# THE SIGNIFICANCE OF THE NORTH WATER TO WHALES AND WALRUSES

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## INTRODUCTION

It has been known since William Baffin in 1616 circumnavigated Baffin Bay that there is an open-water area in Northern Baffin Bay that doesn't freeze in winter. This recurring polynia was known by the bowhead whalers as the North Water and it was frequently visited by whalers and expeditions during the 19$^{th}$ century. The area was attractive because of its year-round open water conditions and because of the abundance of marine mammals and especially the precious bowhead whale. For the very same reasons the area around the North Water was also highly attractive to Inuit settlers long before its discovery by European expeditions. For 4000 yrs the North Water was the gateway from Canada to Greenland and it was at the same time also an important area for several waves of Inuit settlements along the coast, some of which persist today in the modern Polar Inuit culture in Northwest Greenland.

The recurrent open water area in northern Baffin Bay is apparently maintained by the prevailing strong northerly wind from Smith Sound that, particularly in years with an ice-bridge across the narrowest point of Smith Sound, clears the area south of the ice bridge for newly formed ice. This ice-machine also brings water and nutrients from the deeper layers to the surface that feeds into a highly productive food web that eventually also sustain large numbers of marine mammals and sea birds.

The maritime Inuit subsistence culture in Northwest Greenland relies entirely on access to marine resources in the North Water but the sustainability of the exploitation of especially walruses and narwhals has recently been questioned. At the same time the physical conditions and especially the sea ice coverage in the North Water is suspected to be impacted by global warming. It is therefore important to census the marine mammals inhabiting the North Water to determine the sustainability of the current harvest levels and to establish a baseline for evaluating future changes in the usage of the North Water by marine mammals.

In this study we conducted an aerial survey of the North Water in spring 2009 to determine distribution and occurrence of walruses, narwhals and belugas.

## MATERIAL AND METHODS

### *Survey platform*

All visual aerial line transect surveys were conducted as a double-platform, or double-observer, experiment with independent observation platforms at the front and rear of the survey plane. The survey plane was a DeHavilland Twin Otter and target altitude and speed were 213 m and 168km $h^{-1}$, respectively. Two observers sat in the front seats just behind the cockpit and two observers sat in the rear seats at the back of the plane. The within aircraft distance between front and rear observers was approximately 4 m and a long-range fuel tank and recording equipment installed between the front and rear seats prevented visual or acoustic cueing of sightings between the two platforms. All four observers had bubble windows that allowed them to view the trackline straight below the aircraft.

The observers collected data on sightings (species, group sizes and characteristics), recorded declination angles to sightings using inclinometers and kept a record of sighting condition (sea state and visibility). The time between when a group of whales was first seen and when it passed abeam where the distance was measured was estimated by the survey leader for a sub-set of sightings. The data from the four observers were recorded on a specially designed, four channel video and audio recording computer (sDVRms) developed by Redhen (www.redhen.com). The Redhen system was connected to a GPS and all sightings were logged in a GPS logfile. Although all observations were spoken into a common recording system the observers could not hear one another.

The survey was conducted in the North Water between 19 and 30 May 2009 covering the area between 75°57'N to 79°N (Fig. 1). Ten strata were constructed in this area and they were surveyed by transects aligned east-west, systematically between the coast of West Greenland and the east coast of Ellesmere Island or the continuous fast-ice east of Ellesmere Island. The realized effort was slightly less than originally planned due to unfavourable weather conditions (sea states>3 and horizontal visibility<1 km) (Fig. 1).

*Collection of data on the availability correction*

Two female narwhals were captured in nets in Melville Bay in August-September 2007 and one female was captured in Uummannaq in November 2008 (cf. Dietz and Heide-Jørgensen 1995). The whales were tagged with satellite linked time-depth-recorders (SLTDR, SPLASH-tag from Wildlife Computers) that were bolted through the dorsal ridge of the whales with nylon pins. As well as providing satellite positions of the three whales the tags also collected data on the time spent at, or above, 2 m depth; the depth to which narwhals can reliably be detected on the trackline (Richard *et al.* 1994, Heide-Jørgensen 2004). The data were collected in one hour increments over a 24 hour period across 10 depth bins, rounded to the nearest 5% that the whales were above the threshold depth. The data were relayed through the Argos Data Collection and Location System and decoded using Argos Message Decoder (Wildlife Computers). Daily averages were calculated and used for deriving monthly averages that matched the survey dates.

Information on "at surface time" for walruses was obtained from activity measurements from the saltwater switch (SWS) of satellite-linked transmitters (SLT) that were deployed during 12-14 July 2009 on walruses in southern Kane Basin at ca. 79° N (see Born et al. 2009 for details).
The internal system of the SLTs continuously checked the status of the SWS ("dry" vs. "wet") every 0.25 sec and recorded the activity of the SWS in 60-min intervals. This information was stored in "timelines" (TIM) that show what percentage of each 60-min interval the SLT was dry. Percentage of "dry"-time/h was given in a total of thirteen increments ranging from "0%" (every measurement was wet) to "100%" (every measurement was dry). Two increments were 5% (i.e. >0-<5%; ≥95-<100%) and nine increments between >5% and <95% SWS dry were 10%. TIMs with information on haul-out activity during 24 h were transmitted along with the "time-at-temperature" histograms (Wildlife Computers 2006). For analysis of time at surface all ≥70% dry intervals were subtracted from the total sum of 60-min intervals during July and August. Subsequently, % of time per day at water´s surface (i.e. % of time when SWS was dry) was calculated to get the at-surface time. Hence, for each animal we determined the percentage of time per hour and day at the water´s surface during July and August.

*Perpendicular distance*

The declination angles ($\psi$) were converted to radial distances ($r$) of the animal using the following equation taken from Buckland *et al*. (2001) and modified according to Lerczak and Hobbs (1998a and 1998b):

$$x = \cos(\psi)\left\{(R+v)\sin(\psi) - \sqrt{R^2 \sin^2(\psi) - 2(2R+v)\cos^2(\psi)}\right\}$$

where $R$ is the radius of the Earth (taken to be 6,370km) and $v$ is the height of the airplane (which flew at a height of 213m). As the declination angles were measured when animals were abeam, the radial distance $r$ corresponded to the perpendicular distance.

*Detection function estimation*

Although the observers were acting independently, unmodelled dependence of detection probabilities on unmodelled variables can induce correlation in detection probabilities. Since it may not be possible to record all variables affecting detection probability, unmodelled heterogeneity may persist even when the effects of all recorded variables are modelled. Laake and Borchers (2004) and Borchers *et al*. (2006) developed an estimator based on the assumption that unmodelled heterogeneity occurred at all perpendicular distances, except at zero perpendicular distance (i.e. on the trackline) – called a point independence model. The alternative – a full independence model - assumes no unmodelled heterogeneity at any distance. Thus, the point independence model is more robust to the violation of the assumption of no unmodelled heterogeneity than the full independence model. Full independence models are useful if animals move in response to the survey vessel between detection by one observer and detection by the other observer. However, during an aerial survey, where the plane is moving much faster than the animals, responsive movement between duplicate detections should be negligible and so point independence models are preferable.

Incorporating the point independence assumption involves estimating two models: a multiple covariate distance sampling (DS) detection function for combined platform detections, assuming certain detection on the trackline (Marques *et al*. 2004); and a mark-recapture (MR) detection function to estimate detection by an observer. This latter function is the probability that an animal, at given perpendicular distance $x$ and covariates $z$, was detected by an observer, given that it was seen by the other observer. It is modelled using a logistic form:

$$p_{1|2}(x,z) = p_{2|1}(x,z) = \frac{\exp\left\{\beta_0 + \beta_1 x + \sum_{k=1}^{K} \beta_k z_k\right\}}{1+\exp\left\{\beta_0 + \beta_1 x + \sum \beta_k z_k\right\}}$$

where $\beta_0$, $\beta_1$, …, $\beta_K$ represent the parameters to be estimated and $K$ is the number of covariates. The intercept of $p_{1|2}(0,z)$ and $p_{2|1}(0,z)$ are combined to estimate the detection probability on the trackline. Explanatory variables can be included into both the DS and MR models and Akaike's Information Criterion (AIC) and goodness of fit tests were used for model selection.

