Fully corrected estimates of common 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 and September 2007. A total of 8,670km of survey effort covered 11 strata in sea states <5 with a total stratum area of 213,807km^2. The 27 sightings of common 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 analyse 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 common minke whales (n = 27) and correction for an instantaneous availability that included submergence of whales. Using data from sea states <3 (n = 22) the 'at surface' abundance of common minke whales was 1,866 (CV = 0.30) whales. A correction for whales missed by the observers with a simple mark-recapture estimator resulted in a corrected abundance of 1,904 (CV = 0.30) whales. Adjusting for the availability bias resulted in a fully corrected estimate of 16,609 (95% CI 7,172–38,461) common minke whales. Method 2 used only detections of common minke whales that were observed to break the surface (n = 19). Applying this method to effort data at sea state <3 (n = 14) resulted in an 'at surface' abundance of 1,174 (CV = 0.39) whales. A correction for whales missed by the observers increased the abundance to 1,198 (0.39) whales. Adjusting for the availability bias resulted in a fully corrected estimate of 22,952 (95% CI 7,815–67,403) common minke whales.

KEY WORDS: COMMON MINKE WHALE; ABUNDANCE ESTIMATE; AERIAL SURVEY; SATELLITE TAGGING; WEST GREENLAND

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 conducted with the intention of obtaining uncorrected line transect estimates of the abundance of common minke whales; however, too few sightings were obtained to generate estimates. After 1985, surveys were conducted as combined cue counting and line transect surveys. Based on surveys conducted in 1987 and 1988, a cue counting estimate of 3,266 (CV = 0.31) common minke whales for both years combined was obtained. A survey in 1989 obtained too few sightings for any meaningful abundance estimate, however a survey in 1993 resulted in a cue counting estimate of 8,371 (CV = 0.43) common minke whales (Larsen, 1995). An estimate of 10,792 (CV = 0.59) common minke whales corrected for perception bias was obtained based on a survey conducted in 2005 (Heide-Jørgensen *et al.*, 2008).

The seven aerial surveys conducted between 1984 and 2005 provided between 9 and 44 primary common minke whale sightings. Most sightings were of single individuals and sightings were widely dispersed on the banks of West Greenland (Heide-Jørgensen and Laidre, 2008). Given the demonstrated difficulties in visually detecting common minke whales it is unlikely that future surveys will obtain significantly more detections.

This study presents the results from the most recent survey for common minke whales in West Greenland conducted in August and September 2007. Furthermore, we explore the options for converting the at-surface abundance of common minke whales to fully corrected total estimates of abundance. This requires the application of correction factors which adjust for whales missed by the observers ('perception bias') and for whales that are not available to be detected at the surface ('availability bias').

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* plane (Air Greenland, *www.airgreenland.gl*), with long-range fuel tanks and four independent observation platforms each with bubble windows. Sightings and a log of the cruise track (recorded from the aircraft GPS) were recorded on a *Redhen* SDVR (spatial digital video recorder). Declination angle to sightings was measured with *Suunto* inclinometers and the declination angles were converted to the 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 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. 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). Transect lines were placed in an east-west direction except for in south Greenland, where they were placed in a north-south direction (Fig. 1). The surveyed area was divided into 11 strata in addition to several inshore strata. The southern strata were planned to be covered first.

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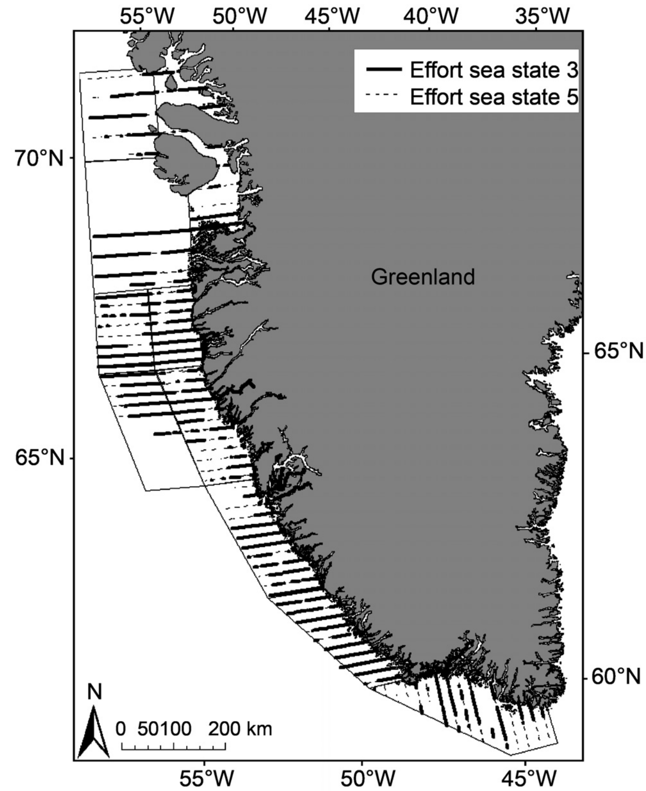

Fig. 1. Effort in sea state <3 and <5 off West Greenland during the aerial survey in 2007.

