Revised estimates of minke whale abundance in West Greenland in 2007

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ABSTRACT

A visual aerial line transect survey for common minke whales (*Balaenoptera acutorostrata*) was conducted off West Greenland in August-September 2007. A total of 8670 km of survey effort covered 14 strata in sea states <5 with a total stratum area of 213,996 km^2. The 27 sightings of minke whales were all within a strip width of 300m and the average time from first detection to when the sighting passed abeam was 1.7 sec. Due to the uniform and narrow distribution of the detections strip census methods were used to analyze the survey. Two methods were deployed to correct the strip census estimates for whales missed by the observers and whales that were submerged during the passage of the plane. Method 1 included all detections of minke whales (n=27) and correction for an instantaneous availability that included submergence of whales. Using only data from sea states <3 (n=22) the 'at surface' abundance of minke whales was 1,866 (cv=0.30) whales and a correction for whales missed by the observers with a simple mark-recapture estimator resulted in a corrected abundance of 1,904 (0.31) whales. Adjusting for the availability bias resulted in a fully corrected estimate of 17,307 (95% 7,628-39,270) minke whales. Method 2 used only detections of minke whales that were observed to break the surface (n=19). Applying this method to effort data at sea state<3 (n=14) results in an 'at surface' abundance of 1,208 (cv=0.36) whales and correcting for whales missed by the observers increased the abundance to 1,233 (0.37) whales. Adjusting for the availability bias resulted in a fully corrected estimate of 22,952 (95% CI 8,444-62,383) minke whales.

INTRODUCTION

Aerial surveys for common minke whales (*Balaenoptera acutorostrata*) have been conducted at regular intervals in West Greenland since 1984. The first two surveys in 1984 and 1985 were aimed at obtaining uncorrected line transect estimates of the abundance of minke whales, however, too few sightings were obtained to generate plausible estimates. After 1985 the surveys were conducted as combined cue counting and line transect surveys. Based on the surveys in 1987 and 1988 a cue counting estimate of 3,266 (cv=0.31) minke whales for both years combined was generated. The survey in 1989 generated too few sightings for any meaningful abundance estimation where as the

survey in 1993 resulted in a cue counting estimate of 8,371 (0.43) minke whales (Larsen 1995). A survey in 2005 resulted in an estimate of 10,792 (0.59) minke whales corrected for perception bias (Heide-Jørgensen et al. 2008a).

The seven aerial surveys conducted between 1984 and 2005 provided between 9 and 44 primary sightings with most sightings of single individuals and widely dispersed on the banks of West Greenland (Heide-Jørgensen and Laidre 2008). Given the difficulties in visually detecting minke whales it seems unlikely that future surveys will result in significantly more detections and estimation of the total abundance of minke whales in West Greenland must to a large extent rely on applying correction factors for whales missed by the observer and whales that are not available to be detected at the surface.

Here we present results from the most recent survey for minke whales in West Greenland conducted in 2007 and explore the options for converting the at-surface abundance estimate to a fully corrected estimate.

MATERIAL AND METHODS

Aerial survey

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 (Air Greenland, www.airgreenland.gl), with long-range fuel tank and four independent observation platforms each 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. Declination angle to sightings was measured with Suunto inclinometers and the declination angles were converted to perpendicular distance of the animal to the trackline using an equation to adjust for earth curvature (Buckland et al. 2001). Target altitude and speed was 213 m and 167 km hr^{-1}, respectively.

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 (Fig. 1). The surveyed area was divided into 11 strata plus several inshore strata. The southern strata were planned to be covered first.

Availability correction factors

Two methods were utilized to develop corrections factors for minke whales that were submerged during the survey:

Method 1: Minke whales were photographed from an airplane in Faxafloi Bay in Iceland in September 2003. The photo system included two Hasselblad cameras with Phase One 10.6-megapixel H10 digital backs, mounted in a sideward horizontal angle of 16 degrees to ensure only marginal sideward overlap. The digital backs were oriented with 3992 pixels in the vertical direction, and 2656 pixels in the horizontal direction. Lenses were 40 mm, and combined with a flying altitude of 1700 feet, provided a combined coverage

of approximately 480 meters. The light sensitivity of the H10 backs was set to 400 ASA and the shutter speed to 1/500 sec. The average speed of the plane on effort was approximately 95 knots so that a point on the ground was available to be photographed for approximately 10 seconds. On average, images were taken 2.6 sec. apart, and a point on the ground would generally be on four subsequent images. An average time interval of 2.6 sec. between subsequent images only allowed for an approximate estimate of the average availability period of a surfacing minke whale. The surfacing and diving cycle of a minke whale was defined into a sequence of 'states' that were used to describe the surfacing behavior of a single whale. These states are given in Table 1. Each image in a sequence of images of a surfacing or diving minke whale was categorized into one of these surfacing or diving states. All states between 'emerging' and 'diving' were assumed to be states where an observer could visually identify a minke whale. The interval between these states was used to estimate the correction factor for non-visible submerged whales. However, owing to the limited number of images and time that was available for each point on the ground, few full surfacing/diving sequences from 'emerging to 'diving' were obtained. Therefore, instead of estimating complete availability periods, the time periods between consecutive states in the surfacing/diving sequence were estimated. This was accomplished by evenly distributing the time period between two consecutive images of surfacing/diving states. For example, if two images were taken 2.5 sec. apart with first image of 'surfacing' and the second image of 'back breaking surface' (or the next behavior category), each state was assigned a time period of 1.25 sec. The average time periods between subsequent surfacing/diving states was then estimated from all obtained estimates.