*Estimating density and abundance*

Available pod, or group, density ($D_{Gi}$) and abundance ($N_{Gi}$) for stratum $i$ were estimated as follows:

$$\hat{D}_{Gi} = \frac{1}{2wL_i}\sum_{j=1}^{n_i}\frac{1}{\hat{p}_{ij}} \qquad \text{and} \qquad \hat{N}_{Gi} = A_i \hat{D}_{Gi}$$

where $A_i$ is the size of stratum $i$, $w$ is the truncation distance, $L_i$ is the total effort in stratum $i$, $n_i$ is the total number of detections in the stratum $i$ and $\hat{p}_{ij}$ is the estimated probability of detecting pod $j$

in stratum *i*, obtained from the fitted model described previously. In order to account for availability bias, corrected abundance (denoted by the subscript 'c') was estimated by

$$\hat{N}_{Gc\,i} = \frac{\hat{N}_{G\,i}}{\hat{a}}$$

where the parameter $\hat{a}$ is the estimated proportion of time animals are available for detection. Using the delta method the coefficient of variation (CV) of $\hat{N}_{Gci}$ is given by

$$cv\left(\hat{N}_{Gc\,i}\right) = \sqrt{cv^2\left(\hat{N}_{G\,i}\right) + cv^2(\hat{a})}$$

Similarly, the density ($D_i$) and abundance ($N_i$) of individual animals in stratum *i* was obtained using

$$\hat{D}_i = \frac{1}{2wL_i}\sum_{j=1}^{n_i}\frac{s_{ij}}{\hat{p}_{ij}} \qquad \text{and} \qquad \hat{N}_i = A\hat{D}_i$$

where $s_{ij}$ is the size of pod *j* in stratum *i*. These estimates were corrected for availability bias in the same way as for group density. The expected pod size in stratum *i* is estimated by

$$\hat{E}[s_i] = \frac{\hat{N}_i}{\hat{N}_{G\,i}} \qquad (1)$$

*Chapman estimator*

MRDS models require a sufficient number of sightings to be able to estimate the model parameters reliably. A much simpler MR model is an estimator due to Chapman (1951) and is based only on the numbers of sightings and duplicates and thus assumes that detection does not depend on perpendicular distance. The number of groups in the covered region is given by

$$\hat{N}_{Gc} = \frac{(n_1+1)(n_2+1)}{(m+1)} - 1$$

where $n_i$ is the number of groups detected by observer *i* and *m* is the number of duplicates. The variance is given by

$$\text{var}(\hat{N}_{Gc}) = \frac{(n_1+1)(n_2+1)(n_1-m)(n_2-m)}{(m+1)^2(m+2)}$$

## RESULTS

### *Sea ice conditions in the North Water in late May 2009*

There was an unusual large proportion of open water with no signs of recent fast-ice formation in the North Water in late May 2009 (Fig. 2). Only along the east coast of Ellesmere Island could larger stretches of fast-ice be found. On the Greenland side no fast-ice could be seen along the outer coast from Kap York to north of Inglefield Land. The Wolstenholme Fjord on the Greenland side had broken fast ice with the ice edge unusually far into the fjord. The Inglefield Bredning fjord had fast-ice with an ice edge at the eastern corner of the island Qeqertarsuaq. In Smith Sound transects were flown as far north as 79°N without detection of sea ice except for fast-ice along Ellesmere Island. Sea ice could not be seen from the aircraft north of 79°N. The prevailing northern wind prevented the formation of new ice and few pieces of old fast ice were available for walruses for haul-out.

### *Distribution of sightings*

The region of interest covered an area of 54,819km$^2$ and was divided into ten strata where 5,423km of systematically placed track lines were searched (Fig. 1). Walrus (26 unique sightings of groups), narwhal (54 groups), beluga (47 groups), several seal species and two polar bears were detected (Table 1).

Most of the walruses were distributed on a belt across from Greenland to Ellesmere Island in the southern part of the NOW at a latitude of ~76°30'N. Only two sightings were made north of 77°N with the northernmost at 77°48'N (Fig. 3). The walruses were found across the North Water over both shallow and deep (>500m) water. Of the 26 unique sightings of walruses only 5 were on ice, the rest were animals in the water. Most walruses were detected as solitary individuals but two groups of four were seen (Table 2). The average group size was slightly lower in water (1.4, cv=0.11)) compared to the detections on ice (2.0, 0.35).

Narwhals were widely distributed on the eastern side of NOW during the survey with the core distribution at 77°09'N and 72°W close to the southern entrance to Inglefield Bredning (Fig. 4). There were also ten sightings of narwhals that had passed Inglefield Bredning and were located at the latitude of 77°42'N and closer to Ellesmere Island than to Greenland. Narwhals were mainly detected over deep water (>500m) and were usually seen as a single animals but with few larger groups (5-10 individuals) on the Greenland side of the North Water.

Belugas were not detected north of 77°20'N but they were found both coastally along West Greenland and offshore in the middle of the North Water (Fig. 5). Most detections were solitary whales and the average swim direction of 23 beluga pods was southwest (232°).

### *Validation of sightings*

For some duplicate sightings, the observers had recorded different declination angles and thus the sightings had different perpendicular distances. Fig. 6 shows that there does not appear to be any systematic bias between the observers (which could occur, for example, if angles from observer 1 were always greater than observer 2). Thus, the mean perpendicular distance for the sightings was used.

The majority of sightings were of single animals (Table 2) but for some duplicate sightings, observers had also recorded different pod sizes. In the majority of cases, the difference between the two estimates was one animal but for a sighting of narwhal in stratum 9, observer 1 recorded 22 animals and observer 2 recorded 7 animals (see Fig. 6). In all cases, the mean pod size was used (rounded down to the nearest integer).

### *Detection functions*

While the models described previously (known as MRDS models) do not require $g(0)$ to be one, MRDS models do rely on the probability of detection on the trackline being at a maximum (or minimum). The detection probability may not be at a maximum on the trackline if it is difficult to see directly below the plane. However, the histograms of the perpendicular distributions do not suggest that there were problems searching below the plane (Fig. 7).

For the DS model, both half-normal and hazard-rate functions were fitted, initially with no explanatory variables (apart from perpendicular distance) and then explanatory variables were included. Explanatory variables were incorporated into the DS model via the scale parameter

(Marques and Buckland 2004). The available explanatory variables were pod size, side of plane (left and right) and Beaufort sea state. Pod size and Beaufort sea state were included both as continuous variables and as a factor variable; the pod size factor variable contained two levels to represent pod sizes of one and greater than one and Beaufort factor had three levels to represent Beaufort sea states 0, 1 and ≥2 (Table 3). The same explanatory variables were included in the MR model, in addition to a variable indicating observer (1 and 2).

Walrus were detected both on ice and in the water (Table 4). An MRDS model was fitted to walrus detected in the water and a Chapman estimator was fitted to walrus on ice. Sightings of walrus in the water were truncated at 400m; this excluded one sighting which was detected at a perpendicular distance of over 600m.

The final MRDS models fitted are given in Table 5 and the estimated detection function plots can be seen in Figs 8, 9 and 10. The models for beluga and narwhal indicated a substantial decline in detection probability as perpendicular distance increased. However, the model for walrus indicated that, within a distance of 400m, the probability of detection was constant.

The average probabilities of detection on the trackline were estimated for each observer and from these estimates, the probability that an animal was detected by either observer 1, observer 2 or both observers, was calculated (Table 6). The probability of detection on the trackline for the observers combined was estimated to be 0.97 (cv=2.33) for beluga, 0.81 (cv=6.40) for narwhal and for walrus in the water 0.82 (cv=11.0).