Availability correction factors

Two methods were utilised to develop correction factors for common minke whales that were submerged during the survey.

Method 1

Common minke whales were photographed from a plane 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 3,992 pixels in the vertical direction, and 2,656 pixels in the horizontal direction. Lenses were 40 mm, and combined with a flying altitude of 1,700 feet (about 518m), provided a combined coverage of approximately 480m. The light sensitivity of the H10 backs was set to 400 ASA and the shutter speed to 1/500sec. 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 10s. On average, images were taken 2.6s apart, and a single point on the ground would generally be found on four sequential images. An average time interval of 2.6s between subsequent images allowed for an approximate estimate of the average availability period of a surfacing common minke whale. The surfacing and diving cycle of a common minke whale was defined into a sequence of 'states' that were used to describe the surfacing behaviour of a single whale (Table 1). Each image in a sequence of images of a surfacing or diving common minke whale was categorised 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 common 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 2.5s apart with the first image of 'surfacing' and the second image of 'back breaking surface' (or the next behaviour category), each state was assigned a time period of 1.25s. 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 common minke whales in West Greenland, Svalbard/ Norwegian waters and Iceland during 1998–2002. 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 250ms. The tags were attached to a spear that acted as an anchor in the blubber. The actual transmitter was located on the outside of the skin of the whale (see Heide-Jørgensen *et al.*, 2001; 2003 for details). The repetition period of the transmissions was 45s. The salt-water switch was positioned 11cm off the whale skin allowing for longer detection of dry periods.

The transmitters collected information on the duration when the salt water contacts were dry, interpreted as the fraction of the surfacing time for the whale. Dry periods were sampled as the total time between transmissions where the salt water switch was dry, i.e. out of the water. The accumulated numbers of seconds with dry readings of the salt water switch were transmitted to the satellites. Based on the proportion between the accumulated number of seconds with dry readings and the elapsed time between transmissions (determined by the satellite) the fraction 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. The reception of the data was determined by the passage of a satellite and the sampling time therefore was of

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 was categorised 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 period			Submerging period				
Sea state	Emerging	Surfacing	Head breaking	Back breaking	Just dived	Diving	Emerging time	Submerging time
0	–	–	–	2.62	2.66	1.32	–	6.60
1		2.84	2.10	–	–	–	4.94	–
1	1.35	1.36	1.36	–	–	–	4.07	–
1	–	–	–	0.94	1.03	1.03	–	3.00
2	–	–	–	2.63	0.90	0.90	–	4.43
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	3.28
2	–	–	–	–	–	–	–	–
2	0.69	1.31	1.31	–	–	–	3.31	–
2	0.71	0.71	0.71	0.94	0.94	0.94	2.13	2.82
2	–	–	–	0.50	0.50	0.50	–	1.50
2	0.89	0.89	0.89	1.34	1.34	0.00	2.67	2.68
2	1.28	1.29	1.29	0.00	2.53	1.28	3.86	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	–	–	–	5.68	–
3	0.58	0.58	0.58	0.78	0.78	0.78	1.74	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	3.76	2.28
3	0.69	0.69	0.69	0.68	0.68	0.68	2.07	2.04
3	0.75	0.75	0.75	0.75	0.75	0.75	2.25	2.25
4	–	–	–	2.62	0.86	0.86	–	4.34
4	1.26	1.26	1.28	–	–	–	3.80	–
4	–	–	–	0.90	0.90	0.90	–	2.70
4	–	–	–	2.62	1.33	1.33	–	5.28
				N			**15**	**21**
	All			**Mean**			**3.15**	**3.51**
				cv			**0.09**	**0.09**

variable length. The sampling was independent of the whale's behaviour.

