Abundance of walruses in Eastern Baffin Bay and Davis Strait

MP Heide-Jørgensen[1], KL Laidre[2], S Fossette[3,4], M Rasmussen[5], NH Nielsen[1] and RG Hansen[1]

[1] *Greenland Institute of Natural Resources, P.O. Box 570, DK-3900, Nuuk, Greenland*
[2] *Polar Science Center, Applied Physics Laboratory, 1013 NE 40th Street, Seattle, WA 98105-6698,USA*
[3] *Department of Biosciences, College of Science, Swansea University, Singleton Park, Swansea SA2 8PP, UK*
[4] *Present address: NOAA, Southwest Fisheries Science Center, 1352 Lighthouse Avenue, Pacific Grove, CA 93950, USA*
[5] *Danish Meteorological Institute, DK-2100 Copenhagen, Denmark*

ABSTRACT

Walruses (*Odobenus rosmarus*) are exploited for subsistence purposes in West Greenland. However, current information about the abundance of walruses subject to harvest in eastern Baffin Bay has been unavailable despite being critical for maintaining sustainable catch levels. Three visual aerial surveys were conducted in 2006 (21 March to 19 April 2006), 2008 (3 to 12 April) and 2012 (24 March to 14 April) to estimate the number of walruses on the wintering grounds in eastern Baffin Bay and Davis Strait. Data on the fraction of walruses that were submerged below a 2 m detection threshold during the surveys were obtained from 24 walruses instrumented with satellite-linked-time-depth-recorders in northern Baffin Bay in May–June 2010–2012. An availability correction factor was estimated at 36.5% (*cv*=0.08) after filtering of data for an observed drift of the pressure transducer of more than 2.5 m. The surveys resulted in walrus abundance estimates that were corrected for walruses submerged below the detection threshold and for walruses that were missed by the observers. The estimates of abundance were 1,105 (*cv*=0.31, 95% CI 610–2,002) in 2006, 1,137 (0.48, 468–2,758) in 2008 and 1,408 (0.22, 922–2,150) in 2012.

INTRODUCTION

In Baffin Bay and Davis Strait walruses (*Odobenus rosmarus*) winter on banks located between 66º30′N and 68º15′N along West Greenland. Their occurrence in this area is due to the availability of shallow water (<100 m) with suitable benthic prey densities and sea ice for hauling out. Walruses occur along West Greenland between fall and May when the sea ice starts melting and gradually disappears (Born et al. 1994). The period between May and late fall is spent along the coast of East Baffin Island.

Walruses have been hunted for subsistence purpose in West Greenland for centuries (Born et al. 1994). Historical and current exploitation rates are, however, relatively high and most likely unsustainable on a long term basis (Born et al. 1994, Witting and Born 2005, NAMMCO 2006, COSEWIC 2006). Walrus hunt quotas in West Greenland were implemented in spring 2007 with an annual quota for a landed catch of 80, 65 and 50 animals in 2007, 2008 and 2009, respectively (Anon. 2006). During 2010–2013 a fixed quota of 61 walruses was established for West Greenland (http://dk.nanoq.gl). The initial quotas were based on incomplete abundance information (cf.