## ***Density and abundance estimates***

*Estimates for narwhal and beluga uncorrected for availability*

Pod and individual estimates of density and abundance, uncorrected for availability bias (but corrected for observer bias), are given in Table 7. Expected pod sizes were estimated for each stratum using equation (1); in some strata there were too few sightings to be able to estimate the variance adequately and therefore the coefficients of variation are likely to be poorly estimated. The at surface abundance of beluga was estimated to be 863 (cv=0.33; 95% CI 460 – 1,620) and for narwhal 1,602 (cv=0.25; 95% CI 982 – 2,610).

*Estimates for narwhal and beluga corrected for availability*

Narwhal were considered to be available for detection when they were within 2m of the surface and beluga within 5m of the surface. This was estimated using time-at-depth data relayed through satellites from whales instrumented with satellite-linked radio transmitters. For belugas mean of biases factors used in two different surveys (Heide-Jørgensen and Acquarone 2002; Innes *et al*. 2002) was used. The data indicated that beluga spend on average 43% of the time above five metres depth (cv=0.09). For narwhals the average value for three narwhals providing at-surface-time (<2 m) during May and June (one transmitting in 2009) was used. The three narwhals spend on average 15% of the time above 2m depth (cv=0.14, Table 8).

Pod and individual estimates of density and abundance corrected for availability bias are given in Table 11. The abundance estimate for beluga was 2,008 animals (cv=0.34; 95% CI 1,050 – 3,850) and for narwhal 10,677 animals (cv=0.29; 95% CI 6,120 – 18,620).

*Estimates for walrus*

At any one time, the total number of walrus in the region is the sum of walrus on the ice plus those in the water. Here, we estimate the total numbers of walrus in the study region by estimating the total numbers of walrus within the covered region and then scale up for the study region as follows:

$$\hat{N}_G = \frac{A}{2wL}\left(\hat{N}_{G\ ice} + \frac{\hat{N}_{G\ water}}{\hat{a}_w}\right)$$

where $\hat{N}_{G\ ice}$ is the number of walrus on ice in the covered region estimated from the Chapman estimator and $\hat{N}_{G\ water}$ is the number of walrus in the water in the covered region estimated from the MRDS model (predicting only for the covered region) and $\hat{a}_w$ is the availability bias factor for walrus in the water at the surface (Table 10). In this way, we have accounted for both observer bias and availability bias (walrus on ice are assumed to be always available for detection). The covered region was based on a truncation distance of 172.5m (the maximum perpendicular distance of a walrus detected on the ice). This estimator assumes that the proportions of walrus on ice and in the water are the same throughout the region of interest as they are in the covered region. The total number of walrus in the study region was estimated to be 2,676 animals (%cv=32.0; 95% CI 1,460 – 4,920) (Table 11c).

## DISCUSSION

### *Survey bias*

The estimates presented here are corrected for both observer perception bias and availability bias. Perception bias was addressed using a double-platform survey protocol and using MRDS analysis methodology. The small numbers of walrus detected on the ice precluded the use of MRDS models and so a much simpler estimator was used. This estimator assumed that detection was constant within a specified strip (172.5m wide) but since the results indicated that the probability of detection of walrus in the water appeared to be constant to a distance of 400m, this assumption made for walrus on ice seems plausible.

The availability bias correction assumes that the survey was instantaneous, which is not strictly the case as the animals will have been within detectable range for more than an instant, thus the correction in this way may yield somewhat positively biased results.

### *The use of the North Water by whales and walruses*

The large amount of open water detected in the NOW area during the aerial survey in May was unusual for the season. Between 40 and 80% sea ice coverage with open water only in northern Smith Sound was the general situation for late May during 1979-96 (Barber et al. 2001) and usually fast-ice prevails in all the fjords and along the shores. The lack of sea ice affected the whales and walruses by allowing them access to larger areas but it only provided few options for walruses for haul-out on ice.

Previous aerial surveys of marine mammals in the North Water were conducted in March-April 1978, March 1979 and March 1993 (Finley and Renaud 1980, Richard et al. 1998). All these surveys were flown over very different sea ice conditions than during the present survey. In all the previous surveys Smith Sound had an ice bridge across the sound from Ellesmere to Greenland, and pack-ice with sheets of new ice covered the area south of the ice edge. Occasional leads and cracks provided open-water access for marine mammals and in the 1993-survey it was estimated that sea ice covered 90% of the North Water (Richard et al. 1998). The 2009-survey was conducted two months later in the season but in a more typical year the ice bridge across Smith Sound would persist through June (Ingram et al. 2002). It was already obvious in January 2009 that the North Water showed an unusual low rate of ice formation and that most ice generated in Smith Sound was blown south out of the North Water area (http://www.dmi.dk/dmi/index/nyheder/nyheder-2/nordvandet_forbinder_himmel_og_hav.htm). It is important to monitor if this large area with open water is a persistent pattern in the North Water or if 2009 was an anomalous year.

Walruses were observed in all three surveys but in low numbers in 1978 (36) and 1993 (13). In March 1979 a total of 700 walruses were counted in leads on the Canadian side of the North Water. Even though the numbers fluctuate widely it is obvious that the North Water is an important wintering area for walrus.

Similarly belugas were mainly seen in narrow leads and cracks on the Canadian side along Devon Island, at eastern Lancaster and Jones sound and at southern Smith Sound in all three surveys, but in 1993 belugas were also detected in the central part of the North Water. In March 1978 belugas (85) were detected on the Greenland side close to Northumberland Island. The sum of the sightings was 402 in 1978, 214 in 1979 and 733 in 1993, but these numbers are negatively due to partial coverage and no correction factors applied, nevertheless it appears from these surveys that a considerable number of belugas winter in the North Water.

Far less narwhals were detected in the North Water; none in 1978, 12 in 1979 and 15 in 1993. From this it is obvious that narwhals don't use the North Water to the same extent as belugas do during the winter.

The situation in the ice-free North Water in May 2009 was evidently very different from the situation documented in the previous surveys conducted in March-April. Narwhals were clearly much more abundant than belugas in May 2009 and this is likely due to immigration of narwhals into the North Water region from the Baffin Bay. Narwhals spend the summer in the fjords adjacent to the North Water and they are particularly abundant in Inglefield Bredning but can also be found further north in Smith Sound. Based on more or less discrete summer concentrations Heide-Jørgensen et al. (2009) operates with two possible narwhal stocks in the North Water; the Inglefield Bredning and the Smith Sound (with adjacent fjords) stocks. However, no substantial information is available to corroborate this delineation and it is possible that these two concentration areas are connected and that this would explain the fluctuations in abundance that has been documented for Inglefield Bredning (Heide-Jørgensen et al. In press). The total abundance of narwhals in the North Water was 10677 (cv=0.29) of which all those south of Northumberland Island seem to be heading towards the ice edge at the southern entrance (south of Qeqertarsuaq) to the summering ground in Inglefield Bredning. The narwhals in stratum 7 and 8 and the northern part of stratum 9 have apparently passed Inglefield Bredning, the main summering ground in the North Water. If the 1700 narwhals in stratum 7 and 8 are assumed to summer in Smith Sound and Buchanan Bay then the abundance in the remaining strata is 8.467 (cv=0.29). These whales are assumed to summer in Inglefield Bredning and the estimate is remarkably similar to the abundance estimate of 8.447 (cv=0.25) determined from a summer survey of Inglefield Bredning in 2007 (Heide-Jørgensen et al. in press).

Belugas were also present in large numbers in the North Water although not as abundant as the narwhals. Whereas narwhals were heavily concentrated in stratum 9 – the entrance to Inglefield Bredning – belugas were more uniformly distributed in the North Water. It is well known that large numbers of belugas winter in the North Water but is also assumed that most of these move towards the summering grounds inside the Canadian high Arctic archipelago in spring and that there is an increasing abundance of belugas at the ice edge in Lancaster Sound in May and June. There are no real known summer concentrations of belugas in the North Water area and even though some are occasionally seen in summer on the Greenlandic side there is no summer resident population there or along the east coast of Ellesmere Island. It is therefore most probable that the belugas found in the North Water in May are on their way towards the Canadian summering grounds and that the survey was too late to capture the peak abundance of belugas in the North Water. This is corroborated by the more southern distribution of the belugas in the surveyed area and the general southwest-ward swimming direction of these whales.