Correction for non-instantaneous availability

Common minke whales are available for detection for a short period of time during aerial surveys (i.e. some whales may be seen ahead of the plane). Therefore, the probability that an animal is available is different from being available at a randomly-chosen instant in its dive cycle. Laake *et al.* (1997) derived an equation for estimating the average probability of detecting a whale at the surface to correct for this:

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

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 common minke whale sightings in the survey in 2007 were made within 300m from the trackline and it was 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 ($\hat{E}[a]$). A Chapman estimate was used to correct for perception bias ($\hat{p}'$) by the observers:

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

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). Variance of ($\hat{p}'$) was estimated with Jackknife methods.

Individual animal abundance in stratum A was then developed from:

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

It is assumed that the whales were only available for detection when tags were dry and that the time spent dry ($\hat{a}'$) was known from photographic recordings of surfacing

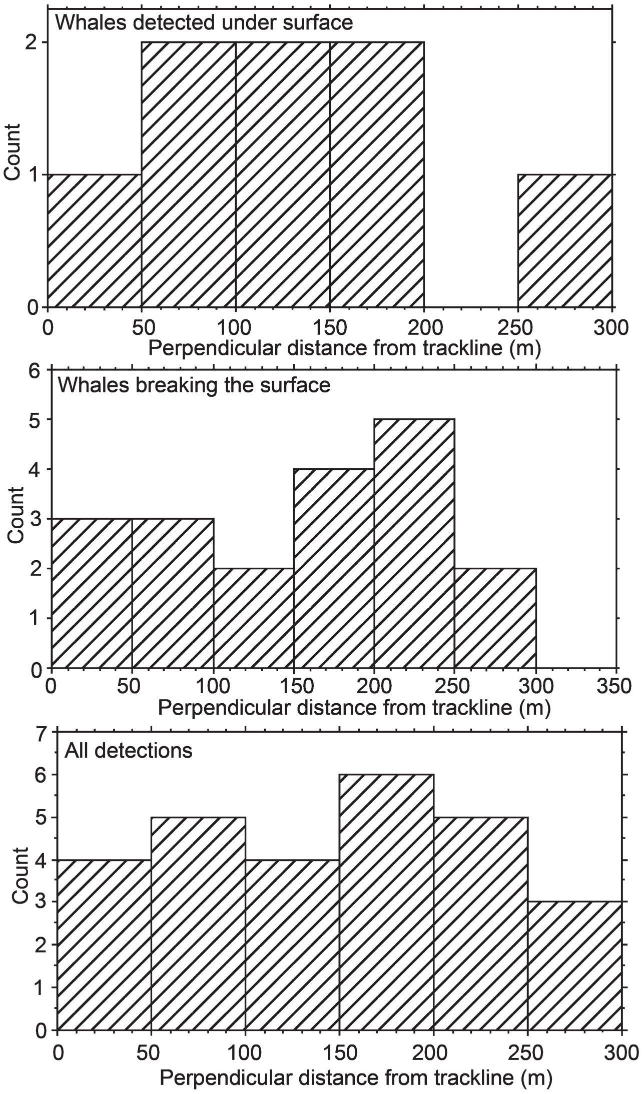

Fig. 2. Distribution of detections of minke whale sightings in 2007 ($n = 27$) for Method 1 (upper panel, whales detected below the surface), Method 2 (middle panel, whales breaking the surface), and all detections (lower panel).

common 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

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

RESULTS

A total of 8,670km of survey effort was conducted in sea states <5, covering 11 strata with a total stratum area of 213,807 km^2 (Fig. 1), with only 66% of the effort in sea state <3 (Fig. 3). Due to unfavorable weather conditions during the survey period the area west of Disko Bay (stratum 4) had low coverage. Common minke whales were widely distributed in the surveyed area and were found in most strata coastally and offshore (Fig. 3). Out of the 35 sightings of common minke whales, 27 on-effort sightings were obtained

