Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2016/037

Central and Arctic Region

Estimate of Cumberland Sound beluga (*Delphinapterus leucas*) population size from the 2014 visual and photographic aerial survey

Marianne Marcoux, Brent G. Young, Natalie C. Asselin, Cortney A. Watt, J. Blair Dunn, and Steven H. Ferguson

Fisheries and Oceans Canada
501 University Crescent
Winnipeg, Manitoba, R3T 2N6

April 2016 (Erratum: October 2016)

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Marcoux, M., Young, B.G., Asselin, N.C., Watt, C A., Dunn, J.B., and Ferguson, S.H. 2016. Estimate of Cumberland Sound beluga (*Delphinapterus leucas*) population size from the 2014 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/037. iv + 19 p. (Erratum: October 2016)

TABLE OF CONTENTS

ABSTRACT

Belugas (*Delphinapterus leucas*) in Cumberland Sound are a genetically distinct population in the Canadian eastern Arctic. They have been designated as threatened by the Committee on the Status of Endangered Wildlife in Canada due to a possible decline in abundance. To provide an update to the 2009 population estimate an aerial survey was conducted in August 2014. The 2014 survey had two components; a photographic survey of Clearwater Fiord (a small inlet in the northwest corner of Cumberland Sound), and a visual survey of the northern and western parts of Cumberland Sound. The photographic survey completely covered Clearwater Fiord four times as this is known to be an area where belugas aggregate in the summer months. The survey of the northern part of Cumberland Sound was completed twice, whereas the survey of the western part of Cumberland Sound was completed once. Different correction factors for availability bias were calculated according to the presumed depth at which belugas could be seen from the aircraft and on photos. The corrected estimate for Clearwater Fiord was 603 [coefficient of variance (CV) = 0.076, 95% confidence interval (CI) = 519–699], while the estimate for the northern part of Cumberland Sound was 548 (CV = 0.445, 95% CI = 240–1256). No belugas were seen in the western part of Cumberland Sound. This resulted in a total population abundance of 1151 (CV = 0.214, 95% CI = 760–1744) belugas.

Abondance de la population de béluga (*Delphinapterus leucas*) de la baie Cumberland Sound obtenue à partir de relevés visuels et photographiques lors du survol de 2014

RÉSUMÉ

La population de bélugas (*Delphinapterus leucas*) de la baie de Cumberland est une population distincte et a été désignée comme menacée selon le Comité sur la situation des espèces en péril du Canada. Nous avons estimé l'abondance de la population de bélugas de la baie de Cumberland par survol aériens durant le mois d'août 2014. Le survol comprenait deux parties : un relevé aérien photographique du fjord Clearwater et un relevé visuel de la partie nord et la partie ouest de la baie de Cumberland. Le relevé photographique offrait une couverture complète du fjord Clearwater et a été complété quatre fois. Le relevé visuel de la partie nord de la baie de Cumberland a été complété deux fois alors que le relevé de la partie ouest a été complété une fois. Nous avons aussi calculé des facteurs de correction pour les bélugas qui ne peuvent pas être vus par les observateurs des survols ou sur les photos. Le nombre estimé de belugas dans le fjord Clearwater, corrigé pour les individus submergés non-visibles, était de 603 [coefficient de variation (CV) = 0,076, intervalle de confiance de 95% (IC 95%) = 519–699]. L'estimation corrigée pour les bélugas de la partie nord de la baie de Cumberland était 548 (CV = 0,445, IC 95% = 240–1256). Aucun béluga n'a été vu dans la partie ouest de la baie de Cumberland. Le nombre total corrigé de bélugas de la population de la baie de Cumberland est estimé à 1151 (CV = 0,214, IC 95% = 760–1744).

INTRODUCTION

Belugas (*Delphinapterus leucas*) in Cumberland Sound are a separate population from other populations in the Canadian eastern Arctic based on genetic evidence (de March et al. 2002; de March et al. 2004). According to traditional knowledge, there might be as many as three different types of belugas that visit Cumberland Sound year-round (Kilabuk 1998). In the summer, belugas from the Cumberland Sound population aggregate in Clearwater Fiord located in the northwest corner of their annual range (Figure 1) (Richard and Stewart 2009).

Commercial whaling between 1868 and 1939 resulted in a depleted abundance of belugas in the Cumberland Sound stock (Mitchell and Reeves 1981). The intensive commercial whaling likely ended because of a significant reduction in beluga abundance, probably less than 1000 individuals in the 1970s (Brodie et al. 1981). Aerial surveys and cliff observations between 1979 and 1984 estimated between 400 and 600 individuals at the surface (Richard and Orr 1986). More recent aerial surveys, conducted in 1990, 1999, and 2009, estimated population numbers of approximately 1000, 2000, and 800 individuals, respectively (Richard 2013). In comparison, according to hunting records, the population in 1923 was estimated at over 5,000 individuals (Mitchell and Reeves 1981). Due to this decrease, the Cumberland Sound beluga population was designated as Threatened by the Committee on the Status of Endangered Wildlife in Canada in 2004 (COSEWIC 2004).

In addition to past exploitation by commercial whaling, the beluga population in Cumberland Sound is also the subject of subsistence harvests by local Inuit. Since the early 1980s, the harvest has been managed under a quota system (Richard and Pike 1993). To effectively manage this population, an up-to-date abundance estimate is necessary. However, the most recent attempts at abundance estimation have been largely unsuccessful. A recently attempted aerial survey in 2005 was not completed due to inclement weather conditions, while large confidence intervals make the 2009 abundance estimate unreliable (Richard 2013).

The objective of this study is to provide an updated abundance estimate of belugas in Cumberland Sound. To achieve this objective, visual and photographic aerial surveys were conducted in Cumberland Sound in August 2014. A reliable estimate of the current population level will contribute to the long-term monitoring of the recovery of this population, and will inform management by providing information necessary for determining a recommended harvest level.

METHODS

STUDY AREA

The aerial survey was designed to cover the August range of belugas in Cumberland Sound. Inuit knowledge has identified Clearwater Fiord as an important area for belugas, particularly in July and early August during calving (Kilabuk 1998). Additional belugas can be found on the west side of Cumberland Sound (Kilabuk 1998). Using data from 14 belugas instrumented with satellite-linked transmitters, Richard and Stewart (2009) estimated an August home range for Cumberland Sound belugas for which the 95% kernel distribution is contained within Clearwater Fiord. Similarly, previous August aerial surveys have found the highest densities of belugas within Clearwater Fiord and a few scattered sightings in other areas (Richard 2013). Consistent with these earlier findings, and to facilitate comparisons with previous aerial surveys, all areas surveyed in 2009 (Richard 2013) were included in the study area (Figure 1). Lastly, consultation with the Pangnirtung Hunters and Trappers Organisation (May and August 2014) helped to confirm that the area covered by the survey corresponded to the August range of the Cumberland Sound beluga population.