No bowhead whales were observed during the survey which seems to be somewhat unusual since both historic and recent observations suggest that the North Water are used by bowhead whales during winter and spring (Holst and Stirling 1999, Richard et al. 1998, Greenland Institute of Natural Resources unpubl. data). Bowhead whales tagged with satellite transmitters in Disko Bay in May 2009 did not visit the North Water area during their northward migration (Greenland Institute of Natural Resources).

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Table 1 Summary of survey data; strata, survey effort and the number of sightings by observer *1*, observer *2* and by *both* observers.

| Stratum | Size ($km^2$) | k | Effort (km) | Beluga | | | Narwhal | | | Walrus | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *1* | *2* | *Both* | *1* | *2* | *Both* | *1* | *2* | *Both* |
| 1 | 5 773.13 | 5 | 455.65 | 2 | | | | | | 2 | 1 | |
| 2 | 7 458.27 | 5 | 427.70 | 1 | 2 | 1 | 3 | 1 | 1 | | | |
| 3 | 4 160.65 | 11 | 695.80 | 16 | 13 | 10 | 5 | 6 | 3 | 2 | | |
| 4 | 3 270.98 | 5 | 299.48 | | | | | | | 5 | 7 | 4 |
| 5 | 3 969.45 | 6 | 418.98 | 9 | 10 | 8 | 3 | 6 | 3 | 5 | 5 | 5 |
| 6 | 3 532.73 | 11 | 719.80 | | | | 6 | 6 | 4 | 6 | 4 | 4 |
| 7 | 6 328.62 | 9 | 547.58 | 1 | 1 | | 1 | 1 | | | 1 | |
| 8 | 6 774.44 | 11 | 811.71 | 4 | 3 | 3 | 13 | 10 | 7 | | | |
| 9 | 4 152.31 | 17 | 648.41 | 6 | 5 | 4 | 11 | 6 | 6 | 1 | | |
| 10 | 9 418.01 | 5 | 457.40 | | | | | | | | | |
| Total | 54 838.59 | 85 | 5 482.51 | 39 | 34 | 26 | 42 | 36 | 24 | 21 | 18 | 13 |

Table 2. Pod sizes (after taking the mean of duplicate sightings). The maximum pod sizes for beluga and narwhal were 12 and 14, respectively.

| Pod size | Beluga | Narwhal | Walrus in water | Walrus on ice |
|---|---|---|---|---|
| 1 | 37 | 38 | 15 | 3 |
| 2 | 6 | 8 | 5 | 1 |
| 3 | 1 | | | |
| 4 | 1 | 2 | 1 | 1 |
| 5-9 | | 5 | | |
| ≥10 | 2 | 1 | | |

Table 3. Numbers of unique sightings in each level for the factor explanatory variables

| Species | BF | | | Pod size | | Side | |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | ≥2 | 1 | ≥2 | Left | Right |
| Beluga | 7 | 14 | 26 | 37 | 10 | 22 | 25 |
| Narwhal | 26 | 10 | 18 | 38 | 16 | 28 | 26 |
| Walrus | 4 | 11 | 6 | 15 | 6 | 9 | 12 |

Table 4. Numbers of walrus detected on ice or in the water. The final column is the number of unique sightings.

| Habitat | Observer | | | Unique sightings |
|---|---|---|---|---|
| | 1 | 2 | Both | |
| In water | 19 | 14 | 12 | 21 |
| On ice | 2 | 4 | 1 | 5 |
| Total | 21 | 18 | 13 | 26 |

Table 5 Explanatory variables included in the final MRDS models fitted to the data. The explanatory variables are perpendicular distance (D), pod size (Size), beaufort (BF) and side of plane (Side). A subscript indicates that the variable was fitted as a factor variable with that many levels. The 'DS model' column shows the explanatory variables that were included via the scale parameter; no additional variables were included for walrus.

| Species | DS model | MR model |
|---|---|---|
| Beluga | $BF_3 + Size_2$ | D + BF + Size |
| Narwhal | $BF + Side_2$ | $Size + Side_2$ |
| Walrus in water | - | $BF_3 + Side_2$ |

Table 6. Probability of detection by observer for each species. CVs are given in parentheses.

| Species | Observer 1 | Observer 2 | Both observers |
|---|---|---|---|
| Beluga | 0.84 (0.06) | 0.84 (0.06) | 0.97 (0.02) |
| Narwhal | 0.60 (0.10) | 0.60 (0.10) | 0.81 (0.06) |
| Walrus in water | 0.66 (0.15) | 0.66 (0.15) | 0.82 (0.11) |
| Walrus on ice | 0.25 (0.68) | 0.50 (0.56) | 0.63 (0.36) |

Table 7. Estimates uncorrected for availability bias of encounter rate (groups/km), group density ( $\hat{D}_G$, groups/km$^2$), group abundance ( $\hat{N}_G$ ), animal density ( $\hat{D}$ , animals/km$^2$), group abundance ( $\hat{N}$ ) and expected group size.

a) Beluga

| Stratum | Encounter rate | $\hat{D}_G$ | $\hat{N}_G$ | $\hat{D}$ | $\hat{N}$ | $\hat{E}[s]$ |
|---|---|---|---|---|---|---|
| 1 | 0.0044 (1.02) | 0.0048 (1.03) | 28 (1.03) | 0.0048 (1.03) | 28 (1.03) | 1.00 (0.00) |
| 2 | 0.0047 (0.93) | 0.0128 (0.95) | 95 (0.95) | 0.0128 (0.95) | 95 (0.95) | 1.00 (0.00) |
| 3 | 0.0273 (0.59) | 0.0588 (0.67) | 245 (0.67) | 0.0877 (0.57) | 365 (0.57) | 1.49 (0.35) |
| 4 | | | | | | |
| 5 | 0.0263 (0.53) | 0.0352 (0.52) | 140 (0.52) | 0.0400 (0.51) | 159 (0.51) | 1.14 (0.08) |
| 6 | | | | | | |
| 7 | 0.0037 (0.98) | 0.0090 (1.00) | 57 (1.00) | 0.0090 (1.00) | 57 (1.00) | 1.00 (0.00) |
| 8 | 0.0049 (0.67) | 0.0056 (0.82) | 38 (0.82) | 0.0142 (0.87) | 96 (0.87) | 2.54 (0.52) |
| 9 | 0.0108 (0.87) | 0.0097 (0.86) | 45 (0.86) | 0.0137 (0.90) | 64 (0.90) | 1.41 (0.09) |
| 10 | | | | | | |
| Total | 0.0086 (0.31) | 0.0118 (0.35) | 647 (0.35) | 0.0157 (0.33) | 863 (0.33) | 1.33 (0.17) |

b) Narwhal

| Stratum | Encounter rate | $\hat{D}_G$ | $\hat{N}_G$ | $\hat{D}$ | $\hat{N}$ | $\hat{E}[s]$ |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | 0.0070 (0.57) | 0.0145 (0.57) | 108 (0.57) | 0.0145 (0.57) | 108 (0.57) | 1.00 (0.00) |
| 3 | 0.0115 (0.41) | 0.0327 (0.50) | 136 (0.50) | 0.0371 (0.55) | 154 (0.55) | 1.13 (0.08) |
| 4 | | | | | | |
| 5 | 0.0143 (0.37) | 0.0286 (0.37) | 113 (0.37) | 0.0372 (0.35) | 148 (0.35) | 1.30 (0.15) |
| 6 | 0.0111 (0.51) | 0.0313 (0.57) | 111 (0.57) | 0.0554 (0.54) | 196 (0.54) | 1.77 (0.38) |
| 7 | 0.0037 (0.95) | 0.0057 (0.98) | 36 (0.98) | 0.0084 (0.97) | 53 (0.97) | 1.48 (0.01) |
| 8 | 0.0197 (0.42) | 0.0317 (0.44) | 215 (0.44) | 0.0411 (0.46) | 278 (0.46) | 1.30 (0.10) |
| 9 | 0.0170 (0.37) | 0.0334 (0.39) | 139 (0.39) | 0.1600 (0.48) | 664 (0.48) | 4.79 (0.34) |
| 10 | | | | | | |
| Total | 0.0098 (0.20) | 0.0156 (0.21) | 857 (0.21) | 0.0292 (0.25) | 1 602 (0.25) | 1.87 (0.18) |

