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Size and trend of the Cumberland Sound beluga whale population, 1990 to 2009

Taille et tendance de la population de bélugas de la baie de Cumberland, 1990 à 2009

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ABSTRACT

This document reports on the results of aerial surveys conducted in 1990, 1999 and 2009 to estimate the present size and trend of the Cumberland Sound beluga whale population. Aerial surveys of the known summer range of beluga whales in the Sound were flown in August of those three years. The results show greater numbers of belugas in 1999 than in 1990 or 2009. The 2 August 2009 surveys produced an imprecise population estimate of 788 belugas (2.5-97.5 bootstrap percentiles = 310-1,679). Comparison of population estimates for the three years of surveys appear to imply that the population changed with rates of increase or total mortality that are unrealistic. Consequently, there must be sampling error which is unaccounted for by the survey results. Several possible sources of bias are identified. Some aggregations of belugas within the surveyed areas may have been missed and part of the population could have been outside of the surveyed area and that proportion varied between survey years. Additionally, there may have been inter-annual variation in diving behaviour of belugas during surveys which would have influenced the applicability of the dive correction. Finally there may have been unmeasured differences in efficiency at detecting belugas (e.g., observer error, visibility conditions) between survey years. More surveys and a population dynamic model are required to better estimate the size of, and trend in, this small population.

RÉSUMÉ

Ce rapport porte sur des résultats de relevés aériens effectués en 1990, 1999 et 2009, afin d’estimer la taille et la tendance de la population de bélugas de la baie de Cumberland. Durant ces trois années, on a effectué au mois d’août des relevés aériens de la zone de répartition connue des bélugas de cette baie. Les résultats montrent un plus grand nombre de bélugas en 1999 qu’en 1990 et 2009. Les relevés aériens du 2 août 2009 ont produit une estimation imprécise de la taille de la population dans la zone de relevé était de 792 bélugas (2.5-97.5 pc = 310-1,679). Une comparaison des estimations du nombre de bélugas au cours de ces trois années suppose que la population a changé sous l’effet de taux de croissance ou de cause de mortalité qui paraissent improbables. En conséquence, il doit y avoir des sources d’erreur d’échantillonnage non expliquées par ces résultats d’inventaires. Des sources d’erreur possibles sont que des troupeaux n’ont pas été vus et qu’une partie de la population était en dehors des zones de relevés et que cette proportion variait d’un inventaire à l’autre. De plus, le comportement de plongée des bélugas a pu varier d’un relevé à l’autre et il y avait peut-être des différences non mesurées dans l’efficacité de détection des bélugas (e.g., erreur d’observateur, condition de visibilité) entre les années de relevés. Pour obtenir une meilleure évaluation de la taille et de la tendance de cette petite population, il sera nécessaire d’effectuer plus d’inventaires et de modéliser la dynamique de population.

INTRODUCTION

The Cumberland Sound population of beluga whales was commercially exploited for more than half a century by whalers and traders (Kemper 1980; Brodie et al. 1981; Mitchell and Reeves 1981). Commercial exploitation declined over the years as the stock was depleted. Since the 1970s, this population has been the subject of several research studies that determined it was severely depleted and could not sustain a large take (Brodie et al. 1981; Richard and Orr 1986). In the early 1980s, numbers were estimated to be in the low hundreds and, for fear that the local subsistence hunt would endanger the population, a quota system was established to regulate catches (Richard and Pike 1993). In 2004, the Cumberland Sound population was designated as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004) and is being considered for listing under the *Species at Risk Act*.

Since 1990, four sets of surveys have been conducted to monitor the status of the population. Three sets were successfully completed in 1990, 1999 and 2009 (Appendix 1). The fourth in 2005 was unsuccessful due to extreme weather conditions which lasted for several weeks. This document reports on the results of the three successful sets of surveys.

METHODS

SURVEY METHODS

The spatial coverage of the surveys was planned following consultation with the Pangnirtung Hunters and Trappers Organisation (HTO) on the extent of the beluga summer range in Cumberland Sound (Figure 1). Kilabuk (1998) also compiled Inuit knowledge on the distribution of Cumberland Sound belugas and his accounts bear close resemblance to the information we were given. Satellite tracking of belugas instrumented in Cumberland Sound confirmed this inferred summer range (Richard and Stewart 2008).