The study area (Figure 1) was divided into three strata:

(1) Clearwater Fiord,

(2) North Stratum and

(3) West Stratum.

A complete coverage photographic survey was conducted in the Clearwater Fiord Stratum and visual line-transect surveys were conducted in the North and West Strata. The North Stratum survey consisted of 18 parallel transects, spaced 5 km apart, with a north-south orientation, while the West Stratum survey consisted of 17 parallel transects, spaced 10 km apart, with an east-west orientation. The surveys were designed using Distance 6.0 (Thomas et al. 2010).

VISUAL SURVEY METHODS

Surveys were flown in a de Havilland Twin Otter 300 between 3 August and 11 August 2014 (Table 1). Visual transects were flown at a target altitude of 1,000 ft (305 m) and a ground speed of 100 knots (185 km/hr). Two observers were seated on each side of the aircraft, using bubble windows to observe belugas and bowhead whales. Sightings were recorded on Sony PCM-D50 audio recorders, and included species, group sizes, and the declination angles (measured with a clinometer) of the sightings. The two observers on the same side of the aircraft were isolated from one another, both visually and acoustically, to ensure independence of observations. One observer on each side of the aircraft was responsible for recording weather and observation conditions such as Beaufort Sea State, glare from the sun (intensity, location, and amount), fog density, and cloud cover.

PHOTOGRAPHIC SURVEY METHODS

Photographic transects of Clearwater Fiord were flown at a target altitude of 2,000 ft (610 m) and a target speed of 100 knots (185 km/h). Complete photographic coverage of the Clearwater Fiord study area was achieved using a Nikon D800 camera, equipped with a 25 mm lens, mounted at the rear of the aircraft, directed straight down, with the longest side perpendicular to the track line. The camera was connected to a GPS unit (to geo-reference photographs) and a laptop computer (to control exposure settings and the interval between photos, and to save photos to the computer’s hard drive). The altitude of the aircraft when the photographs were taken was also recorded. At the target altitude of 2,000 ft, the ground area covered by each photograph was 857.4 m x 585.2 m, resulting in 20% sidelap between photos taken on adjacent transects. At the target speed and altitude, an interval of 9 seconds results in 20% endlap between consecutive photos along each transect. However, variations in speed, altitude, and pitch of the aircraft resulted in the need to use a shorter photographic interval of 7 or 8 seconds. When possible, surveys of Clearwater Fiord were flown to coincide with high tide, which provides better water clarity than low tide (Table 1).

VISUAL SURVEY ANALYSIS

Visual surveys did not result in sufficient beluga sightings to adequately assess observer-bias through mark-recapture methods (Buckland et al. 2004), or to account for decreased detection probability away from the track line using distance analysis (Figure 2; Thomas et al. 2010). Instead, the total count of belugas observed within a 500 m (w) strip on each side of the aircraft was used to estimate the near-surface abundance. The strip began at 100 m from the track line as the area directly below the aircraft is not visible to observers (Figure 2). The right cut-off of the strip, at 600 m, was evaluated by fitting a hazard-rate function with a simple polynomial adjustment to the detection data and corresponded to the width of the shoulder (Figure 2).

Duplicate sightings between the front and the rear observers of each side were identified by looking at the difference in detection time between sightings (less than 5 sec) and in detection angle (equal or less than 10 degrees). This duplicate matching procedure is similar to methods used in recent surveys (see table 1 in Pike and Doniol-Valcroze 2015). Given the small number of detections (see RESULTS section), duplicates were easily identified.

We used standard methods for strip transects for clustered animals. Briefly, k is the number of lines and n_i is the number of groups detected at the surface for each line i which has a length of l_i. $E(s)$ is the expected cluster size.

The probability density function of the perpendicular distances of beluga groups near the surface was estimated using the uniform function:

$$f(y) = \frac{1}{w} = 0.002$$

The encounter rate was calculated using

$$E(n) = n/L$$

where $n = \sum_{i=1}^{k} n_i$ is the total number of clusters detected near or at the surface and $L = \sum_{i=1}^{k} l_i$ is the total survey effort. The variance of the cluster encounter rate was calculated following equation 3 in Fewster et al. (2009):

$$var\left(\frac{n}{L}\right) = \frac{k}{L^2(k-1)} \sum_{i=1}^{k} l_i^2 \left(\frac{n_i}{l_i} - \frac{n}{L}\right)^2$$

The density of belugas near or at the surface, $\widehat{D}$, was estimated using:

$$\widehat{D} = \frac{E(n) \cdot f(0) \cdot E(s)}{2L}$$

The total estimate of belugas near or at the surface is then

$$\widehat{N}_{sur} = \widehat{D} \cdot A$$

where A is the total area covered by the survey.

This near-surface estimate was then corrected to account for diving whales which were not available to be observed (see AVAILABILITY BIAS CALCULATION section).

$$\widehat{N} = \widehat{N}_{sur} \times C_a$$

where C_a is the availability bias correction factor.

The total variance was calculated following the delta method (Buckland et al. 2001):

$$var(\widehat{N}) = \widehat{N}^2 \times \left\{\frac{var(n/L)}{(n/L)^2} + \frac{var[E(s)]}{[E(s)]^2} + \frac{var(C_a)}{{C_a}^2}\right\}$$

The coefficient of variation, $cv(\widehat{N})$, was calculated by dividing the standard error by the estimated abundance, *N*.

The mean number of beluga $\widehat{N}^*$ for the two repeats of the survey was calculated by an average weighted by effort (total length of transect lines).

The variance of the mean estimate was also weighted by effort as follows:

$$var(\widehat{N}^*) = \frac{L_1^2 var(\widehat{N}_1) + L_2^2 var(\widehat{N}_2)}{(L_1 + L_2)^2}$$

Confidence intervals were calculated assuming a log-normal distribution as suggested in Buckland (2001).