Table 8. Data on time available for detection collected from two female narwhals instrumented in Melville Bay in August-September 2007 and on female instrumented in November 2008. The monthly averages for 20162 and 10946 are calculated from daily averages based on 24 hourly recordings of the fraction of time spent at or above 2 m depth. For 3961 monthly averages are based on 6-horuly time-at-depth readings. *n* is the daily average of surfacing times collected between 10:00 and 20:00, SD is the standard deviation of the daily averages.

| | | August * | September | October | November | December | January | February | March | April | May | June | July |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | 0.15 | 0.23 | 0.24 | 0.18 | 0.19 | 0.17 | 0.16 | 0.18 | 0.2 | 0.21 | 0.16 | 0.13 |
| 20162 | n (days) | 31 | 24 | 26 | 29 | 27 | 30 | 16 | 24 | 26 | 31 | 28 | 31 |
| | SD | | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| | Mean | 0.25 | 0.20 | 0.21 | 0.2 | 0.17 | | | | | | | |
| 10946 | n (days) | 2.00 | 30.00 | 30.00 | 29 | 29 | na | na | na | na | na | na | na |
| | SD | 0.04 | 0.02 | 0.01 | 0.01 | 0.01 | | | | | | | |
| | Mean | | | | | 0.17 | 0.20 | 0.18 | 0.25 | 0.27 | 0.13 | 0.11 | 0.05 |
| 3961 | n (days) | na | na | na | na | 18 | 27 | 16 | 9 | 11 | 19 | 13 | 9 |
| | SD | | | | | 0.11 | 0.07 | 0.06 | 0.05 | 0.16 | 0.15 | 0.09 | 0.02 |

* For 20162 the data are from 2008 and for 20167 the data are from 2007

Table 9. Daily mean haulout, in water and at surface percentage of time for three walruses that were monitored with satellite radios during 12 July-31 August 2009 in the Kane Basin region.

| Month 2009 | Animal ID | Age/sex | Days with records | % Time hauled out per day | SD | % Time in water per day | % Time at sea surface | SD | % Time exposed total |
|---|---|---|---|---|---|---|---|---|---|
| July | 3758 | Ad. F | 19 | 31.1 | 21.8 | 68.9 | 16.8 | 4.9 | 47.9 |
| | 4188 | Ad. M | 8 | 42.7 | 31.9 | 57.3 | 20.0 | 5.5 | 62.7 |
| | 8375 | Ad. M | 18 | 44.2 | 33.6 | 55.8 | 15.9 | 4.4 | 60.1 |
| July | | | Mean | 39.3 | | Mean | 17.6 | Mean | 56.9 |
| | | | SD | 7.2 | | SD | 2.2 | SD | 7.9 |
| August | 3758 | Ad. F | 29 | 32.2 | 26.8 | 67.8 | 15.6 | 5.9 | 47.8 |
| | 4188 | Ad. M | 23 | 21.6 | 21.6 | 78.4 | 12.5 | 7.9 | 34.1 |
| | 8375 | Ad. M | 25 | 43.5 | 34.9 | 56.5 | 19.6 | 8.9 | 63.1 |
| August | | | Mean | 32.4 | | Mean | 15.9 | Mean | 48.3 |
| | | | SD | 11.0 | | SD | 3.6 | SD | 14.5 |

Table 10. Abundance estimates corrected for availability bias.

a) Beluga

| Stratum | $\hat{N}_G$ | $\hat{N}$ |
|---|---|---|
| 1 | 64 (1.03) | 64 (1.03) |
| 2 | 222 (0.95) | 222 (0.95) |
| 3 | 569 (0.67) | 848 (0.58) |
| 4 | | |
| 5 | 325 (0.53) | 370 (0.52) |
| 6 | | |
| 7 | 133 (1.00) | 133 (1.00) |
| 8 | 88 (0.82) | 223 (0.88) |
| 9 | 105 (0.86) | 148 (0.91) |
| 10 | | |
| Total | 1505 (0.36) | 2008 (0.34) |

b) Narwhal

| Stratum | $\hat{N}_G$ | $\hat{N}$ |
|---|---|---|
| 1 | | |
| 2 | 720 (0.59) | 720 (0.59) |
| 3 | 908 (0.51) | 1 029 (0.57) |
| 4 | | |
| 5 | 756 (0.39) | 984 (0.38) |
| 6 | 737 (0.59) | 1 305 (0.56) |
| 7 | 270 (0.99) | 355 (0.98) |
| 8 | 1 430 (0.46) | 1 855 (0.48) |
| 9 | 924 (0.41) | 4 429 (0.50) |
| 10 | | |
| Total | 5 715 (0.26) | 10 677 (0.29) |

c) Walrus

The expected group size for walrus on ice is the average group size for those sightings. The numbers in the covered region have been corrected for both observer and availability bias.

| Habitat | Numbers in the covered region | | | Numbers in the study region | |
|---|---|---|---|---|---|
| | $\hat{N}_{Gc}$ | $\hat{E}[s]$ | $\hat{N}_c$ | $\hat{N}_{Gc}$ | $\hat{N}_c$ |
| On ice | 6.5 (0.30) | 1.80 (0.72) | 11.7 (0.78) | | |
| In water | 59.5 (0.33) | 1.35 (0.09) | 80.6 (0.35) | | |
| Total | 66.0 (0.30) | | 92.3 (0.32) | 1 914 (0.30) | 2 676 (0.32) |

