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Survey Index of the Northern Hudson Bay Narwhals, August 2008

Indice du relevé du stock de narvals du nord de la baie d'Hudson – août 2008

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ABSTRACT

The Northern Hudson Bay narwhal stock size was previously indexed by aerial photographic surveys of the summering aggregation area in 1984 and 2000. A new survey was done in August of 2008 to add to the series and allow a full assessment of the stock. The plan was to use a tandem of digital medium format cameras but one broke down so a single digital medium format camera was used instead. A first survey was completed on 21-22 August with a target altitude of 914 m, but cloud cover limited survey altitude in some parts to 549 - 762 m. Another survey was flown at higher altitude the next day, ahead of a storm, but the resulting photographic resolution did not allow adequate detection of narwhals. No survey could be flown in the rest of the aircraft charter period, due to poor weather. The estimate obtained from the 21-22 August survey was 610 narwhals (95% CI: 377 - 988). This survey index is less than half of those obtained in 1984 and 2000. Several factors which may have affected the estimate are discussed. Nevertheless the low index comes after a period of more intense hunting so it is also plausible that the population has declined. A full assessment using population indices and the catch history should be done to inform future co-management of this stock.

RÉSUMÉ

En 1984 et en 2000, on avait établi un indice du stock de narvals du nord de la baie d’Hudson à l’aide de relevés par photographies aériennes de la zone de concentration d’été. Une nouvelle campagne d'évaluation a été réalisée en août 2008 pour continuer la série et permettre un recensement complet du stock. On avait prévu d'utiliser deux appareils photo numériques de format moyen en tandem, mais l'un d'eux est tombé en panne, c'est pourquoi on n'en a utilisé qu'un seul. Un premier relevé a été effectué les 21 et 22 août à une altitude cible de 914 m, mais la couverture nuageuse a limité l'altitude de relevé à 549-762 m à certains endroits. Un autre relevé aérien a été effectué à une altitude supérieure le lendemain, avant une tempête, mais la résolution de ces photographies n'a pas permis de détecter correctement les narvals. Il n'a pas été possible d'effectuer d'autres relevés photographiques aériens durant la période d'affrètement de l'aéronef en raison des mauvaises conditions météorologiques. L'estimation obtenue à partir des relevés des 21 et 22 août a été de 610 narvals (IC de 95 % : 377-988). Le nombre de narvals comptabilisé est plus de deux fois inférieur au nombre obtenu en 1984 et en 2000. Plusieurs facteurs pouvant avoir faussé cette estimation font l'objet de discussions. Toutefois, ce nombre peu élevé a été relevé après une période de chasse plus intensive, il est donc également vraisemblable que la population ait diminué. Il faudrait procéder à une évaluation complète en utilisant les indices de population et l'historique des captures afin de pouvoir orienter la cogestion de ce stock à l'avenir.

INTRODUCTION

The Northern Hudson Bay narwhal population is an isolated narwhal population which has a distinct geographic distribution compared to other Canadian and Greenland population (Richard 1991, Westdal 2008) and can be distinguished from them by genetic and contaminant methods (de March *et al.* 2003, de March and Stern 2003). In summer, the population is most aggregated in Repulse Bay, Frozen Strait, and Lyon Inlet (Fig. 1) but pods of narwhals are seen on occasion further south along the Kivalliq coast (Strong 1988, Richard 1991, Gonzalez 2001). The population is hunted by hunters of the Kivalliq region of Nunavut. Most animals are taken by residents of the hamlet of Repulse Bay, which neighbours the summering aggregation area of the population but hunters from other hamlets also travel to Repulse Bay to hunt narwhals. Quotas have been in place for some time in all Kivalliq communities but they were not based on an assessment of the sustainability of the catch.

Previously, indices of its population size had been obtained from aerial photographic surveys conducted in the early 1980s (Richard 1991) and in 2000 (Bourassa 2003). Given the paucity of population indices available for this stock, and length of time between them, an assessment of the Total Allowable Harvest was made based on the 2000 survey of the stock using the Potential Biological Removal Method (Richard 2008). A minimum of three survey indices is required for a comprehensive assessment.

Towards that end, the purpose of this project was to conduct a new survey in August of 2008 in northern Hudson Bay and obtain an estimate of the numbers of narwhals in the areas of aggregation.

METHODS

In the past, surveys were flown over areas described by local people as the summer aggregation area of narwhals (Richard 1991, Gonzalez 2001, Bourassa 2003). For this survey, kernel home range estimates derived from data from narwhals instrumented and tracked over the month of August 2006 and 2007 were used to delimit the survey area (Westdal 2009; Fig. 2). The home range estimate was fairly similar to the coverage of previous surveys, and the 2008 survey area needed only to be expanded 15 km eastward into Foxe Channel.

In addition, we planned to conduct the survey after another DFO team had instrumented eight or more narwhals with satellite-linked time-depth recorders, so that we could benefit from contemporaneous tracking results to determine if the survey covered the range of these animals. The tagging field crew tried for a period of ten days in early August but was unsuccessful because, unusually, narwhals stayed clear of Repulse Bay where the live-capture camp was set up. The crew studied the option of moving the camp further east where live-capture could have been done, but heavy pack ice prohibited travel to the location and they had to abandon their tagging efforts.