Image sequences tended to include either a complete surfacing (from 'emerging' to 'back breaking') or a complete diving sequence (from 'back breaking' to 'diving'), or a surfacing/diving sequence that lacked an estimate for only one surfacing/diving state interval. The average availability period was therefore estimated from an estimate of the average surfacing period and an estimate of the average diving period based on complete surfacing or diving sequences. When a time interval was missing from a surfacing/diving sequence it was estimated to be the average estimate for that interval.

Method 2: Satellite transmitters (ST-15, Telonics Inc.) were deployed on five minke whales. The transmitters were equipped with two lithium thianyl batteries (M1) and were pre-programmed to be on for 24 hours and off for 72 hours. The transmitters had a conductivity switch (salt water switch) that allowed transmission if the transmitter was out of the water for more than approximately 250 ms. The tags were equipped with a spear that anchored them in the blubber whereas the transmitter with battery mounted was on the outside of the skin of the whale (see Heide-Jørgensen et al. 2003 for details on the tags). The repetition period of the transmissions was 45 sec. A total of five minke whales were instrumented in West Greenland, Svalbard/Norwegian waters and Iceland during 1998-2002. The salt-water switch was positioned 11 cm off the whale skin thus allowing for longer detection of dry periods.

The transmitters collected information on the duration where the salt water contacts were dry, or the fraction of the surfacing time for the whale. The accumulated numbers of seconds with dry readings of the salt water switch were transmitted to the satellites. From the difference between the accumulated dry readings and the elapsed time between transmissions (determined by the satellite) the proportion of time the whale

spent out of the water was calculated. Data were collected and transmitted every fourth day. Data collected between days with scheduled transmissions were excluded.

Sampling of dry periods (= proportion of time with dry salt water switch) was conducted as 'dry readings' between transmissions. The reception of the data was determined by the passage of a satellite and the sampling time therefore was of variable length dependent on i) the duration of satellite passages, and ii) on the time between satellites. The sampling was independent of the whale's behaviour.

Correction for non-instantaneous availability

Because minke whales are available for more than an instant from aerial surveys (some whales may be seen ahead of the plane), the probability that an animal is available is not simply the probability that it is available at a randomly-chosen instant in its dive cycle. To correct for this problem Laake et al. (1997) derived an equation for estimating the average probability of detecting a whale at the surface:

$$\hat{a} = \frac{E[s]}{E[s]+E[d]} + \frac{E[d](1-e^{-t/E[d]})}{E[s]+E[d]}$$

where E[*s*] is the average time the whale is at the surface, E[*d*] is the average time it is below the surface and *t* is the window of time the whale is within visual range of the observers.

Fully corrected strip census estimation

All of the minke whale sightings on the survey in 2007 were made within 300 m from the trackline and it can be assumed that there is a constant probability within that strip width (Fig. 2). Thus a strip census estimate was developed with a simple arithmetic mean of the group size across all strata ($\hat{E}[a]$). To correct for perception bias ($\hat{p}'$) by the observers a Chapman estimate was used:

$$\hat{p}' = \frac{\sum n}{\frac{(S_1+B+1)(S_2+B+1)}{(B+1)} - 1}$$

where *n* is the total number of sightings, S_1 and S_2 are the sightings by observer platform 1 and 2 only and *B* is the sightings by both platforms (Magnusson et al. 1978). The variance of was then estimated from a Taylor expansion series where $\hat{N}_l$ is the estimated individual local animal abundance within the strip width and S_1, S_2 and *B* are assumed to have Poisson distribution where the variance equals the observed value:

$$\text{var}(\hat{N}_l) = (\delta\hat{N}_l/\delta S_1)^2\, var(S_1) + (\delta\hat{N}_l/\delta S_2)^2\, var(S_2) + (\delta\hat{N}_l/\delta B)^2\, var(B)$$

With partial derivatives:

$\delta\hat{N}_l/\delta S_1 = (S_2+B+1)/(B+1)$

$\delta \hat{N}_l / \delta S_2 = (S_1+B+1)/(B+1)$

$\delta \hat{N}_l / \delta B = (B+1)\,[(S_1+B+1)+(S_2+B+1)] - (S_1+B+1)(S_2+B+1) / (B+1)^2$

And the variance of the detection probability ($\hat{p}'$) throughout the strip width is

$$var(\hat{p}') = (\delta \hat{p}'/\delta S_1)^2\, var(S_1) + (\delta \hat{p}'/\delta S_2)^2\, var(S_2) + (\delta \hat{p}'/\delta B)^2\, var(B) + (\delta \hat{p}'/\delta \hat{N}_l)^2\, var(\hat{N}_l)$$

With partial derivatives:

$\delta \hat{p}'/\delta S_1 = 1/2\, \hat{N}_l$

$\delta \hat{p}'/\delta S_2 = 1/2\, \hat{N}_l$

$\delta \hat{p}'/\delta B = 1/\hat{N}_l$

$\delta \hat{p}'/\delta \hat{N}_l = S_1+S_2+2B/2(\hat{N}_l)^2$

Individual animal abundance in stratum *A* was then developed from:

$$\hat{N}' = \frac{\left(\frac{n}{2 \cdot L \cdot 0.300}\hat{E}[a] \cdot A\right)}{\hat{p}'}$$

It is assumed that the whales were available for detection when dry only and that the time spent dry ($\hat{a}'$) was known from photographic recordings of surfacing minke whales (Method 1) or from satellite linked-data recorders (Method 2). In order to account for this availability bias, corrected abundance (denoted by the subscript '*c*') was estimated by:

$$\hat{N}'_c = \frac{\hat{N}'}{\hat{a}'}$$

with estimated CV

$$CV\left(\hat{N}_c\right) = \sqrt{CV\left(\hat{N}'\right)^2 + CV\left(\hat{a}'\right)^2}\ .$$