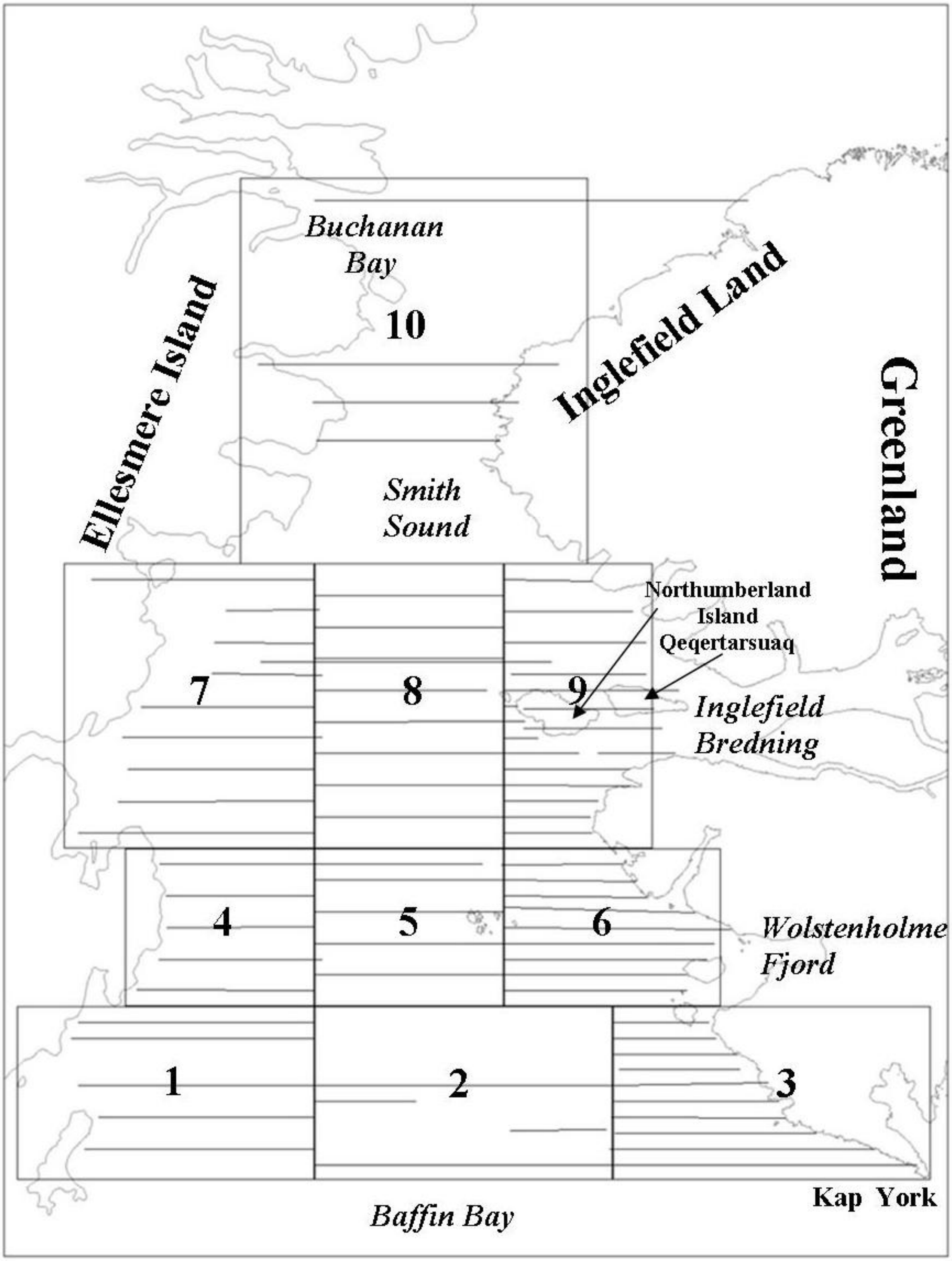


Fig. 1. Transect lines and strata covered in the North Water during the survey in May 2009.

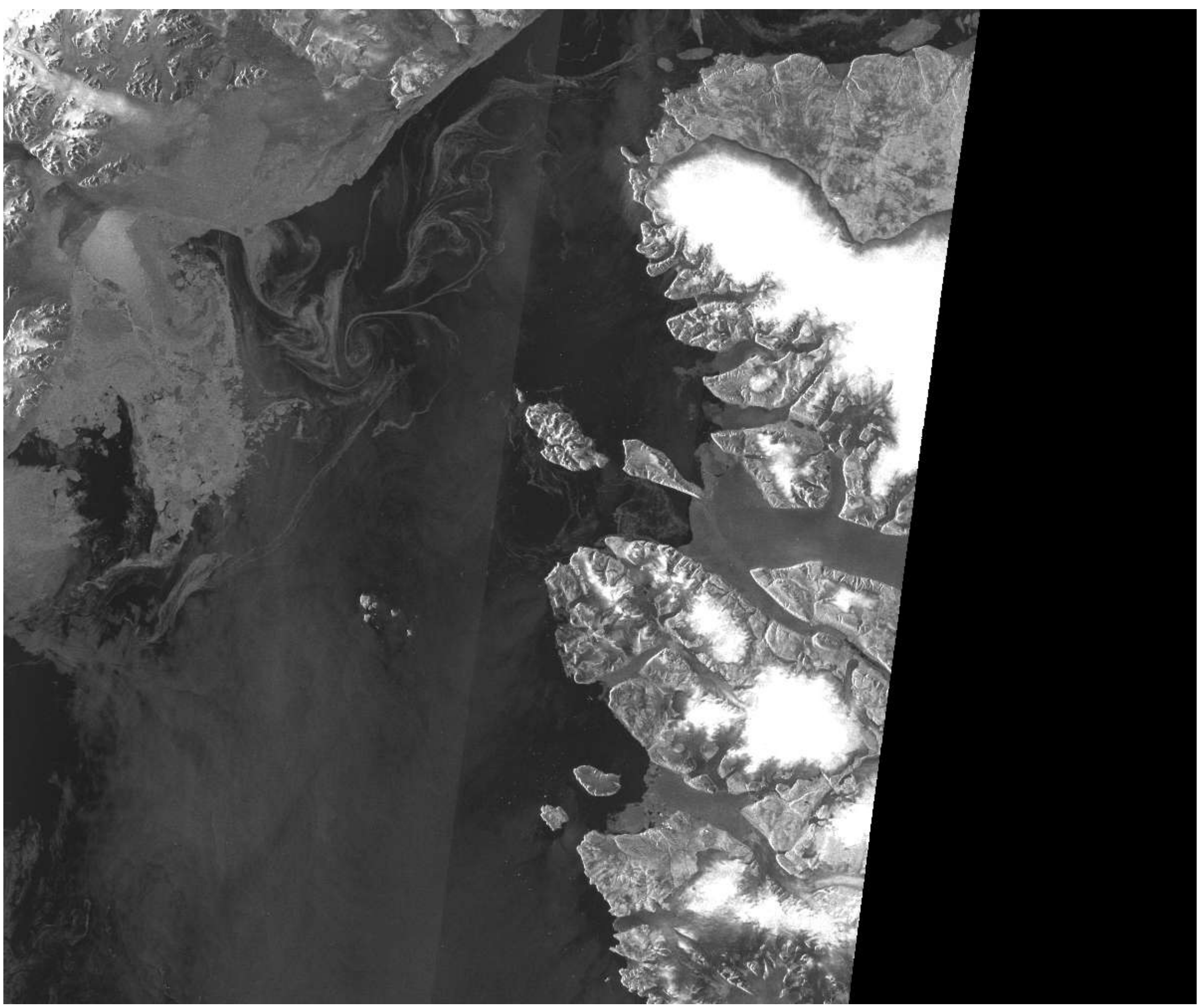

Fig. 2. Ice conditions in the North Water on 15 May 2009.


Walrus by pod size
4 (2)
2 (6)
1 (18)