Aerial surveys were flown in a DeHavilland Twin Otter (DHC-6) in mid-summer of each year. For the 1990 and 1999 surveys, the plane was equipped with a Wild Leitz RC20 camera with a 6" lens (151.7 mm) pointed vertically down through a belly port at the rear of the aircraft. The beluga aggregation area in Clearwater Fiord was surveyed photographically at an altitude of 3,000 ft (914 m) using Kodak Aerocolor 2445 negative film in August 1990 and Agfa colour N400 negative film in August 1999.

In 1990, we used photographic passes set parallel to the main axis of the fiord with a view to obtain complete photo coverage of the number of belugas near the surface. The camera was fired rapidly to obtain an overlap of 60%-80% between consecutive photos (front lap). In addition, photographic transects were positioned to overlap slightly on each side (side lap) so as to obtain a complete coverage of the area of aggregation. Unfortunately, with the imprecision of the navigation system of the plane that year and with high winds at altitude, the plane did not fly on course and, in some case, drifted during flights along the long transects (Figure 2). Aerial visual surveys in 1990 were conducted in the North stratum of Cumberland Sound (Figure 1) using a systematic transect design with a transect spacing of approximately 7 km (Figures 3a and 3b).

In 1999, to avoid the plane drift problem of 1990, we positioned the photographic transects perpendicular to the main axis of the fiord (Figure 4). The plane in 1999 was also equipped with GPS navigation that allowed for rapid adjustments even if the airplane deviated slightly from the prescribed tracks. The photographic overlap was approximately 20% front overlap and 20% side overlap. Aerial visual surveys were also conducted in the North and West strata of Cumberland Sound (Figure 1) using a systematic transect design with a transect spacing of approximately 7 km and 15 km, respectively (Figures 5 and 6).

Another set of surveys were conducted in August 2005. Weather and camera problems did not result in useful data. In particular, a film photo survey done that year was unsuccessful due to inadequate film exposure and an in-flight fuel leak which obscured the camera port's optical glass (Pierre Richard, unpubl. data).

As a result of the 2005 photographic experience, high-resolution digital photography was used for the 2009 surveys to assess photos in flight. We used a pair of Canon EOS 5D Mark II digital cameras with 35 mm lenses pointed on each side of the transect line. The cameras were oriented long side perpendicular to the flight line and angled at a low oblique (18.9°), so that the inner edge of the sensor imaged straight down at the flight line while the outer edge imaged outward, resulting in keystone images on each side of the trackline (Figure 7). The survey altitude in 2009 was 2,000 feet to allow for adequate resolution of belugas on the digital camera sensor. Flight lines were flown parallel to the main axis of the fiord, guided by a GPS moving map display. The photographic overlap was approximately 40% front overlap and 10%-20% side overlap. Additional systematic visual coverage was flown across the North and West strata of Cumberland Sound using a transect spacing of about 9 and 17 km (Figures 8 and 9).

During visual surveys in all three years, there were two observers on each side of the aircraft: a Fisheries and Oceans Canada (DFO) observer and a local observer. In 1990 and 1999, window and strut markers were used to delimit a ground strip of 800 m on each side of the aircraft. In 2009, observers recorded perpendicular angles of sightings using a Suunto clinometer. There were insufficient sightings to use mark-recapture methods to estimate observer bias so the highest beluga count within the 800 m strip on each side of the aircraft was summed for each transect.

In 1990 and 1999, reconnaissance surveys were also flown along bays and fiords of the west side of Cumberland Sound from Nettiling Fiord to at least as far south as Chidliak Bay (Figures 10 and 11). Reconnaissance surveys of the bays and fiords of the northern end of Cumberland Sound were also flown in both years (Figures 10 and 11). In 2009, a reconnaissance survey of Nettiling Fiord and adjacent bays was flown (Figure 12) but fog prevented reconnaissance flights further south along the west coast. Having seen fewer belugas in Clearwater Fiord and the north and west stratum than was usual, reconnaissance flights were also flown on 5 and 6 August around Cumberland Peninsula (Figure 12). Weather did not improve in time to revisit the west side, south of Nettiling Fiord.

SURVEY ANALYSIS

Photographic surveys

The number of belugas near the surface in Clearwater Fiord was calculated from the photographic mosaic resulting from photographic passes as follows:

$$N = N_p \times A_a / A_p$$

where N_p is the total number of belugas counted on photos, A_a is the area of the beluga aggregation and A_p is the sum of the areas of individual photos with belugas.