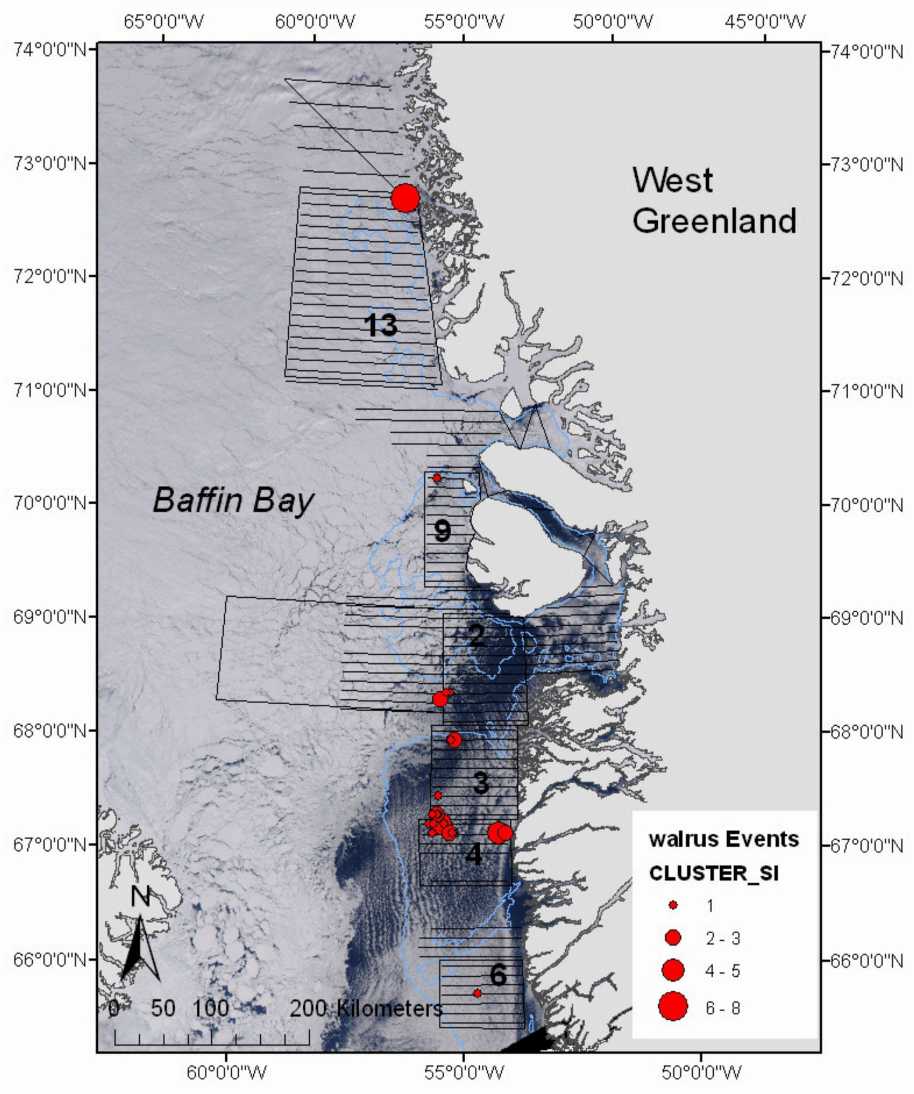

Fig. 1. *Realized survey effort and sightings of walruses in West Greenland in 2006 in the different strata. The strata included in the abundance estimations are indicated by boxes and stratum number. The ice coverage in the surveyed areas can be seen in the Modis satellite image from 3 April 2006. Dots indicate group size.*

NAMMCO 2006) but preliminary abundance estimates were later presented to NAMMCO (2010). To allow for future assessment of sustainable levels of exploitation in West Greenland updated walrus abundance estimates based on the latest analytical techniques are presented here.

For most of the year walruses are widely dispersed over vast areas where they usually occur in clumped groups at relatively low densities (e.g. Fay 1982, Born et al. 1995 and references therein). Hence, the only reasonable way of obtaining abundance estimates is by using aerial surveys covering large areas (e.g. Estes and Gilbert 1978, Gilbert 1989, 1999, Fay et al. 1997, Udevitz et al. 2001). Seven systematic aerial surveys conducted between 1981 and 1994 demonstrated that walruses still occupy their former wintering range in the margin of the Davis Strait pack ice (Born et al. 1994).

In this paper we report on the abundance of walruses in eastern Baffin Bay and Davis Strait based on aerial surveys conducted during March and April in 2006, 2008 and 2012.

METHODS

Aerial surveys in 2006, 2008 and 2012

Visual aerial line-transect surveys were conducted in West Greenland between 21 March and 19 April 2006, between 3 and 12 April 2008 and between 24 March and 14 April 2012. The 2006 survey covered the coastal areas between 65°40′N and 74ºN including the two main wintering areas for walruses (Fig. 1). The 2008 survey was solely designed to obtain an abundance estimate for walruses in West Greenland and this survey concentrated on the main wintering grounds for walruses between 66º30′N and 70º45′N (Fig. 2). The 2012 survey covered coastal and offshore areas between 65º40′N and 75º30′N (Fig. 3).