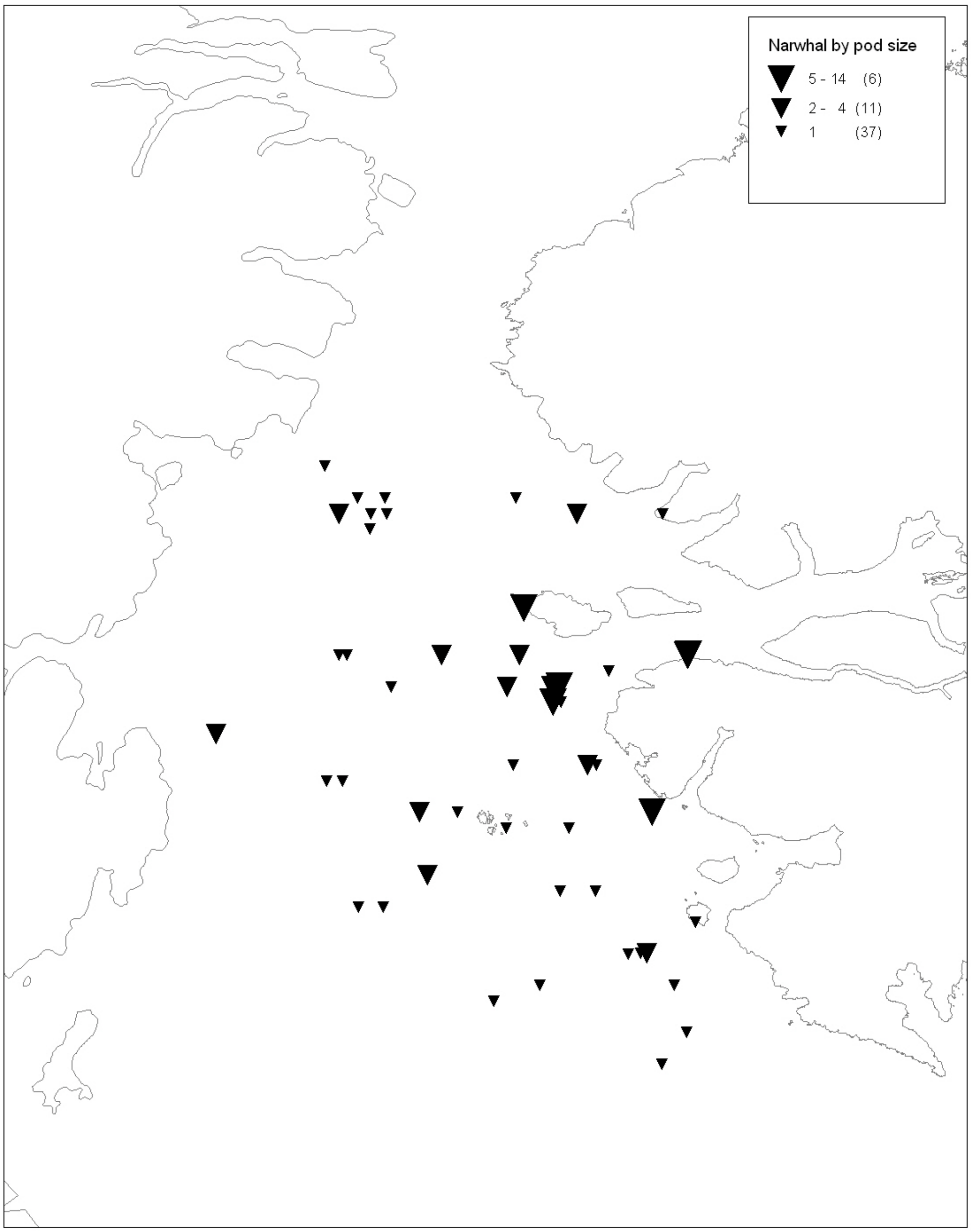


Fig. 3. Observations of walruses during the aerial survey of the North Water in May 2009.


Fig. 4. Observations of narwhals during the aerial survey of the North Water in May 2009.

Fig. 5. Observations of belugas during the aerial survey of the North Water in May 2009.

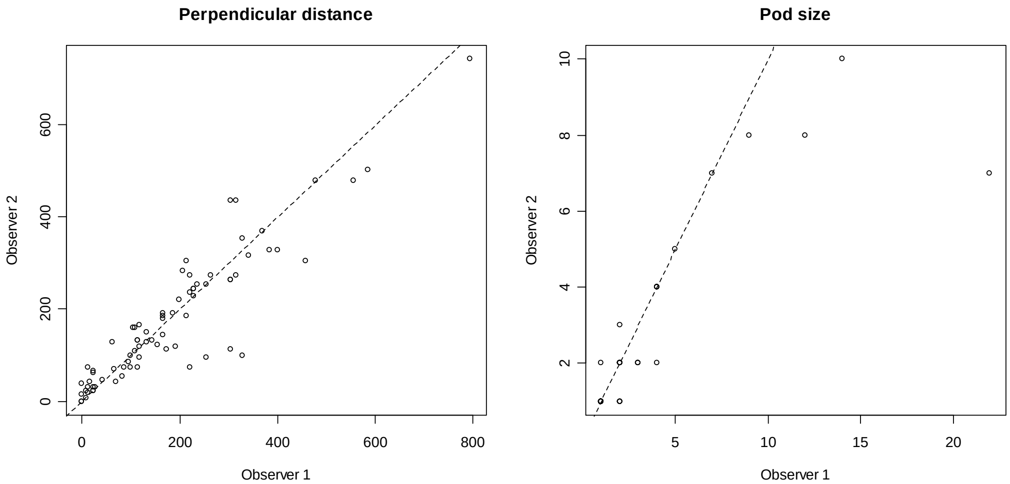


Fig. 6. Differences between duplicate sightings for perpendicular distance (m) and pod size. The dashed line indicates no difference.

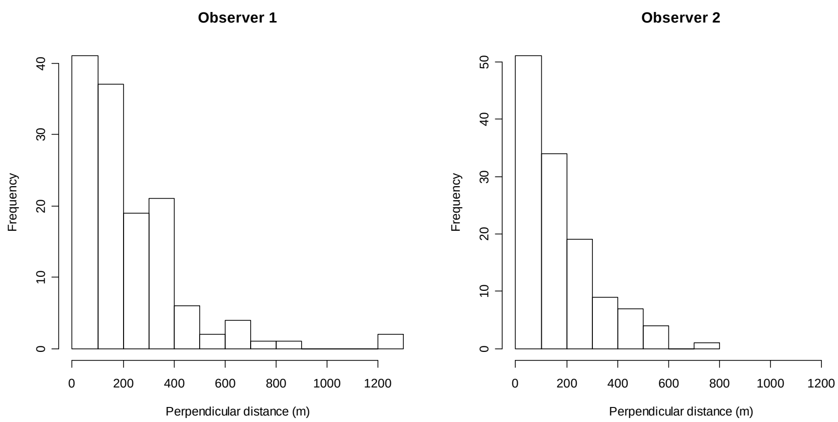


Fig. 7. Histograms of the perpendicular distance to all sightings detected by each observer.

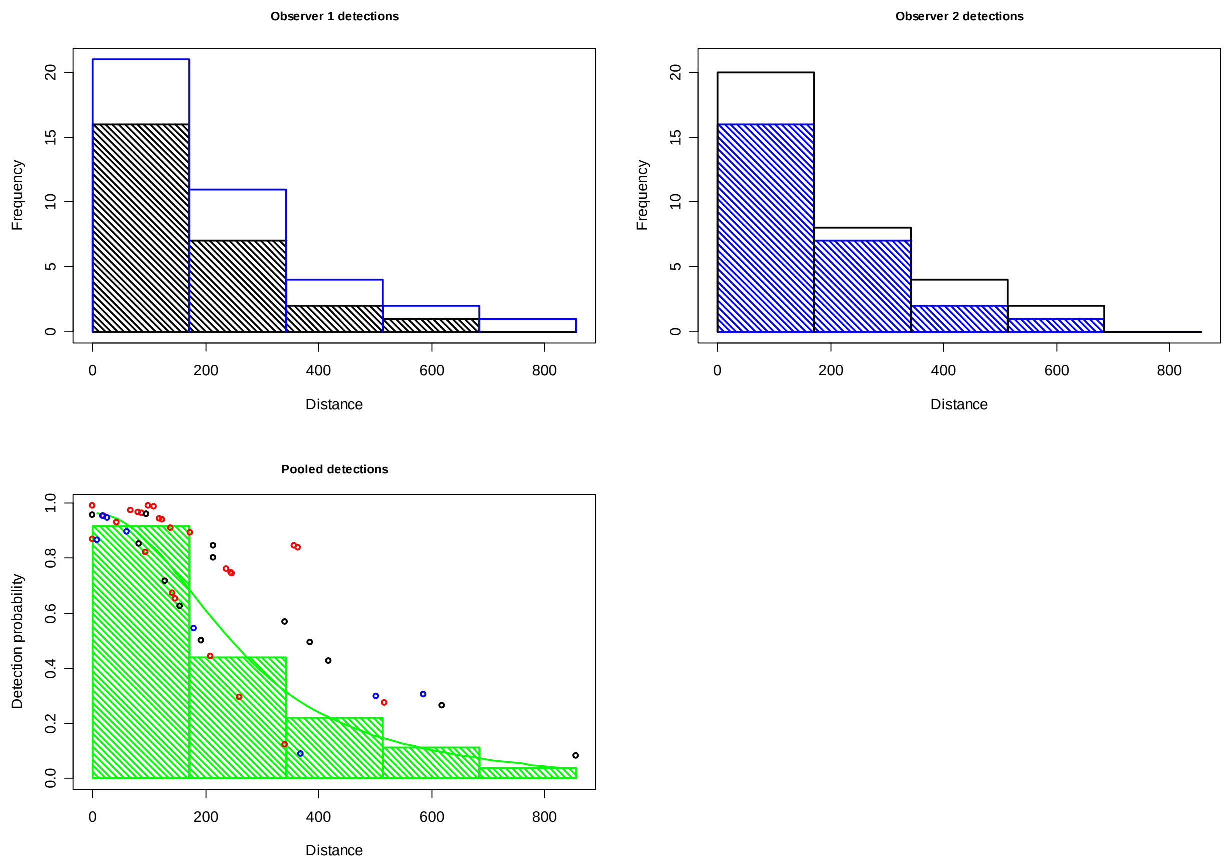


Fig. 5. Beluga. The top plots show the perpendicular distance distribution for each observer. The shaded regions indicate the number of sightings also seen by the other observer (duplicates). The bottom plot shows the perpendicular distance distribution for both observers with the chosen model superimposed. The dots indicate the values for each observer.