The survey crew arrived in Repulse Bay on 17 August, as the tagging crew returned from the field. The plane was grounded by bad weather until 21 August. A clearing in the weather allowed a first survey on 21-22 August. With forecasts of reasonable weather for two consecutive days, we chose to fly a systematic survey design with transects spaced 7 nautical miles (13 km) apart (Fig. 3). This coverage of the survey area could be flown in one and half days.

In the past, aerial large-format film cameras had been used to conduct surveys but the cost of running such a system has become prohibitively expensive and we were never sure that the film had been correctly exposed and developed until well after the survey. Following the successful surveys of Heide-Jørgensen (2004) in northwest Greenland, we planned to conduct this survey with the same aerial medium format digital cameras (Rolleimetrik cameras with Phase One digital 36.9 mm x 24.6 mm sensor) and a Super Angulon 41 mm lens. The initial plan was to fly transects at 2,000 ft (610 m) with the two cameras at an angle to cover both sides of the track line. Unfortunately, one of the lenses broke down prior to the survey during testing, and could not be repaired or replaced until well after the survey period. Consequently, we used the other digital camera alone. It was oriented at an oblique angle of 24.2° facing north to minimize glare off the water. To increase camera coverage of that camera, in an effort to partially compensate for the loss of the second camera, we planned to fly the survey at 3000 ft. Unfortunately, the cloud cover did not allow us to do so throughout the survey areas, so the survey plane was forced to operate below clouds at altitudes varying between 1,800 ft (549 m) in the northwestern part of the survey, 2,200-2,500 ft (671-762m) in the southern part and 3,000 ft (914 m) in the northeastern part (Fig. 3).

On the next day, 23 August, cloud height had increased and the weather forecast was good for at least 12 hours. Consequently, on that day, we flew the whole area using a systematic design with north-south transects spaced 11 nm (20 km) apart. To compensate for the wide transect placement, we took a chance and flew the survey at 4,000 ft (1,219 m) to increase photo coverage. We were both aware that narwhal image size would be quite small and probably hard to read, but fearful that this might be our last chance to survey, as several low pressure masses were gathering to the west.

No other survey could be done after that one because the weather worsened for several days until we reached the end of our air charter contract. The plane had to be returned to Iqaluit base on 28 August.

Aerial photographs were read by two image readers independently. Both had moderate experience with aerial photo sightings. They were instructed to record any sighting of whales, marine mammals or even animal-like sightings that they could not clearly identify. The species, number of individual and x-y coordinates of the sightings were recorded in a database for later inspection. Those sightings were then reviewed by two experienced readers (P. Richard, J. Orr) and species and numbers were confirmed.

The area imaged by each image was calculated using methods of Grenzdörffer *et al.* (2008). The viewing half angle β_y of the lens (*i.e.,* the angle from vertical to outer edge of lens), and the tilt angle α_y and altitude h_g of the camera (Fig. 4) define the distances (D) of the aircraft's path to the edges and center of the area imaged:

$$\begin{aligned} D_{min} &= h_g \tan(\alpha_y - \beta_y) \\ D_{avg} &= D_{max} - D_{min} \\ D_{max} &= h_g \tan(\alpha_y + \beta_y). \end{aligned} \qquad (1)$$

The altitude from the ground (or water surface in this case) converted to the units of the calculated distances.

Image scales (m) are calculated by the following sets of equations:

$$m_{min} = \frac{h_g \cos \beta_y}{f \cos(\alpha_y - \beta_y)}$$
$$m_{avg} = \frac{h_g}{f \cos \alpha_y}$$
$$m_{max} = \frac{h_g \cos \beta_y}{f \cos(\alpha_y + \beta_y)}. \quad (2)$$

where f is the focal length of the camera lens, converted to the same units as the altitude.

The 40 mm lens (actually calibrated to 41.0334 mm) and the 36.9 mm side dimensions (*d)* of the Phase One digital imaging CCD resulted in a viewing half-angle β_y of *arctan(d / 2f)* (Northey 1916 quoted in Wikipedia 2009) equal to 24.2°. The camera was also tilted at 24.2° resulting in the image footprint dimensions, for each altitude flown, shown in Table 1. Note that the distance of the inner edge of the footprint (D_{min}) is 0 because we set the tilt angle to equal the half-viewing angle.

The methods used to calculate the population indices are from Kingsley *et al.* (1985). The count of narwhals and image areas (Table 2) were summed over the images for each transect:

$$Y_i = \sum_{j=1}^{J_i} W_{ij} t_{ij}$$
$$X_i = \sum_{j=1}^{J_i} W_{ij} A_{ij}$$

where Y_i = is the *i* transect's total count, W_{ij} = transect spacing for *j*th interval on *i*th transect (in transect-widths), t_{ij} = narwhal counted in *j*th interval, J_i = number of intervals on *i*th transect, X_i = extrapolated total area of *i*th transect longitude, and A_{ij} = area of *j*th interval.

The mean density $\hat{R}$ is:

$$\hat{R} = \sum_{i=1}^{I} Y_i \Big/ \sum_{1}^{I} X_i$$

and the serial difference estimate of the variance ($S_2{}^2$) of the mean density is given by:

$$S_2{}^2 = \left\{ I \sum_{1}^{I-1} (d_i - d_{i+1})^2 \right\} \Big/ \left\{ 2 \cdot (I-1) \cdot (\Sigma X_i)^2 \right\}$$

where: $d_i = Y_i - \hat{R} X_i$ and I is the number of transects.

Confidence limits are calculated as in Buckland *et al.* (2001).