PHOTOGRAPHIC ANALYSIS

Photographs were examined for belugas on a high resolution monitor (24 in screen). Photographs were georeferenced and examined in ArcMap 10.1 (Esri). When needed, the contrast and the brightness of the photographs were adjusted in Adobe Photoshop (Adobe Systems). One reader read all the photos of Clearwater Fiord. The reader did not have experience with reading marine mammal aerial photographs prior to this analysis. Before starting to record any sightings, photographs with belugas from previous surveys and from the current survey were examined so that the reader could familiarize herself with the shape and size of the target. Once a first reading of all the photos from the four surveys of the stratum was complete, the photos from the first survey of the stratum were re-read without consultation of previous results. All frames for which the first and second reading counts differed were read a third time. In addition, all photographs with questionable detections were read a second time.

On some photos, a proportion of the photo was masked by sun glare, which made it impossible for the reader to evaluate if belugas were present. Therefore, the percentage of the photo covered by sun glare was noted for each photo. In addition, the percentage of sun glare in the first 500 photos was re-evaluated by the same reader for consistency. Similarly, each photo was evaluated to detect the presence of murky water. Murky water was defined as water in which it was impossible to detect belugas that were not at the surface (within 1 meter, Figure 5).

The altitude of the aircraft was recorded for each photograph. The area covered by each photograph, A_{photo}, was calculated as follows:

$$A_{photo} = length * width$$

where $length = \frac{Altitude}{F_s * L_s}$ and $width = \frac{Altitude}{F_s * W_s}$

F_s is the focal length of the camera sensor (25 mm), L_s is the length of the camera sensor (35.9 mm) and W_s is the width of the camera sensor (24 mm). Each photograph had GPS coordinates associated with it and could be projected on a map. The area of water on the photograph A_{water} was calculated by overlaying a high resolution contour map of the coast with the photographs and cropping the portion that was on land:

$$A_{water} = A - Land$$

The area of each photograph was corrected for the portion with glare (A_{glare}) where the reader could not detect animals following:

$$A_{glare} = A_{water} \times (1 - G)$$

where G is the proportion of each photo that was masked by sun glare.

The total area of photographs examined to detect belugas was calculated as the sum of A_{glare} of all the photographs of each survey.

The area covered by each survey (A_{study}) was determined by calculating the area of a polygon made of all the photographs merged together, and removing the areas that were on land.

The number of belugas detected near or at the surface in each photograph was corrected for the instantaneous availability bias (see AVAILABILITY BIAS CALCULATION section).

$$\widehat{N}_{cor} = C_a \times \widehat{N}_{surface}$$

where $\widehat{N}_{surface}$ is the total number of belugas detected near or at the surface. Lastly, the total number of belugas for each survey was calculated by

$$\widehat{N}_{tot} = A_{survey} \times \sum_{i=1}^{I} \frac{\widehat{N}_{cor_i}}{A_{glare_i}}$$

where I is the number of photographs per survey.

The total variance of the estimate from the photographic survey was calculated following the delta method (Buckland et al. 2001):

$$var(\widehat{N}) = \widehat{N}^2 \times \left\{ \frac{var(\widehat{N}_{tot})}{(\widehat{N}_{tot})^2} + \frac{var(C_a)}{{C_a}^2} \right\}$$

Where $var(\widehat{N}_{tot})$ is the variance of the number of beluga detections in the photos and $var(C_a)$ is the variance of the availability correction factor.

The mean number of belugas $\widehat{N}^*$ for the four photographic surveys was calculated by using average weighted by effort (area covered by the survey)

Lastly, the variance of the mean estimate calculated as follows:

$$var(\widehat{N}^*) = \frac{\sum_{i=1}^{4} A_i^2 \, var(\widehat{N}_i)}{\left(\sum_{i=1}^{4} A_i\right)^2}$$

where A_i is the area of the i^{th} repeat of the photographic survey.

AVAILABILITY BIAS CALCULATION

Near surface abundance estimates were corrected to account for belugas that were diving and were unavailable to be seen by observers (availability bias). Satellite linked time depth recorder tags (SPLASH tags, Wildlife Computers) were deployed on belugas to transmit daily information on their location and diving behaviour. Three female belugas were tagged in Cumberland Sound (66°16’18 N, 67°05’90 W), near the community of Pangnirtung, Nunavut, in July of 2006 (n = 1), and August of 2007 (n = 2; Table 2). Methods for beluga capture and tagging have previously been published (Orr et al. 2001). In short, belugas were captured in nets set perpendicular to the shore from a small island along the migratory route of the belugas on a daily basis, as weather permitted. Once caught, two inflatable zodiac boats with at least three passengers would boat out to the net, pull the beluga to the surface and hold it between the two boats for instrumentation with a satellite-linked transmitter. The belugas were held in place with a hoop net over the head, 3-4 straps along their body and a rubberized rope around the tail stock, which were all tied to loops on the boats. Three 10 mm nylon pins were then placed through the dorsal ridge and the tag was anchored to the pins with high-grade stainless steel wires looped around specially designed washers. This process was approved by the Freshwater Institute Animal Care Committee (FWI-ACC-06-07-010, FWI-ACC-07-08-038, FWI-ACC-08-09-008).

Location data were obtained from the ARGOS system (CLS America). Data were transmitted every two hours but were summarized into four 6-hour histograms, referred to by their starting time, i.e., 2:00, 8:00, 14:00 and 20:00 local time). Each 6-hour histogram was linked to a geographical position, which was the most accurate location estimate collected in the previous 24-hours. For each 6-hour period, all tags provided the time the beluga spent at different depths, combined in bins. All tags were programmed with the same depth bins to calculate the proportion of time belugas spent in the 0–1, 0–2, 0–4, and 0–6 m depth bins with a resolution of 0.5 m (Wildlife Computers). Adult belugas are visible at depths up to 5 m in clear water, while juveniles are visible up to 2 m (Richard et al. 1994). However, in murky waters, such as those in Clearwater Fiord, previous studies have assumed belugas cannot be seen at depths greater than 2 m (Richard 2013). After visual inspection of the photos (see above), it was concluded that in some photos, the water was sufficiently murky in Clearwater Fiord that belugas could only be seen if they were at the surface (0–1 m). Location information from the tags was categorized based on the accuracy of the transmission, varying from poor to good: class A and B, and 0 to 3. Class A and B provide no location information, Class 0 includes an error range of >1500 m, class 1, 500–1500 m, class 2, 250–500 m and class 3, < 250 m (Wildlife Computers). Many of the locations associated with the dive information were of lower class, but the time at depth information is still accurate and valuable. Given the small sample sizes of whales and dive data, particularly for August when the survey was conducted, we did not want to disregard valuable dive data due to inaccurate locations (e.g., on land). Therefore, we used all available daytime (transmissions at 8:00 and 14:00) dive information, and defined locations north of 66°20'N as Clearwater Fiord (Figure 1). We used dive information at these locations to calculate an availability bias correction for strata surveyed in Clearwater Fiord. The dive information associated with locations south of this latitude was used to determine an availability bias for the North and West strata.