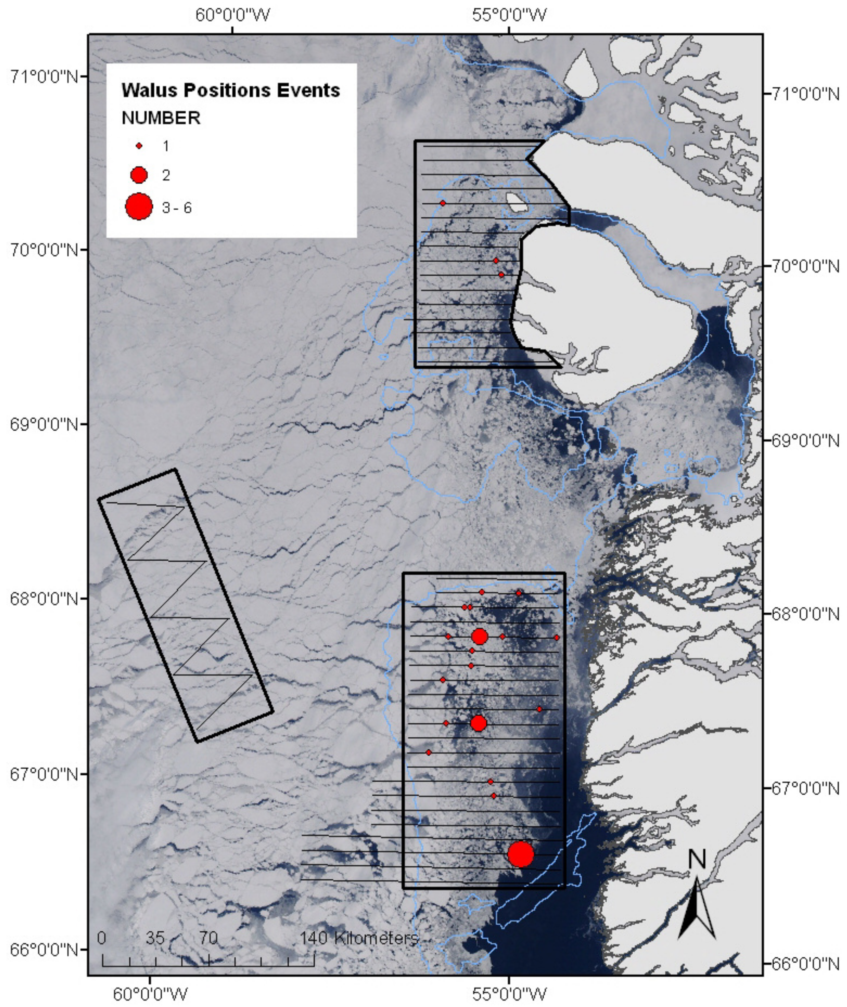

Fig. 2. Realized survey effort and sightings of walruses in two strata in West Greenland in 2008. The offshore stratum was covered for other purposes (see Material and methods) but is included here for documentation. The ice coverage in the surveyed areas can be seen in the Modis satellite image from 3 April 2008. Dots indicate group size.

The survey design utilized systematically placed east-west transects (Fig. 1–3). In all years, the realized effort was slightly less than originally planned due to unfavorable weather conditions with Beaufort sea states >2 and horizontal visibility <1 km. Beaufort sea state was recorded at the start of each transect line and whenever it changed.

All surveys were conducted as a sight-resight experiment with two independent observation platforms on each side of the survey plane (a DeHavilland Twin Otter equipped with four bubble windows). Target altitude and speed were ca. 213 m (700 feet) and 167 km * h^{-1} (90 knots), respectively. Of the six observers that participated in 2006, three also participated in 2008. The two additional observers had experience from previous aerial surveys of marine mammals. In 2012 all four observers were experienced from past surveys. The declination angle to each sighting of each group of walruses was measured using a Suunto inclinometer. Each observer recorded his or her observations independently by speaking to a microphone. Decisions about duplicate detections (animals seen by both observer 1 and 2) were based on coincidence in timing and location of sightings.

During the 2006 survey, data were consecutively stored *en route* on four independent tape recorders with time stamps from a Garmin 100 GPS that also downloaded positions at 1 second intervals to a computer. During the 2008 and 2012 surveys a Redhen msDVRs (www.redhensystems.com) four channel audio and video computerized recording system was used for the same purposes.