RESULTS

Estimates of near-surface narwhals for the 7 nm survey (21-22 August 2008) were obtained for two strata, containing contiguous water bodies. The two strata are more or less divided by Vansittart Island. The western stratum goes from Repulse Bay to Foxe Channel, and the eastern stratum from Lyon Inlet to Foxe Channel, including Gore Bay (Fig. 5). The results are similar, estimates summing to 645 narwhals at the water surface in the stratified case (Table 3) and equal to 610 in the non-stratified case (Table 4). Stratification did not improve the precision of the estimates, as shown by the large variances of the two-stratum estimates (CV = 37% and 108%), compared to the un-stratified estimate (CV = 30%).

As we had feared, narwhal image size made it too difficult to count narwhals in the 23 August photo survey flown at 1219 m and the results were not analyzed further.

DISCUSSION

The more precise estimate of surfaced narwhals is the un-stratified estimate of 610 (95% CI: 377-988). It is a much smaller index of the population than those obtained for the August photo surveys of 1984 and 2000, which numbered, respectively, 1,355 (95% CI: 910-2,100) (Richard 1991) and 1,778 (95% CI: 1,688-2,015) (Bourassa 2003). Several factors could have affected survey results.

The first hypothesized effect is that the number of sightings was reduced due to the heavier than usual pack ice in Frozen Strait (Fig. 6), where narwhals are known to aggregate based on past surveys and tracking studies (Richard 1991, Bourassa 2003, Westdal 2009). The type of pack ice, with small floes, makes detection of narwhals quite difficult. Sightings were more numerous in open water or loose ice than in the area with heavy pack. Nevertheless, several sightings were made in the portion of Frozen Strait with the heaviest pack ice (Figs 6 and 7) so it is not clear without further study how much ice cover affected visibility

The second hypothesized effect is that a portion of the population was not in the survey area during the surveys. Surveys conducted in 2000 did not find narwhals further east in Foxe Channel (Bourassa 2003). Tracking studies have shown that narwhals tagged in early August 2006 and 2007 remained within our survey area (Westdal 2009). In fact, the survey area was adjusted slightly based on those tracking results. The idea that there was a shift in distribution in August 2008 was suggested by the lack of narwhals in Repulse Bay prior to the survey, a fact decried by local hunters who are used to seeing many narwhals in the Bay at that time of year, often fairly close to the hamlet (Fig. 1). This hypothesis is supported by the lack of success of the tagging field crew in August 2008, who kept a 24-hr spotting-scope watch and saw no narwhals in the vicinity of their camp on the north shore of the Bay.

Killer whales have been observed preying on narwhals in northern Hudson Bay in recent years and hunters have suggested that their presence has affected the distribution of narwhals in the region (Gonzalez 2001, Westdal 2009). Killer whales were reportedly seen on 25 July 2008 in Hudson Strait near Ivujivik, Quebec (Steve Ferguson, DFO Winnipeg, pers. comm.). Repulse Bay people heard about the Ivujivik sighting and commented that the reason for the absence of narwhals was that those killer whales were holding the narwhals back in Hudson Strait (Jack Orr, DFO Winnipeg, pers. comm.). While that is a possible reason, there have been many killer whale sightings over the past decade in Hudson Bay and Strait and no reports of any large scale displacement of narwhals out of the Repulse Bay area. In fact, there were two killer whale sightings in the survey area in the summer of 2000 (Steve Ferguson, DFO Winnipeg, pers. comm.) but the August 2000 survey estimate was more than twice this one. In addition, killer whales were seen in Repulse Bay in the summers of 2005 and 2006 (Steve Ferguson, DFO Winnipeg, pers. comm.) but that did not affect the ability of the tagging crew to catch narwhals. In fact, it helped in August 2006 when narwhals came closer to land to avoid the killer whales (Jack Orr, DFO Winnipeg, pers. comm.). Despite the presence and predation by killer whales, the narwhals tagged in August 2005 and 2006 remained in the survey area (Westdal 2009). It therefore remains unclear to what extent killer whales influenced the distribution of narwhals in the survey area in August 2008 and how that affected this estimate of stock size.

A third hypothesized effect is that digital photos do not allow detection of narwhals as readily as large-format film. In the past, narwhal surveys were conducted using a large-format film camera, the cost of which has become prohibitively expensive. In addition, whether the film was correctly exposed could not be determined until it was developed, well after the survey was conducted. The plan here was to conduct the survey with two medium format digital cameras at an angle to cover both sides of the track line. Unfortunately, one of the camera lenses broke prior to the survey and could not be replaced. Consequently, a single digital camera was used. In this survey, following the breakdown of one camera lens, we tried to reach a compromise between survey altitude, to get a large image footprint, and target image size (i.e., the number of pixels which image the animals). The survey altitude was adjusted from the planned 2,000 ft or 610 m (image length = 34 pixels) to a target altitude of 3,000 ft or 914 m (image length = 22 pixels), due to the malfunction of one lens. This resolution is not a problem for detection of narwhals at the surface in open water but may have affected the detection of animals that were just below the surface or partially hidden by ice floes. This hypothesis cannot be verified without thorough experimentation. If this effect is in effect, the greater pack ice coverage of the survey area, especially in Frozen Strait may have affected the sightability of narwhals.

