187 (0.68)	4,468 (0.68)	2.21 (0.50)	14.3	85.1	0	1.0

are available from fin whales in West Greenland or other areas and there is a need to develop methods for collecting this information. Furthermore the CDS estimate is negatively biased due to the lack of correction for whales at the surface that are missed by the observer. MRDS includes correction for this and must be considered the most complete of the two analyses.

Nevertheless, the present abundance estimate is the largest abundance ever recorded for West Greenland. Abundance estimates from surveys in July and August 1987/88 for West Greenland were developed from cue counting techniques and fin whale abundance was estimated at 1,100 (95% CI 520–2,100) (IWC, 1992). In September 2005 a ship-based line transect survey covered the shelf areas out to the 200m depth contour and an abundance of 1,980 (95% CI 913–4,296) fin whales was estimated for West Greenland (Heide-Jørgensen *et al.*, 2007). Simultaneously an aerial line transect survey gave a similar estimate of 1,652 (95% CI 811–3,367) fin whales (Heide-Jørgensen *et al.*, 2008). Correction of the 2005 aerial survey for perception bias increased the abundance estimate to 3,218 fin whales (95% CI 1,431–7,240). The 1987/88 estimate of 1,100 (95% CI 520–2,100) fin whales in West Greenland (IWC, 1992) was a cue counting estimate but did not correct for perception bias. However, considering that the current uncorrected estimate is considerably larger (4,359 whales, 95% CI 1,879–10,114) than the earlier estimates corrected for availability bias (by the cue counting technique in 1987/88) or for perception bias (by independent observers in 2005), it seems likely that the occurrence and abundance of fin whales in West Greenland is under a long-term increase (as also observed in East Greenland – Víkingsson *et al.*, 2009), perhaps stimulated by the recent increase in density of krill on the feeding banks off West Greenland (Laidre *et al.*, 2010).

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