RESULTS

A total of 8670 km of survey effort was conducted in sea states <5 covering 11 strata with a total stratum area of 213,996 km^2 (Fig. 1) with only 66% of the effort in sea state <3 (Fig. 3). Due to unfavorable weather conditions the area west of Disko Bay (stratum 4) had low coverage. Minke whales were widely distributed in the surveyed area and they were found in most strata both coastally and offshore (Fig. 3). Out of the 35 sightings of minke whales 27 on-effort sightings were within a strip width of 300 m. A conventional line transect model showed that the detection probability for minke whales was constant

out to a perpendicular distance of 300m (Fig. 2) and therefore the survey was analysedas a strip census with a fixed strip width of 300 m. Few sightings were made ahead of the plane and the overall average time from first detection to the sighting passed abeam was 1.7 sec thus cue counting estimates were not pursued further.

Two fully corrected abundance estimates were developed from the strip census estimates of 'at-surface' abundance (Table 2):

Method 1: The first method was insensitive to whether the whales were breaking the surface when detected and relies on the photographic method for estimating the fraction of whales that are available to be seen by the observers. For this method all sightings were used and of the 27 sightings of minke whales detected within the strip width of 300 m, 7 were seen by the front observers, 3 by the rear observers, and 17 by both (Table 2). The mark-recapture correction factor for perception bias is then 0.96 (cv=0.04) for sea states <5 and 0.98 (0.05) for ss<3.

There were 39 image sequences with surfacing and/or diving minke whales with one sequence that included two whales while all other sequences included only one whale. An average availability time of 6.6 s was estimated (cv=0.06, Table 1) when using the photographic sequences for sea states <5. When using only image series from sea states <3 this increased to 6.8 s (0.11). Heide-Jørgensen and Simon (2007) estimated a cue rate of 46.1 cues per whale per hour (cv=0.11) for minke whales in West Greenland. The fraction of time a minke whale will be available for an instantaneous sighting process in sea states <3 was estimated at 0.088 (cv=0.16) under the assumption that each cue has the same availability as determined from the photographic sequences. The average time a minke whale was visible for detection from the plane before passing abeam was 2.2 s (bootstrapped cv=0.26) when using the largest period for each observer (Table 4). The sighting process can therefore not be considered perfectly instantaneous. Adjusting for a non-instantaneous sighting process with a surface time of 6.8 s and a visibility period of 2.2 s gives an availability correction factor of 0.12 (cv=0.28).

In order to ensure that the visual detectability was similar to the detectability obtained from the photographic method a strip width of 240m was applied. This is the same strip width on either side of the plane covered by the images (480m), and it gives an 'at-surface' abundance of 1,866 whales (0.30) and corrected for perception bias 1,904 (0.31) minke whales (Table 2). Applying the availability correction factor to the 'at-sruface' estimate corrected for perception bias gives a total abundance of 17,307 (95% 7,628-39,270) minke whales in West Greenland.

Method 2: The alternative method for correcting for availability bias assumes that all minke whale detections are animals breaking the water surface because the correction is based on the time the whales are dry at the surface. Only detections where it was specifically noted that the whale was breaking the surface are included in this estimate which reduces the number of sightings to 19 with 9 detections by both observers, 17 by the front observer, and 11 by the rear observer in sea states < 5. In sea states < 3 this results in 14 sightings with 3 front, 1 rear and 10 duplicates (Table 3). The mark-recapture estimate of perception bias for sea states < 5 is 0.92 (cv=0.05) and 0.98 (0.06) for sea states <3.

The sampling periods of the dry time readings from the satellite-linked recorders of the minke whales varied from 45 s to several thousand seconds (Fig. 4). Most of the periods sampled for surfacing time lasted less than 1000s for all whales monitored and

this probably corresponds to representative sampling during the passage of a satellite, whereas the longer sampling period happens between passages of satellites. Periods when the whales spent more time at the surface will always favour signal reception by the satellites thus averages over longer are periods are preferable. All the whales had a clear prevalence for short surfacing times of less than 4% of the total time they were monitored (Fig. 4).

For samples >500 s the average time the whales were available to be seen at the surface was 1.95 (cv=0.14, Table 5) and the average time a minke whale was available for detection during the survey was 2.6 s (cv=0.29, Table 4), which adjusts the availability correction to 0.0522 (cv=0.33) for a non-instantaneous sighting process with a surface time of 1.52 s and an average dive time of 76.6 s (Table 6). The 'at-surface' abundance estimate with a strip width of 300m was 1,208 (0.37) and corrected for perception bias changes it to 1,233 (0.37). Further correction for availability bias gives a fully corrected estimate of 22,952 (95% CI 8,444-62,383) minke whales in West Greenland in 2007 (Table 2).

DISCUSSION

The distribution of sighting distances from the track line in 2007-survey was very different from the distributions in previous aerial surveys for minke whales in West Greenland. For instance in the 2005-survey most sightings were detected between 300 and 500 m from the trackline with some as far away as 1.6 km (Heide-Jørgensen et al. 2008a). However, in the 2007-survey the same narrow strip width was also evident from the sightings of other species; e.g. humpback whales (Heide-Jørgensen et al. 2008b) and fin whales (Heide-Jørgensen et al. 2009). The observers were instructed to monitor the trackline closely and to collect cues of whales rather than sightings. Two of the observers were trained as harbor porpoise observer which is evident from the narrow search profile. It was also evident that the minke whale sightings were detected almost instantaneously (mean time before passing abeam <2 sec) and that very few sightings were missed by both observers (<4%) compared to previous surveys where <50% of the animals were seen by both observers (Heide-Jørgensen et al. 2008a). These survey characteristics suggest that the search profile of this survey had a narrow search width and was close to being instantaneous. Nevertheless, a correction was applied to adjust for the time the observers were able to detect minke whales and this reduced the availability correction between 32 and 167% for the two methods.