As one or more factors may have affected the results, it is not entirely clear if the 2008 survey was able to index the whole Northern Hudson Bay narwhal population. Nevertheless, the index of numbers (ie: near-surface estimate) is a small fraction of what it was in 1984 and 2000. Since 1998, communities hunting that narwhal stock have reported increasingly larger landed catches: a fivefold increase on average in recent years compared to the 1978-1998 (Fig. 8). Their summed landed catch is well above the recommended total allowable annual landed catch of 57 (DFO 2008). Repulse Bay is the community which reported the largest increase in landed catch. Its largest catch was in 1999 when a reported 166 narwhals were landed. Reports from other communities ranging from the Kivalliq coast to south Baffin Island also suggest an increase in take (Fig. 8, open circles).

Another factor which may also be contributing to population decline is increased killer whale predation. There has been a large increase in killer whale sightings in Hudson Bay and Strait in the 1990s and 2000s (Higdon and Ferguson 2009). As mentioned above, killer whales have been observed preying on narwhals in recent years (Gonzalez 2001, Westdal 2009). The intensity of predation on this narwhal population is presently unknown but it could be important.

The large increase in hunter catches and killer whale predation may therefore be responsible for the observed decline in the population index. A model of the population’s dynamics is needed to determine if this new survey index is likely given the catch history on the stock and past survey indices. It would also be advisable to conduct a new survey, preferably during a year with normal or low ice cover, to test whether the 2008 survey was in fact biased. Whether the bias question is resolved or not, an additional survey would also increase the precision of population dynamic parameter estimates. Such a survey would be more informative if done while Northern Hudson Bay narwhals are being tracked to determine if any narwhals leave the survey area prior to the survey.

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Table 1. Image footprint dimensions at different survey altitudes.

Altitude (ft)	Altitude (m)	D_{min} (m)	D_{max} (m)	$Width_{min}$ (m)	$Width_{max}$ (m)	Area (km^2)
1800	549	0	618	450	678	0.419
2200	671	0	756	550	829	0.626
2500	762	0	859	625	942	0.809
3000	914	0	1031	750	1130	1.165

Table 2. Narwhal counts and area covered by images per transect segments during 21-22 Aug. 2008 narwhal survey (see Fig. 3).

Date	AM/PM	Transect segment	Length (km)	Narwhal count	Area (km^2)
22-Aug-08	AM	T7-1-2	61.03	0	52.8
22-Aug-08	AM	T7-3-4	60.68	9	52.0
22-Aug-08	AM	T7-5-6	58.03	4	49.9
22-Aug-08	AM	T7-7-8	67.82	0	53.7
22-Aug-08	AM	T7-9-10a	42.18	0	36.1
22-Aug-08	AM	T7-9-10-b	23.69	0	21.4
22-Aug-08	AM	T7-11-12a	32.19	0	38.0
22-Aug-08	AM	T7-11-12-b	16.08	0	19.4
22-Aug-08	AM	T7-11-12-c	30.74	0	32.6
22-Aug-08	AM	T7-14-13a	24.97	1	20.1
22-Aug-08	AM	T7-14-13-b	3.60	0	2.5
21-Aug-08	AM	T7-15-16	89.50	10	103.5
21-Aug-08	AM	T7-17-18	91.54	20	110.0
21-Aug-08	AM	T7-19-20	83.12	3	97.0
21-Aug-08	AM	T7-21-22	72.56	0	89.0
21-Aug-08	AM	T7-23-24	56.88	0	69.6
21-Aug-08	PM	T7-26-25	13.21	0	21.0
21-Aug-08	PM	T7-27-28a	14.23	9	22.1
21-Aug-08	PM	T7-27-28b	17.94	0	28.0
21-Aug-08	PM	T7-30-29a	10.13	0	12.8
21-Aug-08	PM	T7-30-29b	55.06	0	75.7
21-Aug-08	PM	T7-32-31a	16.75	0	25.6
21-Aug-08	PM	T7-32-31b	26.47	0	44.3
21-Aug-08	PM	T7-32-31c	13.96	0	22.1
21-Aug-08	PM	T7-34-33	75.45	0	106.0
21-Aug-08	PM	T7-36-35	55.39	0	82.7
21-Aug-08	PM	T7-37-38	46.87	0	65.2
21-Aug-08	AM	T7-40-39	45.82	0	55.0

Table 3. Narwhal counts, area covered by images per transect and estimates for the stratified areas surveyed on 21-22 Aug. 2008.

Transect	West stratum count	West stratum area (km^2)	East stratum count	East stratum area (km^2)
1			0	21.0
2	0	52.8	9	50.1
3	9	52.0	0	88.5
4	4	49.9	0	92.0
5	0	53.7	0	106.0
6	0	57.4	0	82.7
7	0	90.0	0	55.0
8	1	22.6		
9	10	103.5		
10	20	110.0		
11	3	97.0		
12	0	89.0		
13	0	69.6		
Sum	**47**	**847.5**	**9**	**560.4**
N	**12**	**12**	**8**	**8**
Mean density	**0.055**		**0.016**	
Total Area	**10140**			**5190**
Estimate	**562**			**83**
SE density	**0.020**			**0.017**
SE Estimate	**207**			**90**
N_{min} (α 0.05)	**313**			**20**
N_{max} (α 0.05)	**1010**			**354**
CV	**37%**			**108%**

Table 4. Narwhal counts, area covered by images per transect and estimates for the un-stratified area surveyed on 21-22 Aug. 2008.