For the 1990 photo survey analysis, a 60%-80% overlap allowed the identification of duplicate sightings of belugas because there was only about 4-5 sec between frames. Consequently, beluga counts and area per photo were calculated for the non-overlapping portion of each photo, minus the area of any landform. In addition, the beluga aggregation area was difficult to delimit directly from the photos because the plane drift had caused some transects to overlap more than expected and portions of the fiord to be missed by the camera (Figure 2). We therefore approximated the extent at that area from visual observations made during the photographic passes.

For the 1999 and 2009 survey analysis, the low overlap did not allow precise identification of duplicate sightings between consecutive frames. Therefore, beluga counts and individual photo areas used to calculate N_p and A_p , respectively, were for entire frames minus the area of any landform. Photos with one or more belugas were mapped in GIS (Arcview 3.3) and the sum of the area of those footprints was calculated to obtain A_p. The sum of the area of the minimum polygon around the outer edge of overlapping photos with belugas and the areas of lone frames with belugas was used to calculate A_a (Figures 4 and 7).

For the 2009 photo survey analysis, photo pairs were matched to the GPS track to position the footprint of their coverage. Because of the low oblique angle (18.9°), the footprint of a photo on each side of the track is a trapezoid. Trapezoid dimensions were calculated from sensor size, lens focal length and altitude using formulas given in Grenzdörffer et al. (2008) and Northey (1916) (Figure 7). Detailed explanations are also available in Asselin and Richard (2011).

Visual surveys

The number of belugas near the surface in the North and West strata was estimated from visual survey sightings as follows:

$$N_t = k\ \Sigma N_i$$

where N_i is the number of belugas seen on strip transect *i*, ΣN_i is the sum of transect counts, and *k* is the expansion factor from sample count to total population for the area surveyed. The expansion factor *k* is defined as:

$$k = S / W$$

where *S* is the transect spacing and *W* is the transect strip width. Variance and standard error of estimates were calculated using methods of Kingsley (1996).

Correction for diving belugas

To obtain total population estimates, near-surface estimates were corrected for diving animals missed during the survey using the reciprocal of the proportion of time belugas spent at depths where they can be seen. Richard et al. (1994) showed with beluga-shaped target experiments that, in clear water, adult belugas can be seen and identified at depths of 5 m. In addition, Kingsley and Gauthier (2002) found that belugas were visible at Secchi depths (1.5 m and below) in the silted water of the St.-Lawrence estuary, and their helicopter focal follows of belugas in those waters suggest that belugas spent approximately 40% of their time at depths where they were visible. Data on the proportion of time belugas spend near the surface were obtained from seven instrumented Cumberland Sound belugas whose dives were recorded from late July to end of September in 2006-2008 (Pierre Richard, unpubl. data). On the basis of these data, we corrected photo counts for the silted waters of Clearwater Fiord using the proportion of time belugas spent at depths between 0 and 2 m and visual survey estimates for the clear waters of the North and West strata using the proportion of time spent at depths between 0 and 5 m (Table 1).

A dive-corrected stratum estimate, N_c, was obtained using methods of Innes et al. (2002):

$$N_c = N_s / P_s$$

where N_s is the near-surface estimate and P_s is the proportion of time animals spent in surface layers. The standard error (SE) of N_c is:

$$SE(N_c) = (N_c^2 [cv^2 (N_s) + cv^2 (P_s)])^{-2}$$

where coefficient of variation (*cv*) and variance (*var*) are:

$$cv^2 (x) = var(x)/x^2$$

Trend analysis

Indices of total population size were obtained by summing the dive-corrected Clearwater Fiord estimate and the dive-corrected North stratum estimate from the same date where available. Because there is evidence of beluga movement between days from Clearwater Fiord and the Northern stratum, it was not prudent to use stratum estimates from consecutive days, only those obtained on the same days. This limited our comparison to 8 August 1990, 6 and 7 August 1999 and 2 August 2009. The sum of Clearwater Fiord counts and Northern stratum estimates for those days were thus used as indices of the population change over time.

Error bars for those indices were obtained by generating 10,000 bootstrap estimates ($N_{bootstrap}$) in Analytica 4.4 as follows:

$$N_{bootstrap} = [N_{CWF} / Normal(P_{CWF}, SE(P_{CWF}))] + [N_{resampled} * / Normal(P_{North}, SE(P_{North}))]$$

where $N_{resampled}$ was generated by calculating estimates from ten thousand resamples with replacement drawn from a uniform distribution of transect counts for each Northern visual survey, except the 1990 survey, where there had been no sightings on effort. Because the number of transects varied, the first six transects from north to south were used in the resample. This resulted in having to drop a Northern Stratum transect on 7 August 1999 and one on 2 August 2009, both with zero sightings (Tables 2 and 3). Ten thousand samples of $P_{stratum}$, (i.e., P_{CWF} and P_{North}) were drawn from a Normal($P_{stratum}$, SE($P_{stratum}$)) distribution. The 2.5 and 97.5 percentile estimates were used as error bars.