We calculated weighted averages to determine the average time all belugas spent in the 0–1, 0–2, 0–3, 0–4, and 0–6 m bins during the day. Weighted averages took the average for each beluga, weighted it based on the number of 6-hour blocks collected, and calculated an overall average. Standard errors were calculated using a weighted standard deviation divided by the square root of the number of belugas used in each calculation. Since belugas can be seen to depths of 5 m when the water is clear (Richard et al. 1994), but tags were not programmed to collect information from 0–5 m, an average of the availability bias for 0–4 m and 0–6 m was used to estimate the 0–5 m availability bias. The larger of the two standard errors was used as the standard error for the interpolated 0–5 m bin (Richard 2013). The availability bias correction factor, C_a, was calculated by:

$$C_a = 1/proportion\ spent\ in\ depth\ bin$$

POPULATION ABUNDANCE ESTIMATE

The estimate of the total population abundance was obtained by adding the average estimate from the four repeats of the photographic survey of the Clearwater Fiord stratum and of the two repeats of the north stratum. The total variance was the sum of the variance from the two strata.

RESULTS

VISUAL SURVEY

Two visual surveys of the North Stratum and one visual survey of the West Stratum were completed. Surveys of the North Stratum were flown on 3–4 August and on 10 August, while the survey of the West Stratum was flown on 5 August (Table 1). After inspection of the detection function curve (Figure 2), the observations were left-truncated at 100 m and right-truncated at 600 m.

A total of 78 (10 groups) and 8 (5 groups) belugas were observed on the first and second surveys of the North Stratum, respectively (Figure 3). The estimated number of belugas near the surface was 389 (CV= 0.48) for the first survey of the North Stratum and 41 (CV= 0.57) for the second survey. No belugas were observed on the survey of the West Stratum. Abundance estimates from the three visual surveys are shown in Table 4.

PHOTOGRAPHIC SURVEY

Complete photographic coverage of Clearwater Fiord was possible on four different days. On average, 21.5 % of the photos had murky water and 15% of photos had glare (Table 5). The photos overlapped by an average of 52.7% (Figure 4). Abundance estimates from the four photographic surveys are shown in Table 5.

ESTIMATES CORRECTED FOR AVAILABILITY BIAS

For the visual survey of the North stratum, we used the correction factor based on the weighted averages for the 0–5 m depth bin which results in $C_a = 2.54$ (CV = 0.050). This resulted in estimates of 987[1] (CV = 0.48) and 103 (CV = 0.57), for the first and second surveys of the North Stratum, respectively. The weighted average of the two surveys was 548 (CV = 0.45) (Table 4).

For the photographic survey of Clearwater Fiord, when the water was very murky (e.g., Figure 5B), we used the correction factor based on the 0–1 m dive depth bin during daylight hours for the month of August ($C_a = 4.46$, CV = 0.117). For photos where the water was less murky (e.g., Figure 5A), we used the correction factor based on 0–2 m depth bin ($C_a = 2.06$, CV = 0.056). For the total variance calculation of the photographic population estimate, we used a weighted average variance of the 0–1 m and the 0–2 m dive depth bin where the weight was attributed according to the proportion of photos with murky water (for the 0–1 m bin) and non-murky water (for the 0–2 m bin). Averaging the four photographic surveys resulted in a corrected abundance estimate of 603 (CV = 0.076).

POPULATION ABUNDANCE ESTIMATE

Summing the averaged visual and photographic surveys resulted in a population estimate of 1151 (CV = 0.214, 95% CI = 761–1744, Table 6).

DISCUSSION

Belugas are a challenging marine mammal to count when at low population levels (e.g., Kingsley 1996; Gosselin et al. 2007; Richard 2013; Shelden et al. 2015). Three approaches are generally used to assess beluga abundance. The first approach is to fly airplanes with visual observers to count whales along transects and apply distance sampling methodology (e.g., Lowry et al. 2008). The second approach is to take photographic images or videos along transects to count whales (e.g., Kingsley 1996), while the third approach uses a combination of the two (e.g., Gosselin et al. 2014; Shelden et al. 2015). Visual surveys tend to have a wider strip transect width than photographic surveys because photographic surveys are limited by the angle of the camera lenses used. Given the larger strip width of visual surveys, the chance of

[1] Erratum October 2016 – 867 now reads 987

surveying larger beluga aggregations is higher in the visual compared to the photographic survey. However, it is more difficult to accurately assess the number of individuals in large aggregations in visual surveys since the observers only have a few seconds to count the whales. This is not an issue in photographic surveys. Due to this, we used a combination of both survey methods to gain a more accurate estimate of beluga abundance in Cumberland Sound.

The abundance estimates for Clearwater Fiord calculated for each of the four photographic surveys differed. We used an average of the four estimates to calculate the number of belugas in Clearwater Fiord. It is not clear if the difference in numbers between the surveys is due to communal behaviour of belugas affecting their collective availability at the surface or movement of animals out of Clearwater Fiord. Beluga counts from surveys can vary greatly between days, especially, when population size is small (e.g., Gosselin et al. 2007; Gosselin et al. 2014). Some studies have found a negative effect of Beaufort Sea state on beluga counts (e.g., DeMaster et al. 2001; Gosselin et al. 2007) but it does not seem to have affected the counts in our study. By conducting multiple repeats of the survey and averaging the count, our estimate is consistent with previous approaches (Gosselin et al. 2014) and provides a more precautionary approach towards estimating population size and trends.