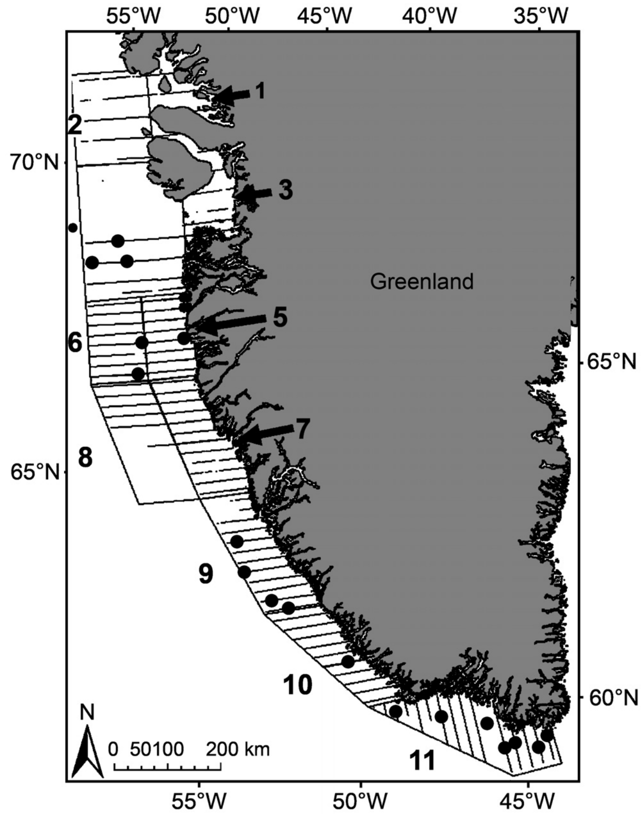

Fig. 3. Effort in sea state <5 and sightings of minke whales by strata off West Greenland during the aerial survey in 2007.

within a strip width of 300m. The perpendicular distribution of sightings demonstrated that the detection probability for common minke whales was constant out to a distance of 300m (Fig. 2) and therefore the survey was analysed as a strip census with a fixed strip width of 300m. Few sightings were made ahead of the plane and the overall average time from first detection to the sighting passed abeam was 1.7s 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), one for each method.

Method 1

The first method was independent of whether the whales were breaking the surface when detected and relied on the photographic method for estimating the fraction of whales available to be seen by the observers. All sightings were used and of the 27 sightings of common minke whales detected within the strip width of 300m, 7 were seen by the front observers, 3 by the rear observers, and 17 by both observers (Table 3). The mark-recapture correction factor for perception bias was 0.96 (CV = 0.03) for sea states <5 and 0.98 (CV = 0.02) for sea state <3.

There were 39 image sequences with surfacing and/or diving common minke whales; one sequence included two whales while all other sequences included only one whale. An average availability time of 6.7s 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 6.8s (CV = 0.11). Heide-Jørgensen

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 (7,117km^2) without sightings of minke whales are not shown here. CV's indicated in parenthesis.

Stratum	Effort (km)	Area (km^2)	Transects	All detections within 240m (group size 1.2, CV = 0.10); $\hat{p}'$ = 0.98, se 0.02 Sightings	$\hat{N}$	$\hat{N}'$	$\hat{N}'_c$	Only detections of whales breaking the surface within 300m (group size 1.2, CV = 0.13); $\hat{p}'$ = 0.98, se 0.02 Sightings	$\hat{N}$	$\hat{N}'$	$\hat{N}'_c$
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 (0.79)	133 (0.79)	1,156 (0.84)	1	108 (0.80)	110 (0.80)	2,115 (0.86)
4: 69°45'–68°N	360	34,272	5	3	694 (0.56)	708 (0.56)	6,180 (0.63)	2	385 (0.96)	393 (0.96)	7,535 (1.02)
5: 68°–66°30'N offshore	478	16,226	9	1	83 (1.12)	84 (1.12)	735 (1.16)	1	69 (0.92)	70 (0.92)	1,344 (0.98)
6: 68°–66°30'N inshore	621	14,902	9	3	175 (0.54)	179 (0.54)	1,559 (0.61)	3	146 (0.55)	149 (0.55)	2,851 (0.63)
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 (0.65)	438 (0.65)	3,817 (0.71)	5	298 (0.46)	304 (0.46)	5,818 (0.56)
10: 62°–60°30'N	741	15,951	10	1	52 (1.02)	53 (1.02)	466 (1.06)	–	–	–	–
11: 60°30–59°N	580	24,085	12	3	303 (0.52)	303 (0.52)	2,697 (0.60)	2	168 (0.71)	172 (0.71)	3,288 (0.78)
Sum	5,160	213,807	91	18	1,866 (0.30)	1,904 (0.30)	16,609 (0.41)	14	1,174 (0.39)	1,198 (0.39)	22,952 (0.51)

Table 3

Number of sightings seen by each observer and the number of duplicates (seen by both observers). The 'Total' column shows the number of sightings seen by observer 1 and observer 2 with the sightings seen by both removed. CVs are in parenthesis.