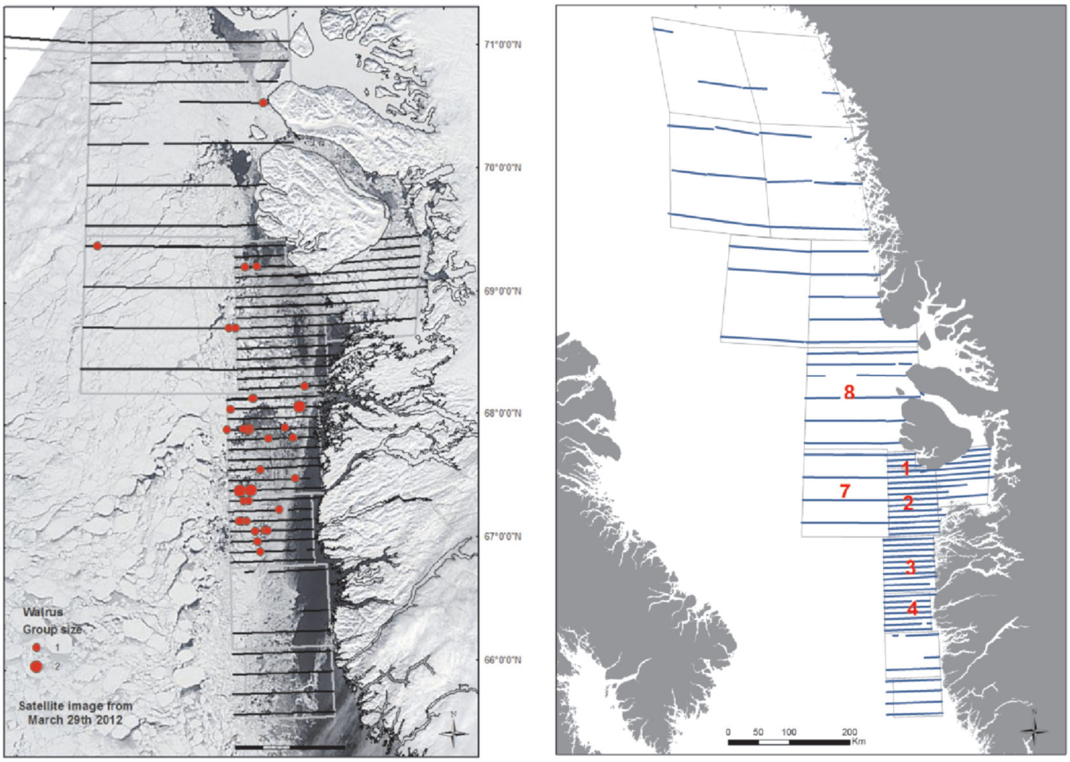

Fig. 3. *Left: Sightings of walruses in eastern Baffin Bay in 2012. The ice coverage in the surveyed area can be seen in the Modis satellite image from March 29th 2012. Dots indicate group size. Only strata with sightings were included in the abundance estimates (see Table 1). Right: Realized survey effort in sea states <2 (blue lines) in entire survey region.*

Fig. 4. *Walrus with satellite linked time-depth-recorder instrumented in northern Baffin Bay (77°28′N and 72°30′W; Photo: Nynne Hjort Nielsen).*

Correction for animals diving below a certain threshold

During visual aerial surveys an unknown proportion of walruses are in the water below a certain depth and are therefore not available for detection. Data from 24 walruses tagged with satellite-linked time-depth recorders (Mk10a SLTDRs Wildlife Computers, cf. Heide-Jørgensen et al. 2013, Fig. 4) in northern Baffin Bay in May and June 2010, 2011 and 2012 were used to develop a correction factor for walruses submerged below the detection depth. The proportion of time spent above 2 m depth was estimated where the depth was measured at a precision of 0.5 m. The Mk10 tags recorded time at surface and at different depths during 6-hr periods and the data were relayed through the Argos Data Collection and Location System and decoded using Argos Message Decoder (Wildlife Computers). Time-at-depth data were extracted for May and June, values of >89% and 0% time at or above 2 m depth were deleted as they were either considered to represent walruses that were hauled out or erroneous data. Daily averages were calculated for daylight hours (10–22 local time) and used for deriving monthly averages. Drift of the pressure transducer (obtained from status messages) was assessed for the study period and data sets that included an observed drift of more than 2.5 m were omitted.

Survey analysis

Angles to sightings were converted to perpendicular distances (Buckland et al. 2001). For some duplicate sightings, the observers had recorded different declination angles and thus the sightings had different perpendicular distances. The mean perpendicular distance for the duplicate sightings was used.