Population estimate in 2009

The population in August 2009 was estimated by summing the estimates for the West stratum on 1 August and the North and Clearwater Fiord strata on 2 August. Error bars for those indices were obtained by bootstrap as described above, i.e.,

$$N_{bootstrap} = [N_{CWF} / Normal(P_{CWF}, SE(P_{CWF}))] + [N_{north\_resampled} * / Normal(P_{North}, SE(P_{North}))]$$

$$+ [N_{west\_resampled} * / Normal(P_{West}, SE(P_{West}))]$$

where P_{North} and SE(P_{North}) were calculated the same way as P_{West} and SE(P_{West}). The 2.5 and 97.5 bootstrap percentile estimates were used as error bars.

RESULTS AND DISCUSSION

Counts in Clearwater Fiord, zone of the largest summer aggregation of belugas in Cumberland Sound, had previously been used as indices of total population size (Brodie et al. 1981, Richard and Orr 1986, Richard 1991), assuming that most belugas, if not all, were in the fiord in summer. No systematic surveys were conducted outside of the fiord to verify that assumption. In August 1990, three photo surveys of Clearwater Fiord were completed with numbers of belugas near the surface varying between 454 and 497 (Table 4) and the North stratum was flown at the suggestion of the Pangnirtung HTO (Figures 3a and 3b). No belugas were seen on transect in the North stratum, but a few sightings were made off -transect.

In 1999, a Pangnirtung HTO representative suggested that we extend our coverage further south into a West stratum so, in August of that year, photographic surveys were conducted in Clearwater Fiord and visual surveys in the North and West strata. Two photographic surveys (6 and 7 August) gave counts in excess of 700 belugas while the third (8 August) gave a count of 492 (Table 4). Two visual surveys of the North stratum yielded estimates of 60 and 213 belugas, while two surveys of the West stratum gave estimates of 37 and 46 (Table 2).[1]

In August 2005, we agreed with the Pangnirtung HTO to resurvey Clearwater Fiord and the North and West strata. As mentioned above, the 2005 survey was largely unsuccessful due to weather and camera problems and the results are therefore unusable for this exercise.

In August 2009, three photo surveys were flown on 30 July, 2 August and 3 August. After the first photo survey was completed, it became apparent that one of the camera's lenses had slipped out of focus due to plane vibrations, while the third survey lost a good portion of a flight line when the plane drifted over another line. Consequently, the cameras missed a large portion of belugas of the fiord's aggregation. That left a single photo survey of Clearwater Fiord, flown on 2 August (Figure 7). That survey yielded a count of 118 belugas after adjustment for overlap (Table 4). Two systematic visual surveys were flown in the North stratum, which yielded estimates ranging between 68 and 190 (Table 3). Due to fog conditions, only one survey of the West stratum could be flown. It yielded an estimate of 25 belugas (Table 3).

Table 5 summarizes the counts for all stratum surveys in the three years and the corrected estimates derived from them.

Reconnaissance surveys in all three years covered other areas identified by the Pangnirtung HTO as being used by groups of belugas in August but only a few small groups were sighted in 1990 and 1999 (Figures 10 and 11). Reconnaissance surveys in 2009 yielded no sightings of belugas (Figure 12).

Stratum estimates from the three strata (i.e., Clearwater Fiord, North and West strata), surveyed on 1-2 August 2009 summed to a total population estimate of 788 (2.5-97.5 bootstrap percentiles = 310-1,679) (Table 6). This estimate is less than half of the previous estimate of 1,960 (SE = 250) reported for August 1999 (DFO 2005).

[1] Note that the sum of stratum counts (photo and visual) for 6 August was previously used to derive a total population estimate. The sum for those three strata was corrected for diving animals, using a preliminary estimate of the near-surface time proportion of 0.5 (Standard Error (SE) = 0.05) from High Arctic belugas equipped with time depth recorders (Mads Peter Heide-Jørgensen, pers. comm.), resulting in an estimate of 1,960 belugas (SE = 249.6). This estimate was used at the time for population modelling and risk analysis (DFO 2005). Here, we are using dive data that was acquired from Cumberland Sound belugas with slightly different results.