Transects	Narwhal count	Survey area (km^2)
1	0	21.0
2	9	102.9
3	9	140.5
4	4	141.9
5	0	159.6
6	0	140.1
7	0	155.2
8	1	77.6
9	10	103.5
10	20	110.0
11	3	97.0
12	0	89.0
13	0	69.6
Sum	**56**	**1407.9**
N	**13**	**13**
Total Area	**15330**	
Estimate	**610**	
SE $\hat{R}$	**0.012**	
SE N	**183**	
Nmin (α 0.05)	**377**	
Nmax (α 0.05)	**988**	
CV	**30%**	

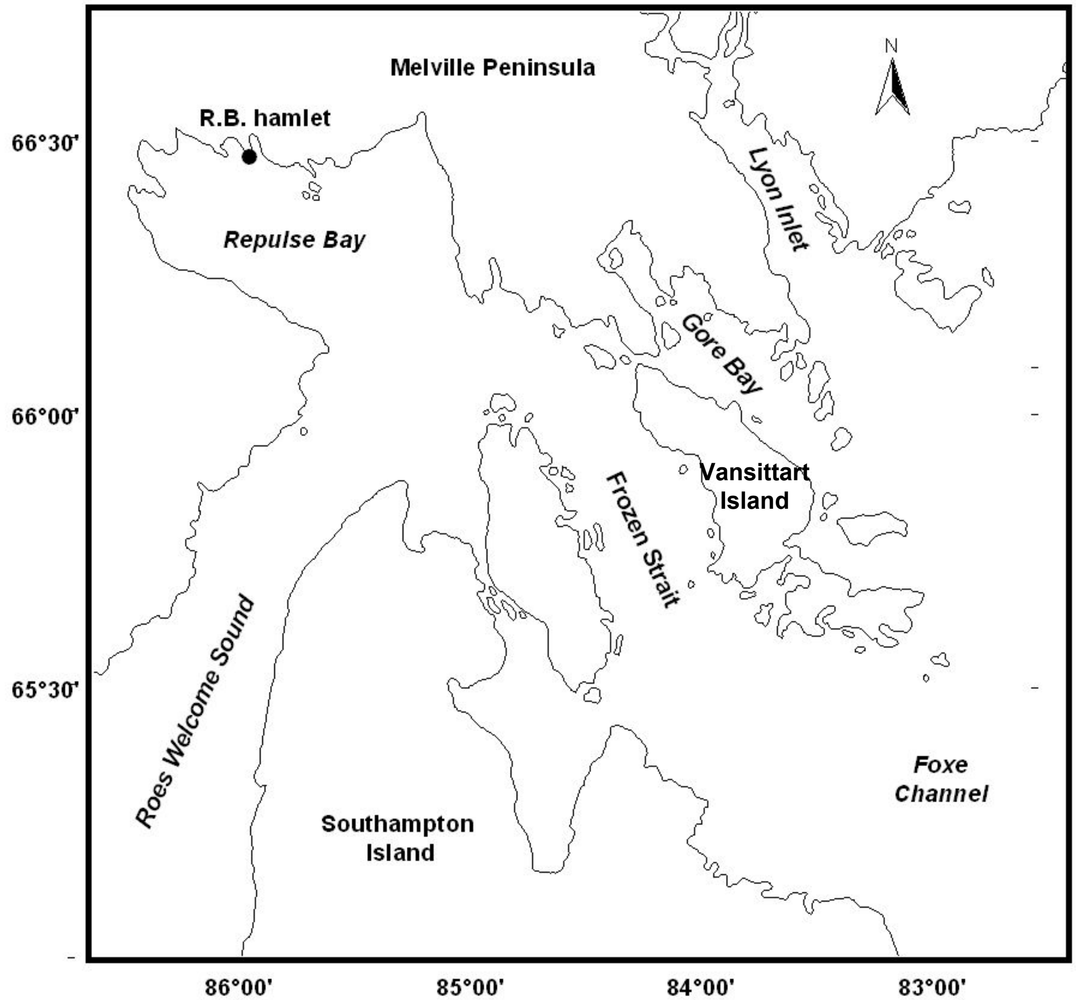

Fig.1. Seasonal range of Northern Hudson Bay narwhal (adapted from Strong 1988).

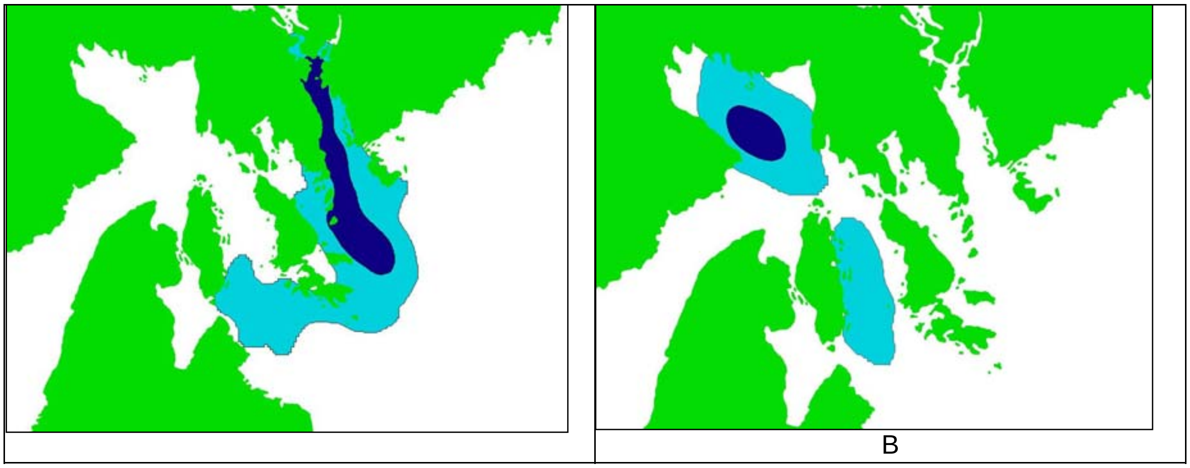

Fig. 2. August home range of narwhals instrumented A) in Lyon Inlet August 2006 and B) in Repulse Bay in August 2007 (Westdal 2009). Light blue and dark blue are 95% and 50% kernel home range probability of occurrence, respectively.