Aerial surveys need to be corrected for whales that cannot be seen by observers because they are too deep underwater (availability bias). Ideally, data from whales equipped with satellite transmitters during the period of the survey should be used to calculate the availability correction factor. Unfortunately, transmitters were not deployed during this study, but we did have dive information from a past tagging study that we analyzed to provide estimates of availability bias. Therefore, we assumed that belugas tagged in 2006–2007 behave similarly to belugas in 2014. In addition, we assumed that the three females tagged were representative of the entire Cumberland Sound population. Re-analysis of past or future tagging effort could investigate patterns in dive behaviour among tagged whales temporally in relation to river outflow, sea state, and other environmental factors. This might help to explain common variation in counts among whales that may indicate socially-linked dive patterns that relate to time at surface and provide more accurate correction estimates. In our study, we used an averaged correction factor and averaged counts. This approach should take into consideration some of the temporal variation in dive behaviour. However, we recognize that communal behaviour was not investigated and therefore could not be accounted for.

In this study, we used different correction factors for availability bias depending on water clarity. The North and West strata are believed to have clear water while Clearwater Fiord has more murky water. Therefore, we assumed we could see belugas within 5 meters of the surface in the clear waters of the North and West strata (Richard et al. 1994; Richard 2013). For the Clearwater Fiord stratum, we assumed that belugas could be seen within 2 meters of the surface when the water was relatively clear and within 1 meter of the surface when the water was very murky. Therefore, for the Clearwater Fiord photographic survey, correction factors were specific to each photo. This approach allowed for more precise correction according to concurrent environmental conditions.

For visual surveys, it was assumed that observers detected all the animals from 100 m to 600 m of the track line. However, some animals are missed by observers causing a “perception bias” (Marsh and Sinclair 1989). We did not correct for perception bias because of the overall low number of groups sighted during visual surveys as well as the low number of re-sightings of belugas between the front and the back observers (re-sighting rate of only 14%). We assumed that the detection probability at the track line, $g(0) = 1$ while it was likely that $g(0) < 1$. This assumption leads to a more conservative estimate of population abundance. Most of the visual observations were made in fiords where the aircraft might not have been perfectly levelled. Some observations might have been missed because of the inclination of the aircraft.

We used an instantaneous availability bias correction for both the photographic and visual surveys. It was not possible to correct for the time belugas were in view during the visual surveys given the small number of detections and the lack of detailed dive cycle data for belugas of the Cumberland Sound population. In visual surveys, the observers have a few seconds to detect whales at the surface and the use of an instantaneous availability bias might over-estimate the abundance. However, the use of instantaneous availability bias is appropriate for the photographic survey.

The population estimate derived from a combination of visual and photographic surveys was 1,151 whales (CV= 0.214). This estimate is not significantly different from the past estimate of 788 (CV= 0.513) in 2009 (Richard 2013). A risk-based model incorporating the 2014 estimate with past estimates should be developed to assess population trend and calculate a sustainable harvest level for the community of Pangnirtung.

ACKNOWLEDGEMENTS

We would like to thank the community of Pangnirtung, the Pangnirtung Hunters and Trappers Organization, the Polar Continental Shelf Program, the Nunavut Implementation Fund (DFO), Species at Risk (DFO), and the Nunavut Wildlife Management Board for their support of this project. Thanks to Leah Montsion who analysed the photos with diligence and enthusiasm, a task that can be difficult and tedious.

REFERENCES CITED

Brodie, P.F., Parsons, J.L., and Sergeant, D.E. 1981. Present status of the white whale (*Delphinapterus leucas*) in Cumberland Sound, Baffin Island. Rep. Int. Whal. Comm. 31: 579–582.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., and Thomas, L. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, USA, Oxford.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, D.L., and Thomas, L. 2004. Advanced distance sampling. Oxford University Press, New York.

COSEWIC. 2004. COSEWIC assessment and update status report on the beluga whale *Delphinapterus leucas* in Canada. Committee on the Status of Endangered Wildlife in Canada.

de March, B.G.E., Maiers, L.D., and Friesen, M.K. 2002. An overview of genetic relationships of Canadian and adjacent populations of belugas (Delphinapterus leucas) with emphasis on Baffin Bay and Canadian eastern Arctic populations. NAMMCO Sci. Publ. 4: 17–38. doi:10.7557/3.2835.

de March, B.G.E., Stern, G., and Innes, S. 2004. The combined use of organochlorine contaminant profiles and molecular genetics for stock discrimination of white whales (*Delphinapterus leucas*) hunted in three communities on southeast Baffin Island. J. Cetacean Res. Manage. 6: 241–250.

DeMaster, D.P., Lowry, L.F., Frost, K.J., and Bengston, R.A. 2001. The effect of sea state on estimates of abundance for beluga whales (*Delphinapterus leucas*) in Norton Sound, Alaska. Fish. Bull. 99: 197–201.

Fewster, R.M., Buckland, S.T., Burnham, K.P., Borchers, D.L., Jupp, P.E., Laake, J.L., and Thomas, L. 2009. Estimating the encounter rate variance in distance sampling. Biometrics 65: 225–236. doi:10.1111/j.1541-0420.2008.01018.x.

Gosselin, J.-F., Hammill, M.O., and Lesage, V. 2007. Comparison of photographic and visual abundance indices of belugas in the St. Lawrence Estuary in 2003 and 2005. DFO Can. Sci. Advis. Secr. Res. Doc. 2007/025. ii + 27 p.

Gosselin, J.-F., Hammill, M.O., and Mosnier, A. 2014. Summer abundance indices of St. Lawrence Estuary beluga (*Delphinapterus leucas*) from a photographic survey in 2009 and 28 line transect surveys from 2001 to 2009. DFO Can. Sci. Advis. Secr. Res. Doc. 2014/021. iv + 51 p.

Kilabuk, P. 1998. Final report on a study of Inuit knowledge of southeast Baffin beluga. Rep. prep. for the Southeast Beluga Management Committee. Nunavut Wildlife Management Board. 74 p. (available from the DFO library).

Kingsley, M.C.S. 1996. Population index estimate for the belugas of the St Lawrence in 1995. Can. Tech. Rep. Fish. Aquat. Sci. 2117. vi + 38 p.

Lowry, L.F., Frost, K.J., Zerbini, A., DeMaster, D., and Reeves, R.R. 2008. Trend in aerial counts of beluga1 or white whales (*Delphinapterus leucas*) in Bristol Bay, Alaska, 1993–2005. J. Cetacean Res. Manage. 10: 201–207.

Marsh, H., and Sinclair, D.F. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. J. Wildl. Manage. 53: 1017–1024.

Mitchell, E., and Reeves, R.R. 1981. Catch history and cumulative catch estimates of initial population size of cetaceans in the Eastern Canadian Arctic. Rep. Int. Whal. Comm. 31: 645–682.