Due to the low number of sightings (19, 21 and 32 within the truncation distance for the 2006, 2008 and 2012 survey, respectively), a simple mark recapture Chapman model was used to estimate the total number of walrus groups ($\hat{N}_G$) available for detection in the survey area, i.e. the area covered by the survey (Chapman 1951). It is based on the numbers of sightings and duplicates and does not model dependence of detection probability on distance or any other covariates:

$$\widehat{N}_G = \frac{(n_1+1)(n_2+1)}{(m+1)} - 1$$

with variance:

$$\mathrm{var}(\widehat{N}_G) = \frac{(n_1+1)(n_2+1)(n_1-m)(n_2-m)}{(m+1)^2(m+2)}$$

where, n is the total number of sightings, n_1, n_2 and m is the number of sightings by the front, rear and both (duplicates) observers, respectively.

At any one time, the total number of walruses is the sum of the number of animals on the sea ice in addition to those in the water. The estimated total numbers of groups in the study region were found by estimating the total numbers of groups within the area covered during the survey and then scaled up for the whole of the study region (only including strata where walrus were detected in water or on ice, see Table 1) as follows:

$$\widehat{N}_G = \frac{A}{2wL}\left(\widehat{N}_{G_{ice}}\right) + \frac{A}{2wL}\left(\widehat{N_c}_{G_{water}}\right)$$

Where $\widehat{N}_{G_{ice}}$ is the estimated number of groups on ice in the survey area and $\widehat{N_c}_{G_{water}}$ is the estimated number of groups in the water in the survey area corrected with the availability bias factor ($\hat{a}$) for walruses in water:

$$\widehat{N_c}_{G_{water}} = \left(\frac{\widehat{N}_{G_{water}}}{\hat{a}}\right):$$

with estimated coefficient of variation (cv) of

$$cv\left(\widehat{N_c}_{G_{water}}\right) = \sqrt{cv\left(\widehat{N}_{G_{water}}\right)^2 + cv\,(\bar{a})^2}$$

In this way, both perception bias and availability bias were accounted for (animals on ice are assumed to always be available for detection). The size of the surveyed area was given by 2wL where the truncation distance w was based on the perpendicular distribution of sightings from the trackline; 600 m for walrus detected on ice and 350 m for walrus detected in water. The mean group size ($\bar{s}$) and its coefficient of variance were estimated across all strata and individual animal abundance and its cv were obtained by

$$\widehat{N} = \widehat{N}_G * \bar{s}$$

and

$$cv(\widehat{N}) = \sqrt{cv\left(\widehat{N}_G\right)^2 + cv\,(\bar{s})^2}$$

Confidence limits were calculated based on the assumption of log-normal distribution with lower limit= $\widehat{N}/V$ and upper limit= $N*V$ and

$$V = \exp\left(z\sqrt{\ln\left(1 + var\frac{\widehat{N}}{\widehat{N}^2}\right)}\right)$$

(Buckland et al. 2001); where the factor z varied with the desired confidence limits (90 or 95%) and the degrees of freedom.

Table 1. Summary information on aerial survey effort in 2006, 2008 and 2012; k is the number of transects searched in each stratum and w is the truncation distance.

		Walrus on ice (w=600m)				Walrus in water (w=350m)			
	Stratum	Size (km²)	k	Effort (km)	Sigh-tings	Size (km²)	k	Effort (km)	Sigh-tings
2006	2	8,941	17	1,328.6	1				
	3	7,813	10	837.0	6	7,813	10	837.0	1
	4					4,928	5	419.4	8
	6					5,180	14	1,144.7	1
	9					5,792	12	491.0	1
	13	27,544	18	2,383.8	1				
	Total	44,298	45	4,549.4	8	23,714	41	2,892.1	11
2008	North	11,778	16	1,150.8	3	11,778	16	1,150.8	1
	South	22,554	22	2,085.2	11	22,554	22	2,085.2	6
	Total	34,332	38	3,236.0	14	34,332	38	3,236.1	7
2012	1					1,274	3	191.0	1
	2	8,941	12	1382.6	2				
	3	7,813	10	977.6	12	7,813	10	977.6	4
	4	4,928	7	521.1	6	4,928	7	521.1	3
	7	20,194	4	633.5	3				
	8					28,677	6	942.7	1
	Total	41,876	33	3514.8	23	42,692	26	2,632.4	9

RESULTS

Distribution of sightings

In 2006, 21 sightings (19 after truncation) were made on 75 transect lines covering 11,642 linear km, or 6,604 km over strata with walrus sightings (Table 1, Fig. 1). The sightings were distributed with 9 groups (8 after truncation) on ice floes and 12 groups (11 after truncation) in water. The survey in 2008 also resulted in 21 sightings but because it specifically focused on prime walrus habitat only 38 transects were flown covering 3,236 linear km. In 2008 there were 14 sightings of walruses on ice and seven in the water (Table 1, Fig. 2). The survey in 2012 covered a total of 75 transects over 7,837 km of which 33 transects (4,458 km) were in strata with

Table 2. Number of sightings of walrus groups on ice and in water by observer 1 (front), observer 2 (rear), and by both observers after truncation at 600 m and 350 m, respectively.