The encounter rate was the largest contributor to the variance of the estimates, which was not unexpected as - despite the large survey effort in 2007 - this has been a common feature of all past surveys of minke whales in West Greenland. Another major contributor to the uncertainty of the corrected estimates is the variance of the time from first detection to when the whales passes abeam. This contributes about 82% of the availability correction factor and is therefore a major uncertainty in the corrected estimates. The small sample size drives the variance estimates and a better model for the forward detection would be desirable. As applied, the forward detection is assumed to have a flat functional form up to the average time a minke whale was available for detection. More realistically is the detection declining at some distance forward from the plane perhaps with an initial 'shoulder' (hazard rate function), but the number of detections when sorted for sea state does not allow for fitting more complex functional forms of the forward detection as suggested by Schweder (2009).

The estimates derived from the two methods not statistically different. The point estimates from the two approaches should ideally have been closer to each other and the difference may be due to different approaches with the correction factors. Method 1 used a photographic technique where minke whales were identified on images taken at an altitude of 519m with an image footprint of 480 m. The availability correction factor using method 1 utilized all sightings and the correction included submergence to the depth at which minke whales can be detected on aerial photographs. It assumes an even detectability of submerged minke whales across the strip width similar to the footprint of the images. Ideally only measurements from whales detected at the center (at the trackline) of the images should be included in the calculation of the availability bias.

The availability correction factor of method 2 utilized only sightings where the whales were breaking the surface and no whales detected below the surface were included in the estimation. The sightings for this survey were collected as cues of minke whales, defined as the dorsal ridge breaking the surface (i.e. the period the whale is dry). The satellite transmitters deployed monitored the periods the five whales were dry and gave consistently dry periods of less than 4 s for whales instrumented at three localities in the North Atlantic (Norway, Iceland and West Greenland). It is assumed that the dry times from the three areas combined are representative of the dry time for minke whales in West Greenland as the whales were tracked in the same season as they occur in West Greenland, are in the summer feeding areas, and are likely exhibiting similar behavior.

For method 2 it can be argued that the dry time collected by satellite transmitters is sensitive to the position of the transmitters on the whale. During the deployment period the transmitters will migrate vertically out through the whale skin and eventually fall out, however at no point does the position of the transmitter relative to the dorsal-ventral line of the whale, change from the date of the attachment. During the absolute end of a transmitters life may sit lower on the whales, but it must also be noted that transmissions and relay of dry periods is only possible when the transmitters are dry during the surfacing of the whales. Also the outward migration of the transmitters may increasingly expose the transmitter to be dry slightly more frequently, however the amount of dry time affected by this change is negligable. The long measuring periods with similarly long dry periods are indicative of poor transmission performance, but when included will add to the negative bias of the correction factor.

Despite the effort to correct for biases the estimates of abundance of minke whales in West Greenland presented here are still negatively biased mainly because survey coverage was poor in the area west of Disko Bay, hence no abundance estimate was included for that area. Nevertheless the estimates from the 2007-survey are the largest obtained in West Greenland and it is probably also the most complete in terms of correcting for bias that negatively affects the abundance estimates.

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Table 1. The sequence of surfacing and diving states used to describe a surfacing minke whale (n=29). Each image in a sequence of images of a surfacing or diving whale was categorized by a single surfacing or diving state. The surfacing sequence is defined by the period from ’emerging‘ to ’back breaking surface‘, and the diving sequence is defined by the period from ’back breaking surface‘ to ’vanishing‘.

	Emerging part			Submerging part			Emer-	Submer-
Sea state	Emer-ging	Surfa-cing	Head breaking	Back breaking	Just dived	Diving	ging time	ging time
0				2.62	2.66	1.32		6.60
1				2.84	1.43		4.94	
1	1.35	1.36	1.36				4.06	
1				0.94	1.03	1.03		3.00
2				2.63	0.90	0.90		4.42
2				1.35	2.52	1.27		5.14
2				2.53	1.26	1.26		5.05
2	1.27	1.26	1.26				3.79	
2	0.93	0.93	1.40	1.40	0.94	0.94	3.26	3.27
2								
2	0.69	1.31	1.31				3.31	
2	0.71	0.71	0.71	0.94	0.94	0.94	2.14	2.83
2				0.50	0.50	0.50		1.51
2	0.89	0.89	0.89	1.34	1.34	0.00	2.68	2.68
2	1.28	1.29	1.29	0.00	2.53	1.28	3.85	3.81
2				0.52	0.52	0.52		1.57
				n			8	10
	ss<3			Mean			3.5	3.3
				cv			0.09	0.12
3	0.95	0.95	0.95				2.85	
3				2.47	1.24	1.24		4.95
3	0.58	2.55	2.55				5.67	
3	0.58	0.58	0.58	0.78	0.78	0.78	1.73	2.34
3				0.94	0.94	0.94		2.82
3	0.69	0.69	0.69				2.07	
3	1.50	1.50	0.76	0.76	0.76	0.76	3.75	2.27
3	0.69	0.69	0.69	0.68	0.68	0.68	2.06	2.03
3	0.75	0.75	0.75	0.75	0.75	0.75	2.24	2.24
4				2.62	0.86	0.86		4.34
4	1.26	1.26	1.28				3.79	
4				0.90	0.90	0.90		2.69
4				2.62	1.33	1.33		5.28
				N			15	21
	ALL			Mean			3.15	3.51
				cv			0.09	0.09

Table 2. Effort, area, sightings and abundance estimates from 11 offshore strata covered in sea states <3 during the aerial survey in West Greenland in 2007. Additional 808 km of effort in inshore strata (7117km^2) without sightings of minke whales are not shown here. Cv's indicated in parenthesis.