Orr, J.R., Joe, R., and Evic, D. 2001. Capturing and Handling of White Whales (*Delphinapterus leucas*) in the Canadian Arctic for Instrumentation and Release. Arctic 54: 299–304.

Pike, D., and Doniol-Valcroze, T. 2015. Identification of duplicate sightings from the 2013 double-platform High Arctic Cetacean Survey. DFO Can. Sci. Advis. Secr. Res. Doc. 2015/034. v + 22 p.

Richard, P.R. 2013. Size and trend of the Cumberland Sound beluga whale population, 1990 to 2009. DFO Can. Sci. Advis. Secr. Res. Doc. 2012/159. iii + 28 p.

Richard, P.R., and Pike, D.G. 1993. Small whale co-management in the Eastern Canadian Arctic: A case history and analysis. Arctic 46: 138–143.

Richard, P., and Orr, J.R. 1986. A review of the status and harvest of white whales (*Delphinapterus leucas*) in the Cumberland Sound area, Baffin Island. DFO Can. Tech. Rep. Fish. Aquat. Sci. 1447.

Richard, P., and Stewart, D.B. 2009. Information relevant to the identification of critical habitat for Cumberland Sound belugas (*Delphinapterus leucas*). DFO Can. Sci. Advis. Secr. Res. Doc. 2008/085: iv + 24 p.

Richard, P., Weaver, P., Dueck, L., and Baber, D. 1994. Distribution and numbers of Canadian High Arctic narwhals (*Monodon monoceros*) in August 1984. Meddelelser Om Grønl. Biosci. 39: 41–50.

Shelden, K.E.W., Sims, C.L., Vate Brattström, L., Goetz, K.T., and Hobbs, R.C. 2015. Aerial surveys of beluga whales (*Delphinapterus leucas*) in Cook Inlet, Alaska, June 2014. AFSC Processed Rep 2015–03: 55 p.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A., and Burnham, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. J. Appl. Ecol. 47: 5–14. doi:10.1111/j.1365-2664.2009.01737.x.

APPENDIX. TABLES AND FIGURES

Table 1. Summary of field work.

Date	Time (EDT)	Stratum	Type	Survey	Transects	Time of closest high tide	Beaufort Sea State
03-Aug-2014	8:15-11:56	Clearwater Fiord	Photo	1	1 - 26	10:46	2
03-Aug-2014	13:21-17:44	North Stratum 1	Visual	1	1 - 11		3
04-Aug-2014	8:10-11:02	North Stratum 1	Visual	1	12 - 18		2
04-Aug-2014	12:47-16:11	Clearwater Fiord	Photo	2	1 - 26	11:42	2
05-Aug-2014	7:57-12:38	West Stratum	Visual	1	1 - 10		0-1
05-Aug-2014	14:04-18:26	West Stratum	Visual	1	11 - 18		1-2
10-Aug-2014	7:55-11:38	Clearwater Fiord	Photo	3	1 - 26	5:44	1
10-Aug-2014	12:55-17:21	North Stratum 2	Visual	2	1 - 11		1
10-Aug-2014	17:51-20:08	North Stratum 2	Visual	2	12 - 18		2
11-Aug-2014	8:38-12:17	Clearwater Fiord	Photo	4	1 - 26	6:30	1-2

Table 2. Deployment date, sex, approximate length for belugas equipped with satellite-linked transmitters in 2006 and 2007 in Cumberland Sound. N is the number of 6-hour blocks included in the analysis.

Deployment Date	Sex	Tag Number	Length (m)	N (North and West Strata)	N (Clearwater Fiord)
07-18-2006	F	57594	-	58	2
07-12-2007	F	57602	350	38	9
07-12-2007	F	37023	315	58	4

Table 3. The weighted average percent of time (±SE) spent by three belugas in each of the depth bins for August in Clearwater Fiord and the North and West Strata. N is the number of 6-hour blocks included in the analysis. Bold indicates the average percent of time in the bins used to calculate the instantaneous availability bias for the 2014 survey.

Whale Location	N	Average % time at 0-1 m ± SE	Average % time at 0-2 m ± SE	Average % time at 0-4 m ± SE	Average % time at 0-6 m ± SE	Interpolated average % time at 0-5 m ± SE
Clearwater Fiord	154	**22.41 ± 2.63**	**48.59 ± 2.71**	69.25 ± 0.40	72.48 ± 0.38	70.87 ± 0.40
North and West Strata	15	14.79 ± 2.56	28.60 ± 2.83	37.51 ± 2.04	41.30 ± 1.66	**39.41 ± 2.04**

Table 4. Abundance estimates from visual survey.

Stratum	Area (km²)	Effort (km)	Area covered (%)	# transects	# unique sightings	# individuals	Surface abundance	$CV_{surface}$ (%)	C_a	CV_{Ca} (%)	Abundance (corrected)	CV (%)	95% CI
North Stratum Aug 03 2014	3299	662	20.1	18	10	78	389	48.1	2.54	5.18	987[‡‡]	48.4	
North Stratum Aug 10 2014	3299	651	19.7	18	5	8	41	56.8	2.54	5.18	103	57.1	
West stratum	8377	829	9.9	17	0	0	0				0		
Average											**548***	**44.5**[†]	**240–1,256**

***Weighted by effort (length of survey)

[†]Calculated based on the average variance weight by effort (length of survey)

[‡‡] Erratum October 2016 – 867 now reads 987

Table 5. Abundance estimates from photographic survey.

Date	# photos	Area covered by photos (km^2)	Sum of photo areas without water (km^2)	Total # belugas in all photos	% photo with murky	% of photos with glare	N corrected for glare and availability bias	CV(%)
3-Aug-2014	534	121.1	204.4	447	19.3	54.7	687	6.83
4-Aug-2014	613	121.9	240.7	598	21.5	1.3	959	7.22
10-Aug-2014	618	122.4	241.8	307	21.8	3.9	405	6.97
11-Aug-2014	609	123.2	241.4	285	23.3	0	371	6.98
Averages	596	122.2	232.1	409	21.5	15.0	**603***	**7.62**†

*****Weighted by effort (sum of the areas of photos)

†Calculated based on the average variance weight by effort (sum of the areas of photos)

Table 6. Total population abundance estimates.