In all years, Clearwater Fiord and the North stratum had most of the sightings. There were no surveys of the West stratum in 1990 and that stratum yielded few sightings in 1999 and 2009. The trend in numbers of belugas in Cumberland Sound over the three years of surveys can only be examined using corrected Clearwater Fiord photo counts and North stratum estimates. In doing so, we assume that the Western stratum contributes little to trend information. The same is supported by the relatively few sightings made during some of the reconnaissance surveys.

Sums of stratum estimates, based on the Clearwater Fiord photo surveys and North stratum visual surveys, varied considerably in the three years of surveys spanning the almost two decades between 1990 and 2009 (Table 7; Figure 13). Numbers of belugas estimated from the 1999 surveys were higher than estimates from the 1990 surveys and considerably higher than the 2009 surveys.

With so few years of survey data, it is unclear how to interpret population trend. Alternative explanations are illustrated by two extreme examples of regression fit (Figure 13). One interpretation is that population numbers represent an initial rise between 1990 and 1999, followed by a sharp decline in population size in the next decade, as illustrated by the second order polynomial fit. This interpretation seems unlikely for two reasons. First, it would require an annual growth rate of around 7% between 1990 and 1997 while experiencing a catch of at least 35-40 animals, not taking into account hunting losses. Beluga populations are thought to be capable of a maximum rate of increase of about 4% per annum, if not hunted (Kingsley 1989). Second, the severe decline implied by the 1999 and 2009 indices of abundance (Table 7) is only possible if hunting mortality was substantially larger (~180 belugas/year) than is presently reported (~42 belugas/year) or if there are important sources of mortality acting on Cumberland Sound belugas that are not taken into account by this assumed maximum rate of increase.

An alternative interpretation is that the trend is linear and the estimates are affected by a larger sampling error than the error bars for the 1990 and 1999 surveys, more in proportion to the error bars for the 2009 survey (Figure 13). Unaccounted sampling error could be due to two things: undetected large groups in survey strata and inadequate survey coverage.

It is conceivable that belugas formed one or more large groups that escaped detection in some surveys, but not in others. This problem was raised for survey results of narwhals in Admiralty Inlet (Richard et al. 2010), although, in that case, such large groups or herds (200+) were in fact detected off-line while ferrying between transects. But the coastline of Cumberland Sound is much more convoluted and peppered with islands so it is possible that large groups or herds were missed. For example, a group of 17 belugas was seen during a visual reconnaissance survey of the coastline of the North stratum on 10 August 1990, when no sighting had been made during systematic surveys of the same stratum a day before. Another example of that is the clustering of 40 belugas on a single transect with none or a single animal on other transects in the 2 August 2009 survey. This largely contributes to the wide error bars for that survey in Figure 13.

Considerable care was taken to document Cumberland Sound beluga summer range using both tracking and traditional knowledge (Richard and Stewart 2008). However, it is possible that part of the population occupied areas that were not surveyed and did so in varying proportions in different survey years.

Other sources of unaccounted error could be due to differences in diving behaviour of belugas during different surveys. Such an effect is not obvious when one compares within-year photo counts for Clearwater Fiord. They are, in fact, similar to one another. Finally there may have been unmeasured differences in efficiency at detecting belugas. Observer errors in detecting belugas and the effect of visibility conditions on detection may have varied between surveys but those effects have not been measured.

In any case, a linear fit is over-simplification of the trend of this population, even if we assume that sources of unaccounted estimation error are affecting the precision of the estimates. A better approach to trend analysis would be to estimate annual population size and growth parameters from a population dynamic model which takes hunting mortality into account, as was done by DFO (2005) and Alvarez-Flores (unpubl. data).

In closing, this study exemplifies the problems of assessing a small cetacean population which ranges over a relatively large area. Many factors can affect the estimation of population size. Similar difficulties were encountered during attempts to determine the size and trend of the small St. Lawrence beluga population, where survey efforts were higher than is the case here (Gosselin et al. 2007).