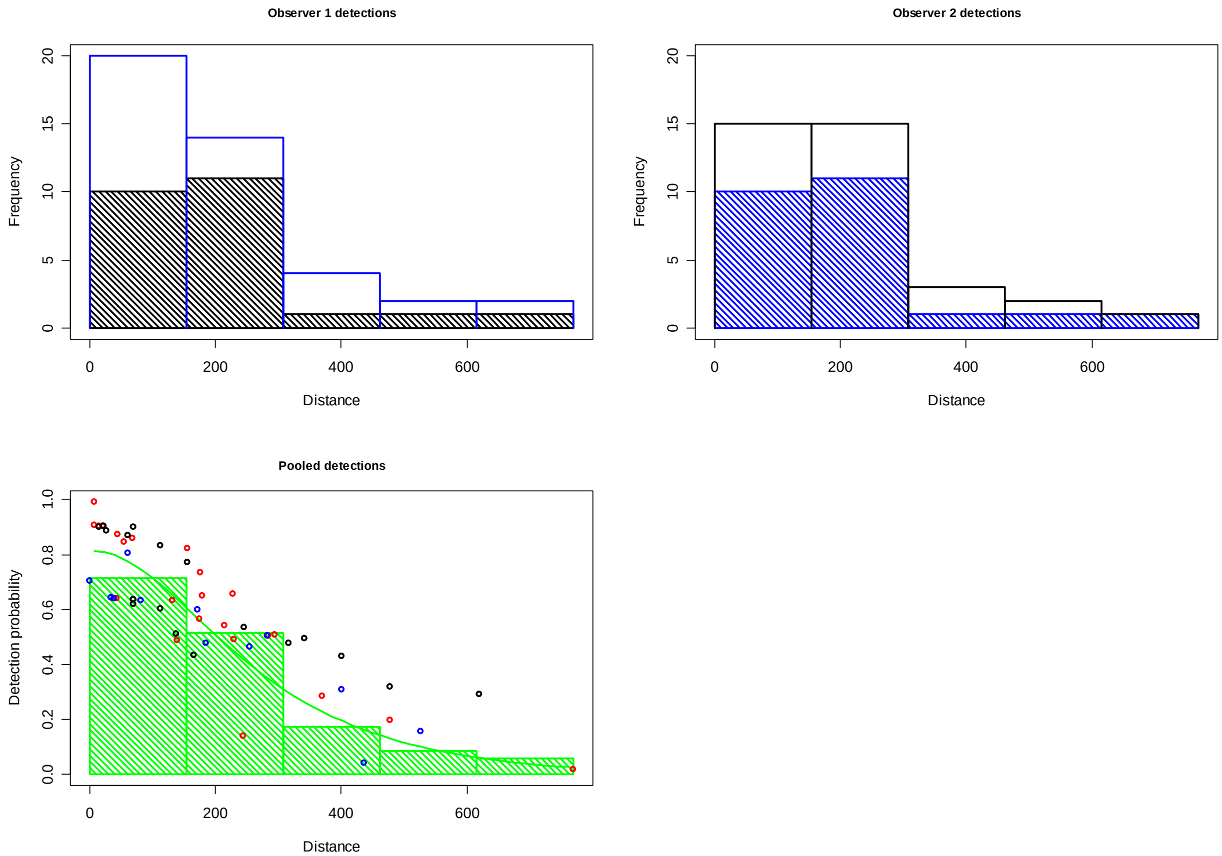


Fig. 6. Narwhal. The top plots show the perpendicular distance distribution for each observer. The shaded regions indicate the number of sightings also seen by the other observer (duplicates). The bottom plot shows the perpendicular distance distribution for both observers with the chosen model superimposed. The dots indicate the values for each observer.

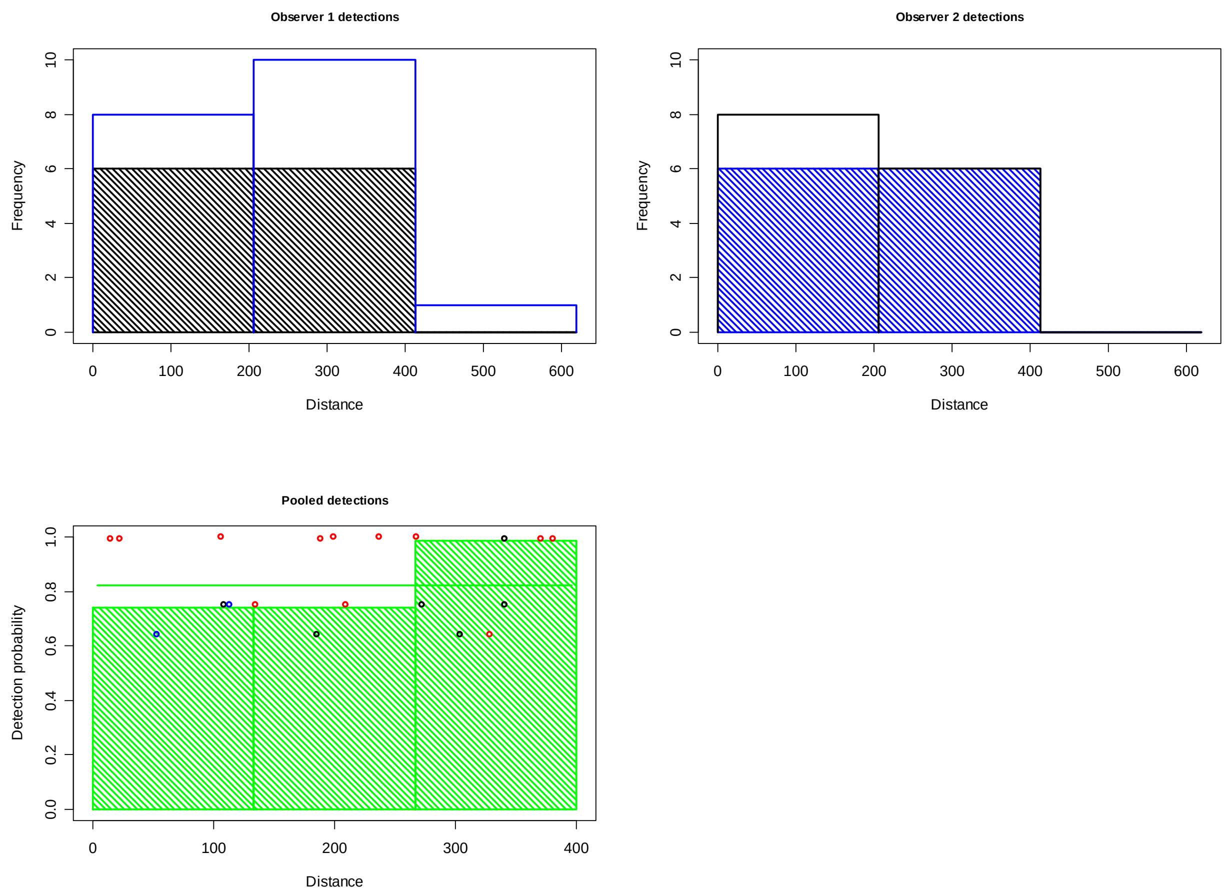


Fig. 7. Walrus. The top plots show the perpendicular distance distribution for each observer. The shaded regions indicate the number of sightings also seen by the other observer (duplicates). The bottom plot shows the perpendicular distance distribution for both observers with the chosen model superimposed. The dots indicate the values for each observer.