	Walrus on ice 2006/2008/2012	Walrus in water 2006/2008/2012
Sightings front observer	7/5/14	4/3/7
Sightings rear observer	2/12/11	9/4/6
Sightings both observers	1/3/2	2/0/4
Unique sightings	8/14/23	11/7/9

walrus sightings. In 2012 there were 36 sightings (32 after truncation) of which 25 sightings (23 after truncation) were walruses on ice and 11 were sightings (9 after truncation) in water.

In all three years walruses were mainly detected over shallow water (<200 m) on the banks along West Greenland. In both 2006 and 2012 when larger areas were covered a few additional walruses were detected north of the main concentration areas (Figs. 1 and 3).

Detection of walruses

The double platform experiment resulted in the following distribution of the 72 sightings from all surveys: 12 animals were seen by both platforms, 28 were seen by the front platform only

Table 3. Percentage of time spent in the upper 2 m of the water column by adult walruses instrumented with SLTDRs in May–June 2010, 2011 and 2012 in northern Baffin Bay (77°N 71°20-W). The percentage of time above 2 m depth and the weekly averages of 6-hr periods during daylight hours are presented together with the observed drift of the pressure transducers. The column 'Included' list the instruments where the transducer drift was at an acceptable level.

				WEEK					
YEAR	IDNO	Sex	Drift	23-31 May	1-7 June	8-14 June	15-23 June	24-30 June	Included
2010	46106	♀	4.5-6.5 m		42.25	35.78	26.13	31.60	
	46108	♀	2.5-5.5 m		78.90	55.00	50.44	40.17	
	46109	♂	3.5-5 m		64.40	49.42	34.43	33.00	
	46113	♀	-4-8.5 m		44.78	36.10	34.44	27.38	
	46114	♀	3 m		92.60				
	46115	♀	-3.5-7 m		56.44	44.50	32.89	48.38	
2011	20684	♀	0.5-1 m			50.27	32.42	37.14	39.94
	20688	♀	-0.5-0.5 m			40.98	34.07	24.56	33.20
	46107	♀	4-5.5			29.61	33.41	53.78	
	46117	♂	3.5-11			36.71	24.92	34.48	
	46160	♀	1.5-6.5			34.83	35.24	44.23	
	46162	♀	na			38.49	28.62	21.14	
	46163	♀	11-18 m			61.65	41.43	30.02	
	46164	♀	4-7 m			37.05	40.13	49.16	
2012	7934	na	0-0.5 m			23.10	26.56	31.41	27.02
	20160	na	0-1 m			16.50	42.96		29.73
	20165	♂	2-3 m	29.79	34.57	36.30	23.57	31.74	
	20167	♀	-1.5 - -1 m	52.75	74.45	57.74	49.93	38.11	54.60
	20169	na	0.5-1 m				42.45	30.03	36.24
	20685	♀	-1-0.5 m	44.86	42.25	36.97	32.09	39.98	39.23
	20689	♀	1.5-2.5 m	50.66	34.70				42.68
	46116	na	5.5 m			62.55	61.15	79.24	
	46118	♀	na	25.74	22.17				
	46155	♀	-1-2.5 m	25.38	24.47	33.96	21.23	22.03	25.41
	Mean			38.20	51.00	40.88	35.64	37.38	36.45
	SD			12.66	22.42	12.15	9.90	13.27	9.04
	cv			0.14	0.13	0.07	0.06	0.08	0.08

Table 4. The Chapman estimate for groups (*N*G) and individual animals (*N*) in the survey area; CV's are given in parentheses. For walrus detected in water, abundance estimates were corrected for availability of group abundance and individual animal abundance.