				All detections (group size 1.2, cv=0.12) $\hat{p}'$=0.98, se 0.05				Only detections at the surface (1.2, 0.13) $\hat{p}'$=0.98, se 0.06			
Stratum	Effort (km)	Area (km^2)	Tran-sects	Sigh-tings	$\hat{N}$	$\hat{N}'$	$\hat{N}_c'$	Sigh-tings	$\hat{N}$	$\hat{N}'$	$\hat{N}_c'$
1: Uummannaq Fjord	153	8,404	3								
2: 71°30'-69°45'N	282	22,631	5								
3: Disko Bay and Vaigat	274	14,653	8	1	130 (0.52)	133 (0.52)	1,205 (0.59)	1	107 (0.53)	109(0.53)	2,115 (0.62)
4: 69°45'-68°N	360	34,272	5	3	694 (0.48)	708 (0.48)	6,439 (0.56)	2	381 (0.80)	389 (0.80)	7,535 (0.87)
5: 68°-66°30'N offshore	478	16,226	9	1	83 (2.21)	84 (2.21)	766 (2.22)	1	68 (0.70)	69 (0.70)	1,344 (0.78)
6: 68°-66°30'N inshore	621	14,902	9	3	175(0.60)	179 (0.60)	1,624 (0.66)	3	192 (0.59)	196 (0.60)	2,851 (0.69)
7: 66°30'-64°N offshore	439	22,085	6								
8: 66°30'-64°N inshore	540	20,264	12								
9: 64°-62°N	692	20,334	12	6	429 (0.56)	438 (0.56)	3,978 (0.63)	5	294 (0.42)	300 (0.43)	5,818 (0.54)
10: 62°-60°30'N	741	15,951	10	1	52 (1.06)	53 (1.06)	485 (1.10)				
11: 60°30-59°N	580	24,085	12	3	303 (0.88)	309 (0.89)	2,810 (0.93)	2	166 (1.31)	170 (1.31)	3,288 (1.35)
Sum	5160	213,807	91	18	1,866 (0.30)	1,904 (0.31)	17,307 (0.42)	14	1208 (0.36)	1233 (0.37)	22,952 (0.50)

Table 3. Number of sightings seen by each observer and the number of duplicates (seen by both). The Total column shows the number of sightings seen by observer 1 and observer 2 with the sightings seen by both removed. Cv's indicated in parenthesis.

All detections					Perception bias
Pod size	Observer 1	Observer 2	Seen by both	Total	$\hat{p}'$
1	22	18	15	25	
2	1	1	1	1	
3	1	1	1	1	
Total	24	20	17	27	0.96 (0.04)
In ss<3	20	18	16	22	0.98 (0.05
Only detections of whales breaking the surface					
Pod size	Observer 1	Observer 2	Seen by both	Total	
1	14	12	9	17	
2	1	1	1	1	
3	1	1	1	1	
Total	16	14	11	19	0.92 (0.05)
In ss<3	13	11	10	14	0.98 (0.06)

Table 4. List of all sightings with details on duplication and on time from first detection to when the sighting has passed abeam. Visibility times for front and rear observers that are underlined were used in Method 2 for estimating the average time a minke whale is visible to the observers before passing abeam.

Stratum	Pod size	Distance (m)	Obs no.	Sea state	Break surface	Seen front	Seen rear	Seen both	First detection front	Abeam front	First detection rear	Abeam rear	Front time	Rear time
3	1	230	199	1	1	1	1	1		15:55:15	15:55:12	15:55:15	0	3
4	1	44	65	2	1	1	1	1	16:44:29	16:44:29	16:44:25	16:44:32	0	7
4	1	152	66	1	1	1	0	0		17:05:33			0	
4	1	122	67	1	0	1	1	1		17:40:45		17:40:47	0	0
5	1	76	22	2	0	1	0	0		15:05:04			0	
5	1	299	45	2	1	0	1	0				17:00:57		0
6	1	233	13	2	1	1	1	1		18:39:55		18:40:00	0	0
6	1	122	200	2	1	1	1	1		15:09:36		15:09:38	0	0
6	1	299	201	3	1	0	1	0				15:20:17		0
6	1	117	202	2	1	1	1	1	15:21:58	15:22:00	15:22:02	15:22:17	2	5
9	3	193	71	2	1	1	1	1	15:37:32	15:37:39		15:37:40	7	0
9	1	245	78	2	1	1	1	1	17:10:40	17:10:44		17:10:45	4	0
9	1	74	159	1	1	1	1	1		11:57:59	11:57:56	11:57:59	0	3
9	1	18	160	1	0	1	1	1		11:58:04		11:58:07	0	0
9	1	115	161	1	0	1	1	1		11:58:12		11:58:13	0	3
9	2	233	162	1	1	1	1	1		11:58:26	11:58:18	11:58:23	0	5
9	1	36	179	1	1	1	0	0		14:36:02			0	
10	1	82	135	2	0	1	1	1	18:42:40	18:42:46		18:42:47	4	0
11	1	286	82	2	0	1	1	1		11:34:01		11:34:05	0	0
11	1	195	84	3	0	1	0	0		12:05:36			0	
11	1	176	88	3	1	1	0	0		12:28:34			0	
11	1	233	97	3	1	1	0	0		13:19:57			0	
11	1	89	100	3	1	1	1	1		14:17:03		14:17:09	0	0
11	1	163	104	1	1	1	0	0		15:07:56			0	
11	1	192	123	2	0	1	1	1	11:30:38	11:30:45		11:30:46	7	0
11	1	84	124	2	1	1	1	1		11:53:44		11:53:43	0	0
11	1	36	222	5	1	0	1	0				18:21:01		0

Table 5. Average percentage of time spent dry for five minke whales instrumented with satellite transmitters. Only samples between 09.00 and 18.00 local time were included.