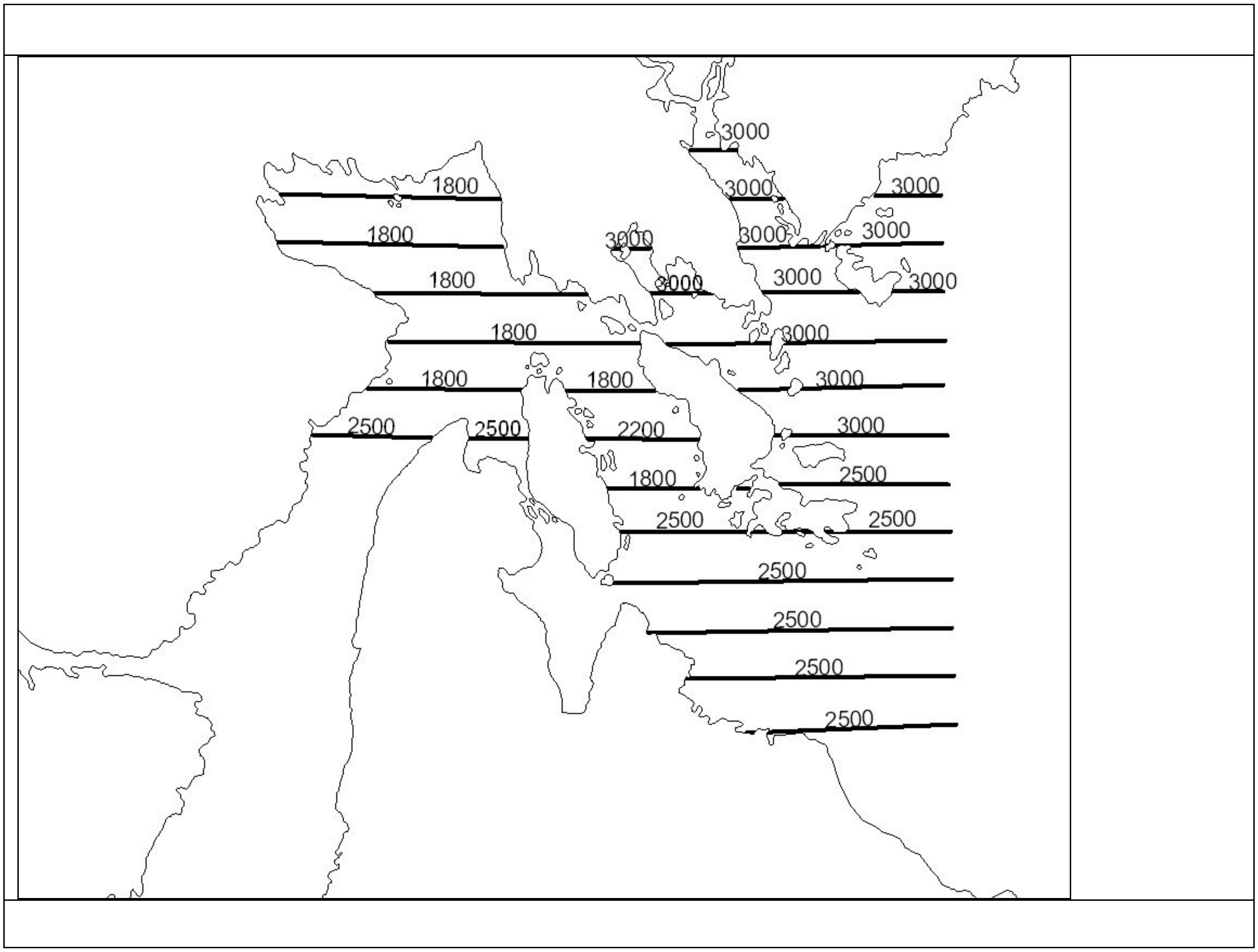

Fig. 3. Design of narwhal systematic survey with a 7 nm (13 km) transect spacing, flown on 21-22 August 2008 (Altitudes actually flown (ft) are shown on transect segments).