	Estimate	CV (%)	95% confidence interval
Visual (North stratum)	548	44.5	240–1256
Photographic (Clearwater Fiord)	603	7.62	519–699
TOTAL	**1,151**	**21.4**	**760–1,744**

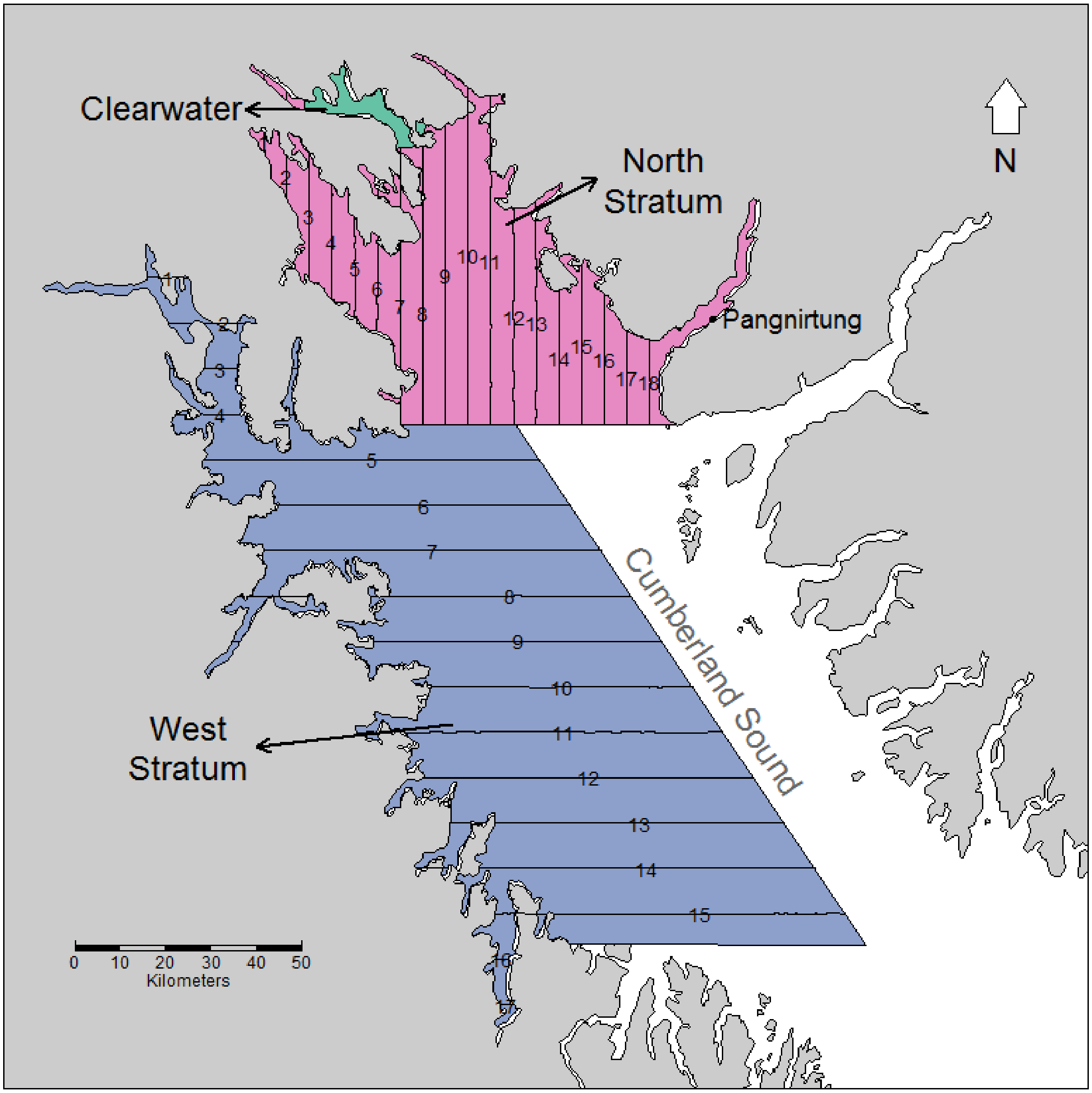

Figure 1. Map of study area showing the three strata and the transect lines for the visual survey.

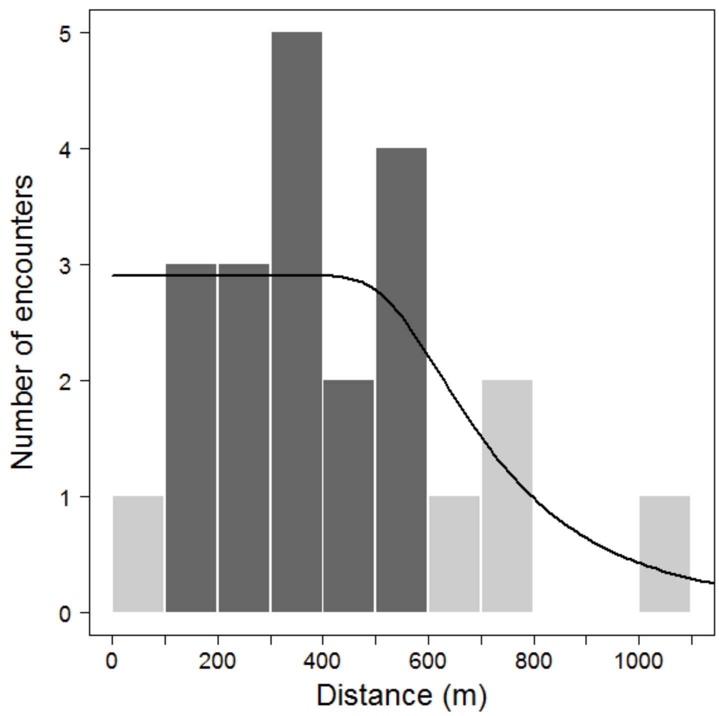

Figure 2. Histogram of perpendicular distances of beluga sightings made during visual aerial surveys of the Cumberland Sound beluga population, August 2014. Line shows fitted hazard-rate function with a simple polynomial adjustment. Dark grey bars show distances included in the analysis after left- and right-truncation.