		ALL	n	SD	>500s	n	SD	Sum of dry time	Sum of sampling time	Ratio	Reference
20168	1998, West Greenland	2.39	82	0.03	2.36	46	0.01	9,956	483,835	0.0206	Heide-Jørgensen unpubl. data
7928	1999, Norway	1.12	191	0.02	1.15	133	0.01	20,612	1,901,427	0.0108	Heide-Jørgensen et al. 2001
13282	2001, Iceland	1.68	166	0.03	1.66	93	0.02	90,452	5,611,340	0.0161	Vikingsson and Heide-Jørgensen unpubl. data
13280	2001, Iceland	1.85	44	0.04	1.85	30	0.01	64,316	2,168,010	0.0297	Vikingsson and Heide-Jørgensen unpubl. data
3960	2002, Iceland	2.74	531	0.05	2.73	253	0.01	189,671	6,984,198	0.0272	Vikingsson and Heide-Jørgensen unpubl. data
Mean		1.96			1.95					0.0209	
cv		0.14			0.14					0.17	

Table 6. Overview of the estimation of availability correction factors for the two methods for minke whales in West Greenland. and compared to observations in Norway. Cv's indicated in parenthesis.

		West Greenland	Norwegian observations (Øien et al. 2008)
Method 1	Time visible at surface	6.8 s (0.11) from Table 1	
	Surfacings per hour	46.1 (0.11, Heide-Jørgensen and Simon 2007)	47.5 (0.05)
	Proportion of time at surface	46.1*6.8/3600=0.0871	
	Availability correction for 2.2 s search time	0.1146 (0.36)	
Method 2	Proportion of time at surface (=dry time)	0.0195 from Table 5	
	Surfacings per hour	46.1 (Heide-Jørgensen and Simon 2007)	47.5 (0.05)
	Duration of surfacings	3600*0.0195/46.1=1.52s	
	Duration of dives	3600*0. 9805/46.1=76.6s	75.8 s (0.05)
	Availability correction for 2.6 s search time	0.0522 (cv=0.33)	