Pod size	Observer 1	Observer 2	Seen by both	Total	Perception bias $\hat{p}'$
All detections					
1	22	18	15	25	–
2	1	1	1	1	–
3	1	1	1	1	–
Total	24	20	17	27	0.96 (0.03)
In ss<3	20	18	16	22	0.98 (0.02)
Only detections of whales breaking the surface					
1	14	12	9	17	–
2	1	1	1	1	–
3	1	1	1	1	–
Total	16	14	11	19	0.94 (0.05)
In ss<3	13	11	10	14	0.98 (0.02)

and Simon (2007) estimated a cue rate of 46.1 cues per whale per hour (CV = 0.11) for common minke whales in West Greenland. The fraction of time a common 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 common minke whale was visible for detection from the plane before passing abeam was 2.2s (bootstrapped CV = 0.26) when the longest period was used for each observer (Table 4). The sighting process cannot be considered perfectly instantaneous. Adjusting for a non-instantaneous sighting process with a surface time of 6.8s and a visibility period of 2.2s results in 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 used. This is the same strip width on either side of the plane covered by the images (480m), and it results in an 'at-surface' abundance of 1,866 whales (CV = 0.30). Corrected for perception bias this results in 1,904 (CV = 0.30) common minke whales (Table 2). Applying the availability correction factor to the 'at-surface' estimate corrected for perception bias results in a total abundance of 16,609 (95% CI 7,172–38,461, 90% CI 8,316–33,173) common minke whales in West Greenland.

Method 2

The alternative method for correcting for availability bias assumes that all common 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 were included in this estimate. This reduces the number of sightings to 19 with 9 detections by both observers, 5 by the front observer, and 3 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 0.94 (CV = 0.05) and 0.98 (CV = 0.02) for sea states <3.

The sampling periods of the dry time readings from the satellite-linked recorders of common minke whales varied from 45s to several thousand seconds (Fig. 4). Most of the periods sampled for surfacing time lasted less than 1,000s for all whales 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 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 >500s the average time the whales were available to be seen at the surface was 1.95s (CV = 0.14, Table 5) and the average time a common minke whale was available for detection during the survey was 2.6s (CV = 0.29, Table 4). This adjusts the availability correction to 0.05 (CV = 0.33) for a non-instantaneous sighting process with a surface time of 1.52 s and an average dive time of 76.6s (Table 6). The 'at-surface' abundance estimate with a strip width of 300m was 1,174 (CV = 0.39) whales and corrected for perception bias resulted in 1,198 (CV = 0.39) whales. Further correction for availability bias resulted in a

Table 4

List of all sightings with details on duplication and on time from first detection to when the sighting has passed abeam. Underlined visibility times for front and rear observers 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

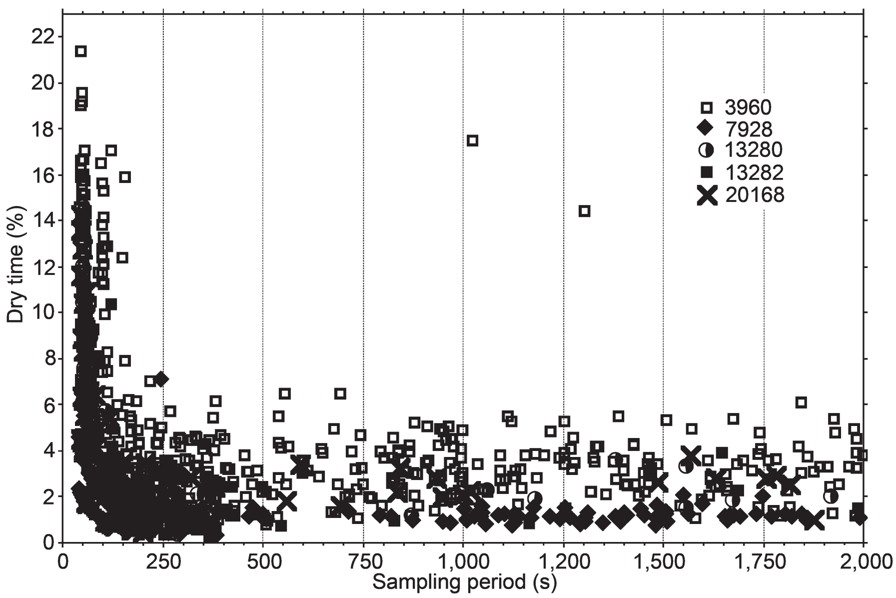

Fig. 4. Proportion of dry time for different sampling periods for five minke whales (see Table 5)

Table 5

Average percentage of dry time 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, W 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	
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	
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 correction methods for minke whales in West Greenland compared to observations in Norway. CVs are in parenthesis.