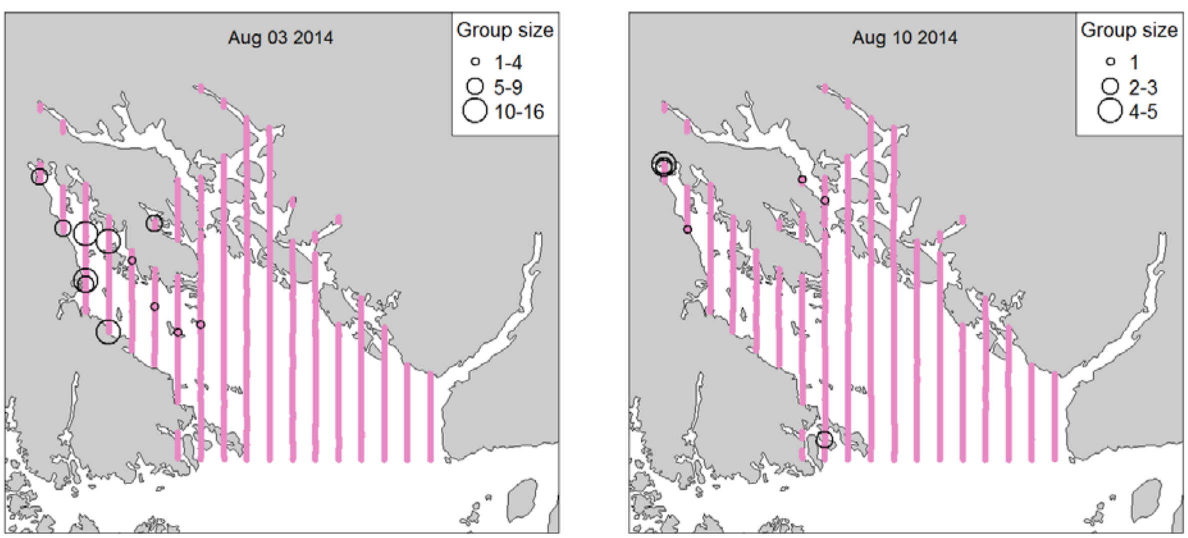

Figure 3. Maps of transects for the North Stratum survey 1 and 2 with beluga group sightings.

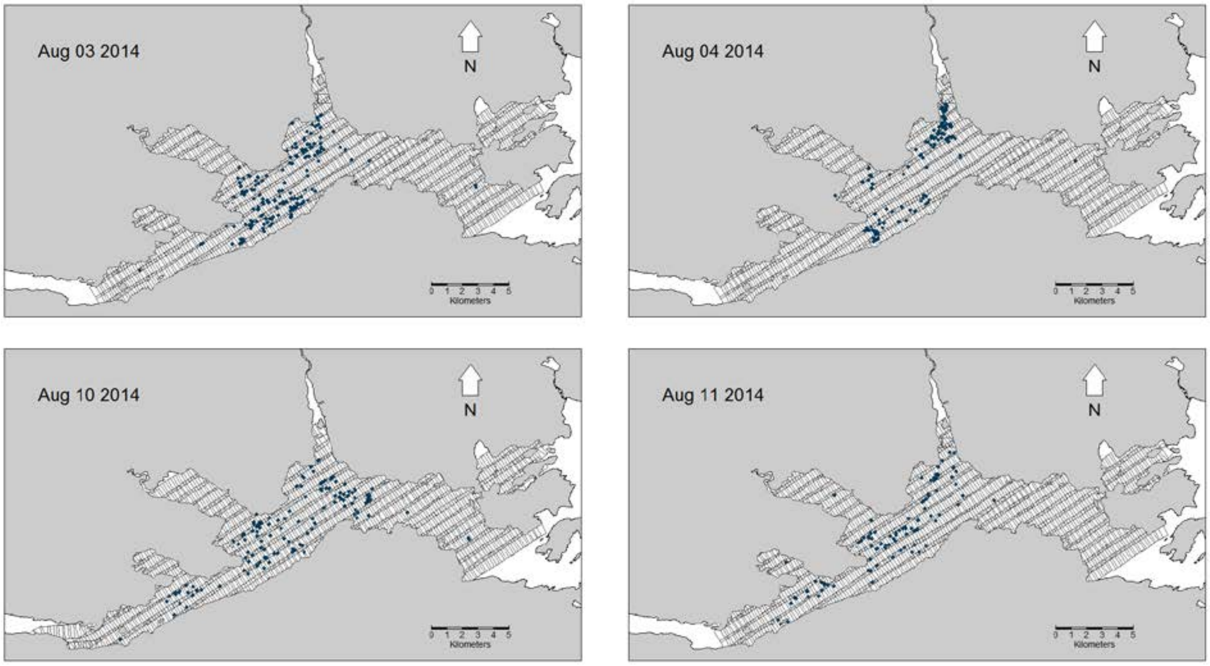

Figure 4. Map of the four photographic surveys of Clearwater Fiord showing beluga sightings and the footprint of each photograph.

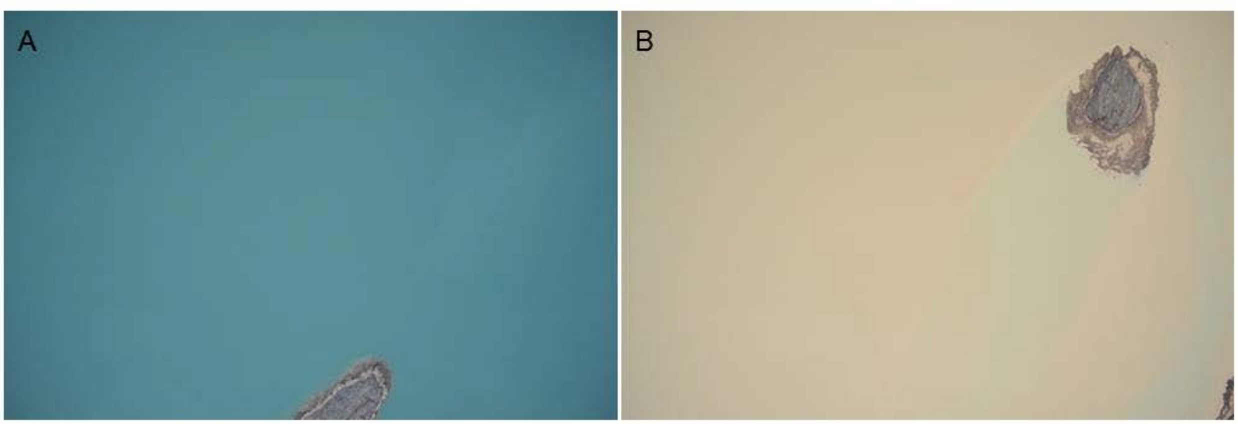

Figure 5. Examples of aerial photographs of Clearwater Fiord with A) clear water and B) murky water.