	Year	Walrus on ice	Walrus in water	Walrus combined
Group size	2006	2.13 (0.35)	1.82 (0.21)	
	2008	1.43 (0.24)	1.14 (0.12)	
	2012	1.17 (0.07)	1.11 (0.09)	
	2006	89 (0.31)	504 (0.29)	593 (0.25)
N_G	2008	164 (0.23)	790 (0.58)	954 (0.48)
	2012	586 (0.39)	648 (0.17)	1,234 (0.21)
	2006	190 (0.47)	915 (0.36)	1,105 (0.31); CI 610-2,002
	2008	234 (0.33)	903 (0.59)	1,137 (0.48); CI 468-2,758
	2012	688 (0.51)	720 (0.33)	1,408 (0.22); CI 922-2,150

and 32 were seen by the rear platform only (Table 2). As indicated it is necessary to distinguish between detection on ice and in the water and the perception bias is therefore dealt with separately for the two habitats.

In 2008 two walruses were recorded by the forward looking video system and neither responded to the plane by escaping into the water. However, one dropped into the water after passage of the plane. Hence no corrections were applied for walruses that escaped into the water before the passing of the airplane reducing their chance of being detected.

Fraction of submerged walruses

Out of 24 SLTDR tags deployed on walruses in northern Baffin Bay in May–June 2010, 2011 and 2012 only seven instruments provided an acceptable level of drift of the depth transducer (≤1m for the study period, Table 3). Additional two tags representing a high and a low surface time provided data that appeared to show a low or symmetrical drift around ≤2.5 m (IDNO 2069 and 46155) and they were included to augment the sample size from late May. Weekly averages from these instruments were used to estimate the proportion of swimming walruses that are visible to an aerial survey (availability correction). Walruses in the water were assumed to be available for detection when they were between 0 and 2 m from the surface and it was estimated that they spent 36.5% (*cv*=0.08) of the time within this depth (i.e. total:surface ratio 2.8).

Estimation of abundance

Walruses in the water were usually not detected beyond 350 m from the track line. This was slightly more than half the detection distance for walruses on the sea ice (i.e. 600 m, Fig. 5).

Attempts to fit a monotonically decreasing detection function to the distribution of distances to the sightings did not provide an improved fit over a simple uniform (flat detection) model that included 95% of the sightings. Therefore the density of walruses was estimated on the basis of a flat detection function. Strip census methods with a half strip width of 350 m for walruses in the water and 600 m for walruses on sea ice were used. Perception bias was addressed using a double-platform survey protocol and a Chapman mark recapture estimator. Availability bias was addressed by correcting the abundance estimates by the percentage of time walrus detected in water were available for detection at the surface. The simple Chapman estimators assume that detection is constant within the truncation distance which may not always be plausible and thus yield negatively biased results.

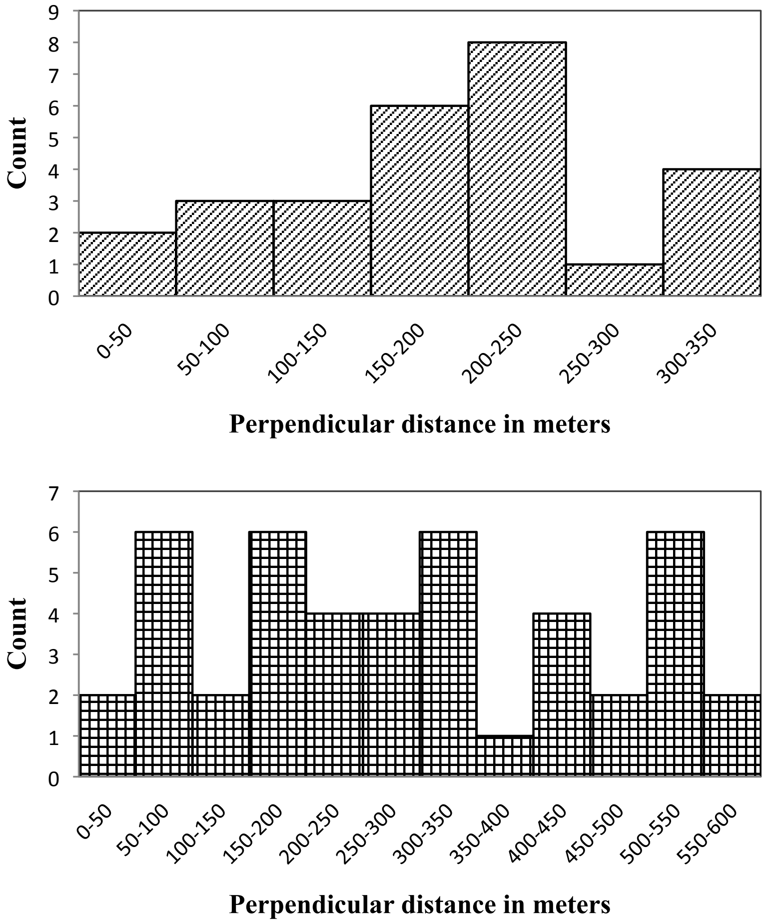

Fig. 5. *Distribution of perpendicular distances to sightings of walruses after the truncation distance of 350 m and 600 m respectively during aerial surveys of walruses in West Greenland. The upper panel shows sightings of walruses in the water, lower panel shows sightings on ice for all years combined. The upper panel displays the distribution of 27 out of 31 sightings of walruses in the water and the lower panel displays 45 out of 47 sightings of walruses on ice.*