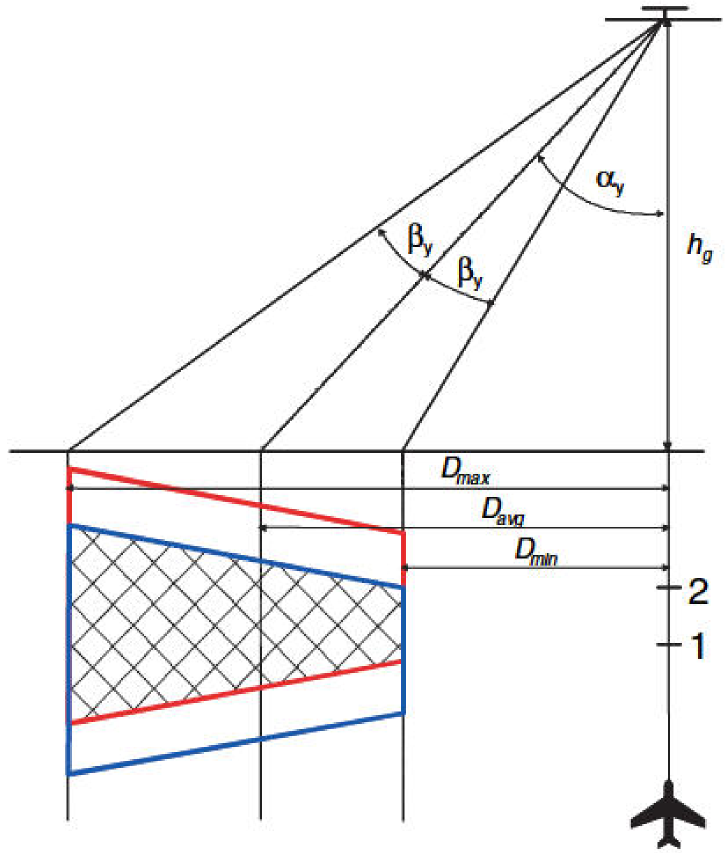

Fig. 4. Geometry of oblique images (reproduced from Grenzdörffer et al. *2008). Note: Refer to text for symbols.*

Fig. 5. Strata used in analysis: western stratum shown in medium grey; eastern stratum in light vertical bars.

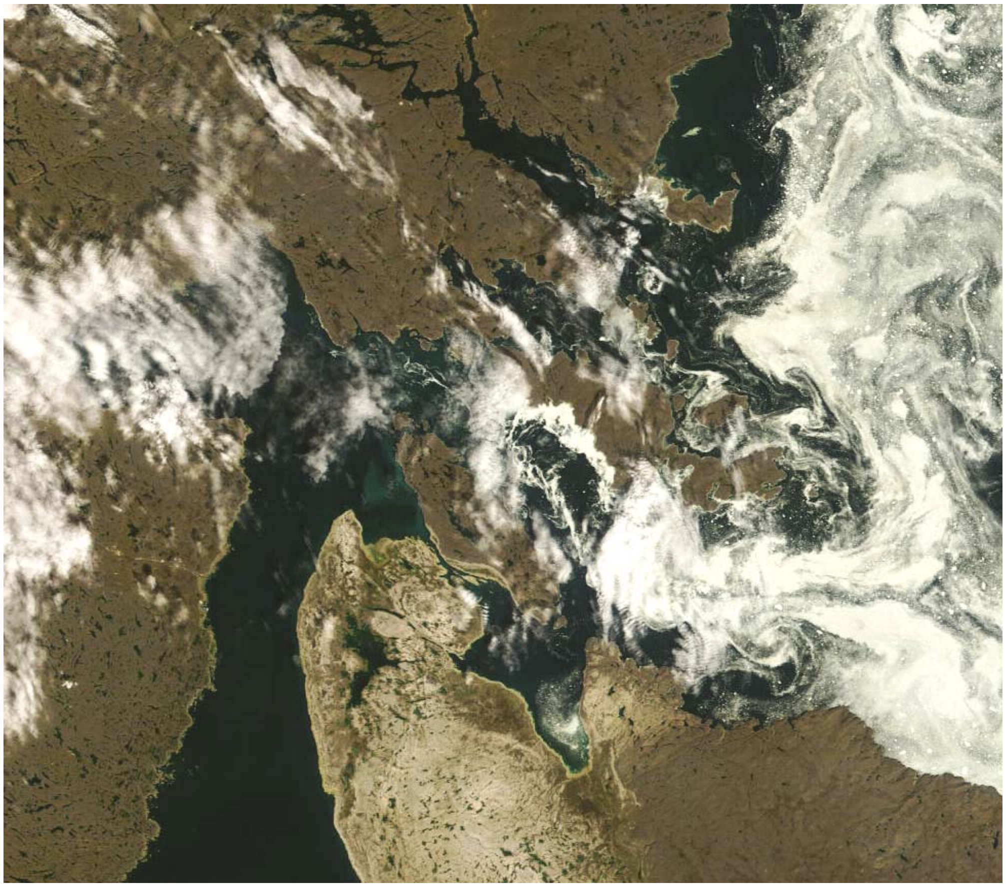

Fig. 6. Approximate sea ice conditions during the 21-22 August 2008 narwhal survey. (Source: MODIS Terra satellite image 23 August 2008)