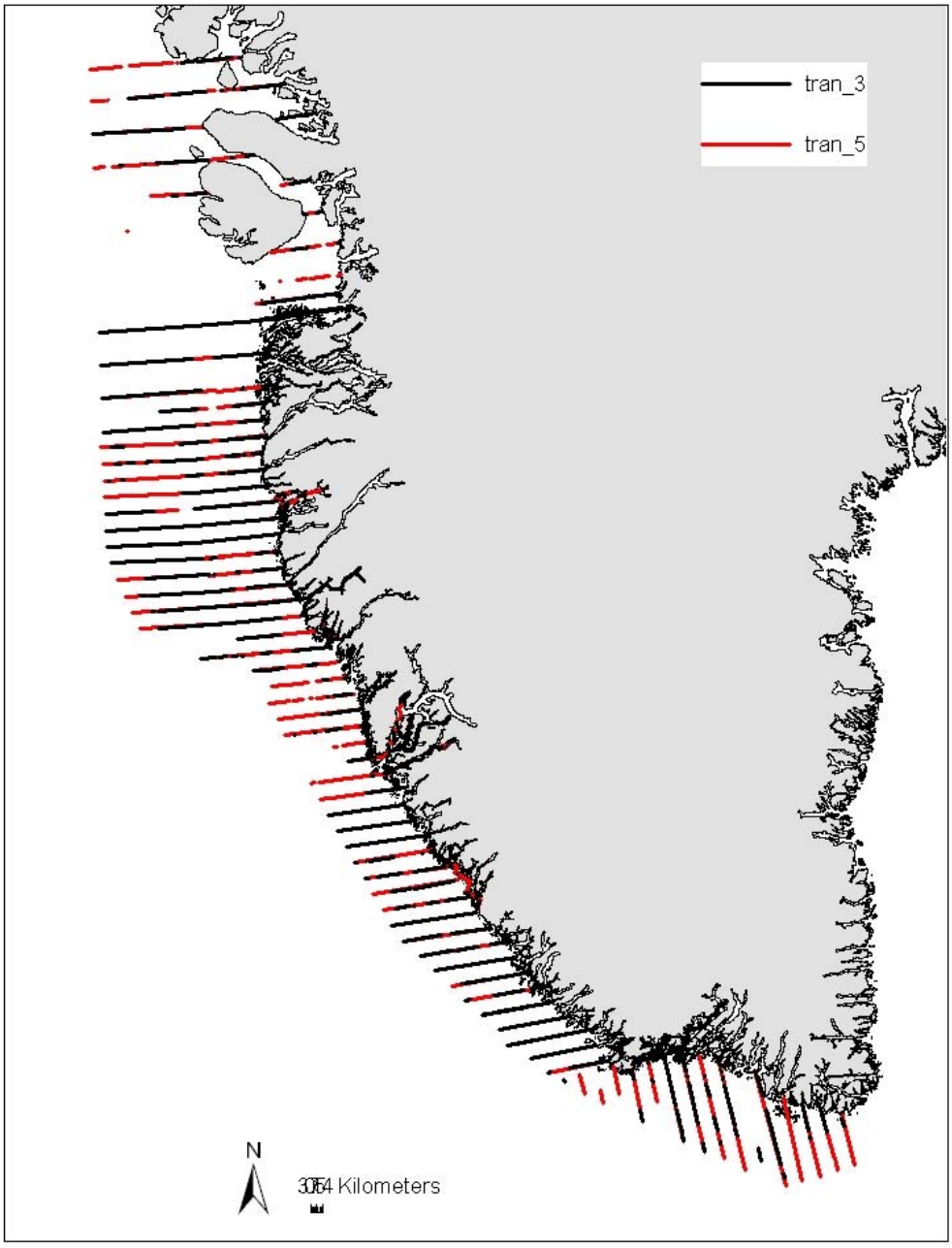

Fig. 1. Effort in sea state <3 and <5 off West Greenland during the aerial survey in 2007.

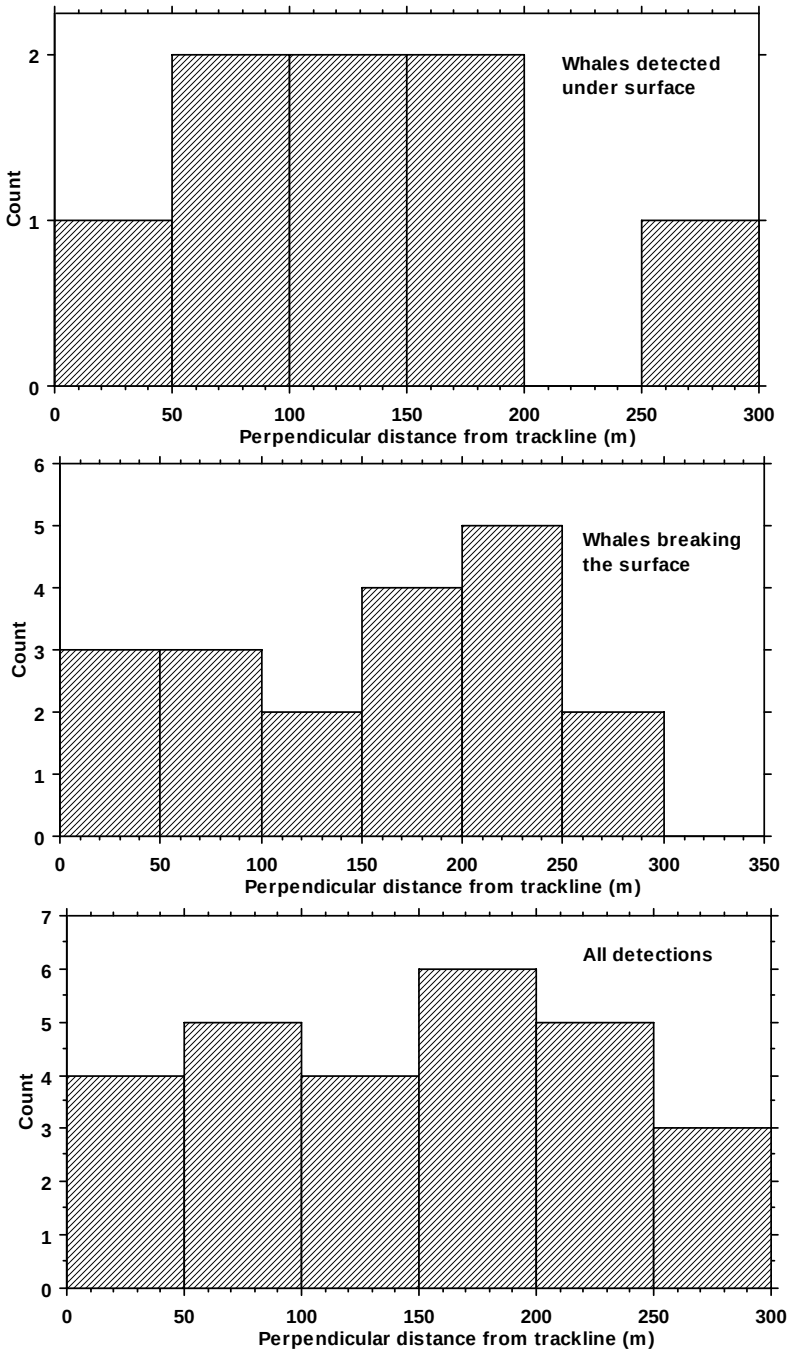

Fig. 2. Distribution of detections of minke whale sightings in 2007 (n=27) for method 1 (upper panel, whales detected below the surface), method 2 (middle panel, whales breaking the surface) and all detections (lower panel).