Group and individual estimates of density and abundance, corrected for perception bias and availability bias are given in Table 4. The total abundance of walruses detected on both ice and in water was estimated to be 1,105 (*cv*=0.31), 1,137 (*cv*=0.48) and 1,408 (*cv*=0.22) individuals in 2006, 2008, and 2012, respectively.

The estimates between years did not differ significantly indicating that the median point estimate of the fully corrected abundance of walruses wintering in West Greenland in 2006–12 was around 1,100 animals.

DISCUSSION

There are a number of well-known difficulties associated with estimation of marine mammal abundance however walruses are clearly among the most difficult species to survey. The difficulties include the fact that they have a clumped distribution, they occur in two different habitats (sea ice and water) with different detection probabilities, they have variable group sizes and availability correction factors that are difficult to obtain simultaneously with the survey. Surveys of walruses notoriously suffer from large variances of sighting rates, unknown proportions of the population diving and therefore unavailable to be counted during surveys, and large annual variations in sea ice distribution and extent (Estes and Gilbert 1978, Gilbert 1989, 1999, Udevitz et al. 2001). Inevitably all these factors influenced the surveys of walruses in West Greenland reported here.

Submerged walruses

No previous studies have addressed the issue with drift of the pressure transducer of satellite transmitters deployed on walruses. The transducer and software generations used in this study evidently had an unacceptably large error or failure rate where the detection of the surface consistently moved to deeper depths with time. This could cause a severe positive bias in the abundance estimates if not addressed properly. It is not possible to correct the drift of the surface reading and instead only data with acceptable surface readings can be retained. The approach in this study was to accept data with ≤1 m of error in surface detection (equal to twice the precision of the pressure transducer) and preferably with a symmetrical distribution of surface readings around 0 m depth. In two cases data from tags with a higher error were included but they did not bias the overall availability correction factor but rather provided additional variance to the estimate.

Ideally measurements of surfacing time should be acquired in the same area and seasons as the aerial surveys. If this is not possible it seems important to collect the data as close to the same seasons as possible. Most data on walrus diving behaviour have been collected during summer and information on time spent submerged by walruses during winter is scarce. In a study of an adult male walrus monitored with a time-depth-recorder (TDR) at Svalbard during summer, Wiig et al. (1993) found that about 24% of the time was spent between 0 and 2 m. In contrast, Jay et al. (2001) found that four Pacific (*O. r. divergens*) walruses in the Bering Sea equipped with TDRs spent 39.7% of the time between 0 and 2 m during summer (total:surface ratio 2.5). Using TDRs and SLTDRs to study walrus activity during late July–August at Svalbard, Gjertz et al. (2001) found that nine walruses spent 39% of their time between 0 and 2 m depth (i.e. total:surface ratio 2.1). The availability correction applied in this study was acquired in the early part of the summer (May–June), or two months later than the survey, and is within the range of values obtained for walruses for other areas and seasons and likely reflects a more general physiological requirement for the surface time of walruses.

Comparison with previous estimates of abundance

Previous estimates of abundance of walruses in West Greenland only addressed the number of animals at the surface and did not include corrections for animals not available to be seen or those missed by the observers (Born et al. 1994). However, using the estimates of walruses at the surface obtained from line-transect aerial surveys conducted in West Greenland in early spring of 1990 and 1991 Witting and Born (2005) included a correction based on data on haul-out percentage and diving activity obtained from SLTDRs deployed on walruses in Northeast Greenland. With these corrections the total number of walruses wintering off West Greenland was estimated at ca. 1,000 (*cv*=0.48; Witting and Born 2005). The estimates from the present study include corrections for the availability of walruses submerged below a detection threshold and a correction for walruses that were missed by the observers. Although the abundance estimates in this study are higher than that from Witting and Born (2005) they do not differ statistically.

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