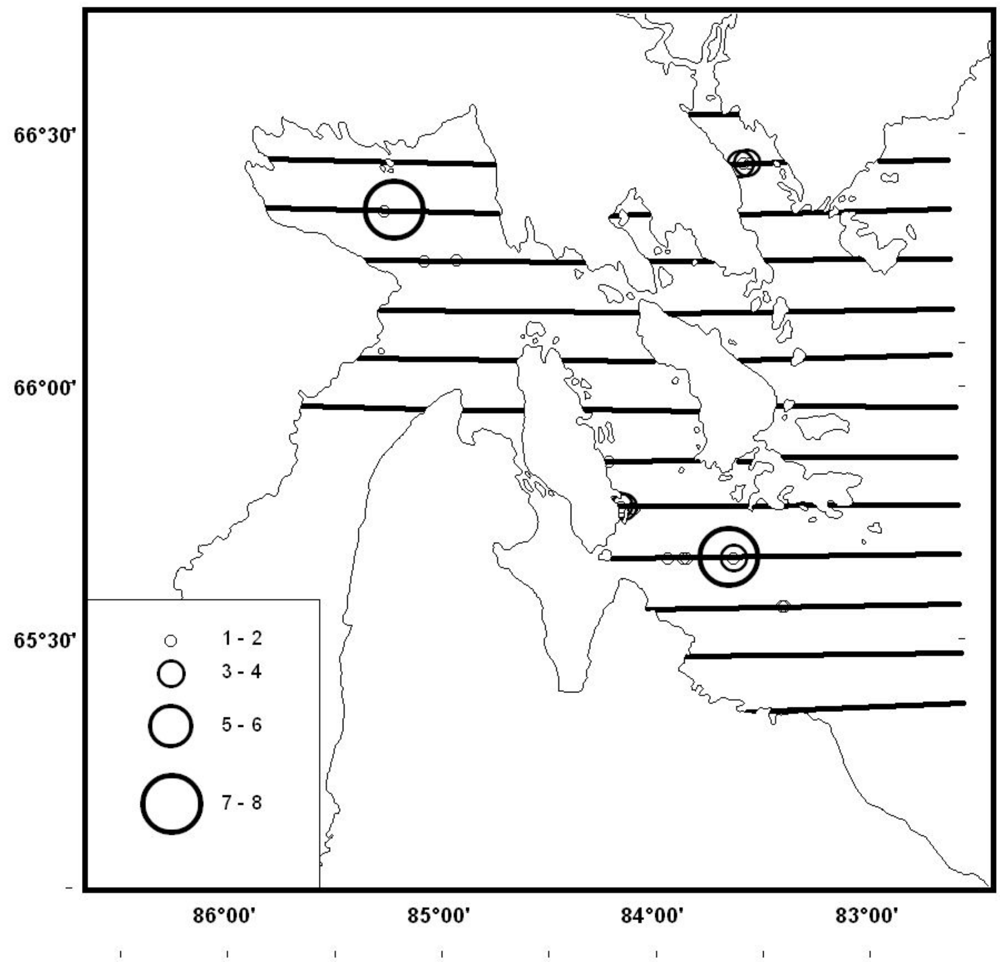

Fig. 7. Distribution of narwhal sightings during 21-22 August 2008 aerial photo surveys

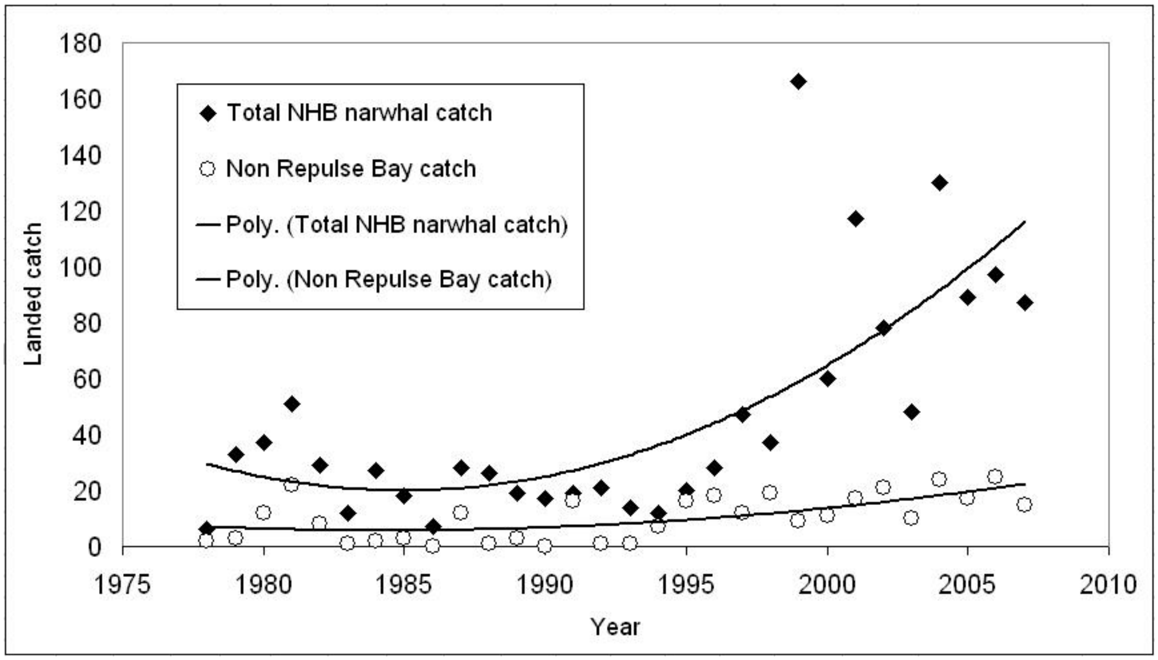

Fig. 8. Northern Hudson Bay narwhal landed catches, 1978-2008. Diamonds are the total annual reported annual landed catches from the Northern Hudson Bay stock by Kivalliq and South Baffin Hudson Strait communities. The open circles are the reported landed catches of communities other than Repulse Bay. (Source: DFO Iqaluit, Fisheries and Aquaculture Management)