	West Greenland	Norwegian observations (Øien *et al.*, 2008)
Method 1		
Time visible at surface	6.8s (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*6.8/3,600 = 0.0871	
Availability correction for 2.2s 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	3,600*0.0195/46.1 = 1.52s	
Duration of dives	3,600*0. 9,805/46.1 = 76.6s	75.8 s (0.05)
Availability correction for 2.6s search time	0.0522 (CV = 0.33)	

fully corrected estimate of 22,952 (95% CI 7,815–67,403; 90% CI 9,585–54,960) common minke whales in West Greenland in 2007 (Table 2).

DISCUSSION

The distribution of sighting distances from the trackline in the 2007-survey was very different from the distributions in previous aerial surveys for common minke whales in West Greenland. Most sightings in the 2005 survey were detected between 300 and 500m from the trackline with some as far away as 1.6km (Heide-Jørgensen *et al.*, 2008). However, in the 2007 survey the same narrow strip width was also evident from the sightings of other species; e.g. humpback whales, *Megaptera novaeangliae* (Heide-Jørgensen *et al.*, in press) and fin whales, *Balaenoptera physalus* (Heide-Jørgensen *et al.*, 2010). 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 harbour porpoise (*Phocoena phocoena*) observers which probably explains the narrow search profile. It was also evident that the common minke whale sightings were detected almost instantaneously (mean time before passing abeam <2s) 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.*, 2008). These survey characteristics suggest that the search profile of this survey had a narrow search width and was close to being instantaneous (i.e. with little searching ahead). Nevertheless, a correction was applied to adjust for the time the observers were able to detect common 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, low encounter rates have been a common feature of all past surveys of common minke whales in West Greenland. Increasing survey effort would ideally reduce the variance on the encounter rate but must be balanced against the logistic difficulties of conducting the survey over a short period of time and in optimal conditions. Another major contributor to the uncertainty of the corrected estimates was the variance of the time from first detection to when the whales passed abeam. This contributed about 82% of the availability correction factor and was therefore a major contributor to the uncertainty in the corrected estimates. The small sample size had a large impact on the variance estimates and a better model for the forward detection would be desirable. As applied, the forward detection was assumed to have a flat functional form up to the average time a common minke whale was available for detection. More realistically the detection is 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.

The estimates derived from the two methods are not statistically different. The point estimates from the two approaches should in theory 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 whales were identified on images taken at an altitude of 519m with an image footprint of 480m. Information on the surfacing time of common minke whales in Iceland in 2003 were combined with cue rates collected in West Greenland in 1996 and 2006 and assumed to be representative of the proportion of time a common minke whale would be available to be seen during the survey in 2007. This is certainly less than ideal but the large variance should cover differences between areas and years.

The availability correction factor using Method 1 utilised all sightings and the correction included submergence to the depth at which common minke whales can be detected on aerial photographs. It assumed an even detectability of submerged common minke whales across the strip width similar to the footprint of the images. Ideally, only measurements from whales detected at the centre (on the trackline) of the images should be included in the calculation of the availability bias.

The availability correction factor of Method 2 utilised 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 common minke whales, defined as the dorsal fin breaking the surface (i.e. the period the whale is dry). The satellite transmitters deployed monitored the periods the five whales were dry and resulted consistently in dry periods of less than 4s for whales instrumented at three localities in the North Atlantic (Svalbard/Norway, Iceland and West Greenland). Only one of the whales was instrumented in West Greenland and it is assumed that the dry times from the three areas combined are representative of the dry time for common minke whales in West Greenland. The whales were tracked in the same summer feeding season as in West Greenland, and are likely exhibiting similar behaviour. The number of measurements of dry periods was considerable and the large variance around the estimate should span any difference in the proportion of dry time between areas.

With 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's skin and eventually fall out. At the end of a transmitter's life the tag may sit lower on the whale thus giving fewer signals and dry period readings. However, 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. 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 negligible. The long measurement periods with similarly long dry periods are indicative of poor transmission performance (i.e. poor positioning of the tag on the whale), but when included, add to the negative bias of the correction factor.

Despite the effort put forth in this study to correct for biases, the estimates of abundance of common minke whales in West Greenland presented here are still negatively biased because survey coverage was poor in the areas west of stratum 9–11. Hence no abundance estimate was included for that area. Nevertheless, the abundance estimates from the 2007 survey are the largest ever obtained in West Greenland and are probably also the most complete in terms of bias corrections that negatively affect the abundance estimates.

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