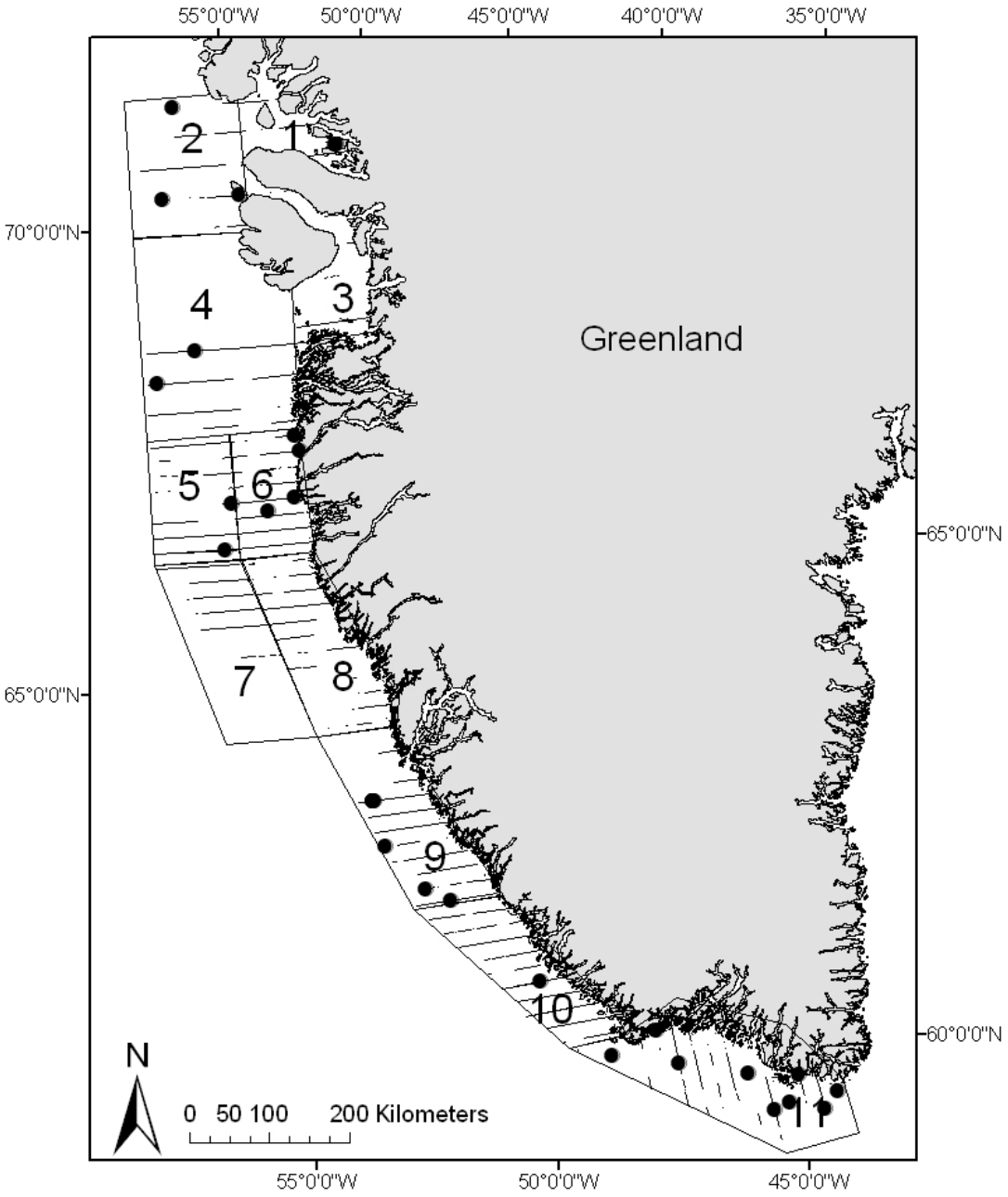

Fig. 3. Effort in sea state <3 and sightings of minke whales by strata off West Greenland during the aerial survey in 2007.

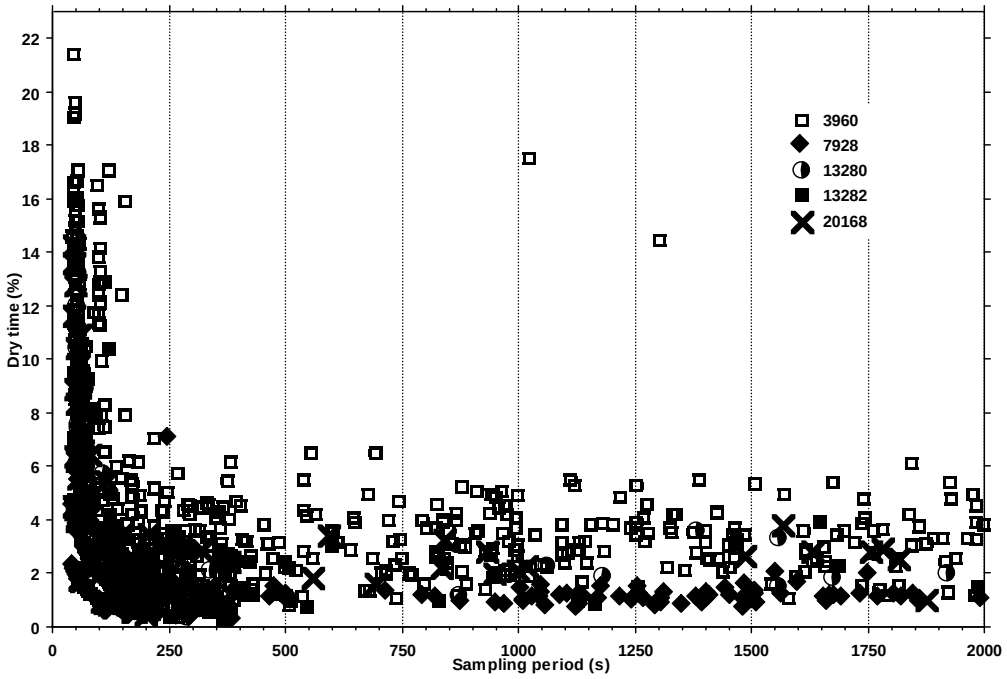

Fig. 4. Proportion of dry time for different sampling periods for five minke whales (see Table 5.