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PERSONAL COMMUNICATIONS

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Table 1. Average proportion of time belugas spent in a depth bin. Bolding indicates data used to correct the abundance estimates for diving animals missed during the survey. SE = standard error; CV = coefficient of variation

Stratum	Depth bin (in m)	Number of animals sampled	Average proportion of time spent in depth bin (%) *	SE (%)†	CV
North & West strata	0-4	7	39.6	1.7	0.044
	0-5	‡	**42.3**	**2.1**	**0.055**
	0-6	7	44.9	2.1	0.047
Clearwater Fiord	**0-2**	**7**	**42.4**	**3.3**	**0.077**

† *Values used for dive correction.*

‡ *Proportion of time in 0-5 m was interpolated from values for 0-4m and 0-6m and the SE used is the largest of the two SEs.*

Table 2. Numbers of belugas counted on transects and resulting estimates from visual surveys of Cumberland Sound, August 1999. The expansion factor (k) is equal to transect spacing (S) divided by transect width (W).The abundance estimate (N_t) is the product of k and ΣN_i. CV = coefficient of variation

Stratum (survey date)	Transect spacing in km (*S*)	Transect width in km (*W*)	Expansion factor (*k*)	Number of transects	Number of belugas on transects	Total number of belugas counted (ΣN_i)	Abundance estimate (N_t)	CV
North stratum (6 Aug.)	7.408	1.6	4.63	6	2	46	213	37%
					7			
					18			
					0			
					4			
					15			
North stratum (7 Aug.)	7.408	1.6	4.63	7	0	13	60	77%
					3			
					0			
					0			
					10			
					0			
					0			
West stratum (6 Aug.)	14.852	1.6	9.28	7	0	4	37	51%
					2			
					2			
					0			
					0			
					0			
					0			
West stratum (9 Aug.)	14.852	1.6	9.28	3	4	5	46	52%
					1			
					0			

Table 3. Number of belugas counted on transects and resulting estimates from visual surveys of Cumberland Sound, August 2009. The expansion factor (k) is equal to transect spacing (S) divided by transect width (W). The abundance estimate (N_t) is the product of k and ΣN_i. CV = coefficient of variation

Stratum (survey date)	**Transect spacing in km (*S*)**	**Transect width in km (*W*)**	**Expansion factor (*k*)**	**Number of transects**	**Number of belugas on transects**	**Total number of belugas counted (ΣN_i)**	**Abundance estimate (N_t)**	**CV**
North stratum (30 Jul.)	9.057	2	4.53	8	0	15	68	40.3%
					3			
					0			
					5			
					6			
					0			
					1			
					0			
West stratum (1 Aug.)	16.683	2	8.34	7	1	3	25	24.5%
					1			
					0			
					0			
					0			
					1			
					0			
North stratum (2 Aug.)	9.263	2	4.63	7	40	41	190	66.0%
					0			
					0			
					1			
					0			
					0			
					0			

Table 4. Photographic counts of the numbers of belugas near the surface in Clearwater Fiord during August 1990, 1999 and 2009 photographic surveys (where N = Np x Aa / Ap).

Date	8-Aug-1990	9-Aug-1990	10-Aug-1990	6-Aug-1999	7-Aug-1999	8-Aug-1999	2-Aug-2009
Total number belugas on photos (N_p)	367	465	379	1,044	1,147	665	167
Area of beluga aggregation (km^2) (A_a)	22.9	27.5	30.3	32.0	40.8	35.9	15.5
Sum of photo areas (km^2) (A_p)	18.3	25.7	25.3	46.4	60.2	26.5	21.9
Number of belugas in Clearwater Fiord (N)	459	497	454	720	777	492	118

Table 5. Corrected stratum abundance estimates for all three survey years

Date	Stratum	Surface estimate	CV	Dive Correction	CV	Corrected estimate	CV
8 Aug. 1990	CWF	459	-	2.37	0.077	1087	0.077
8 Aug. 1990	N	0	0	2.36	0.050	0	0
6 Aug. 1999	CWF	720	-	2.37	0.077	1704	0.077
6 Aug. 1999	N	213	0.367	2.36	0.050	503	0.371
7 Aug. 1999	CWF	777	-	2.36	0.077	1834	0.077
7 Aug. 1999	N	60	0.768	2.37	0.050	142	0.770
2 Aug. 2009	CWF	118	-	2.36	0.077	279	0.077
2 Aug. 2009	N	190	0.660	2.37	0.050	450	0.662

Table 6. Corrected stratum and total abundance estimates for 2009.

Date	Stratum	Surface estimate	CV	Dive Correction	CV	Corrected estimate	CV
2 Aug. 2009	CWF	118	-	2.36	0.077	279	0.077
2 Aug. 2009	N	190	0.660	2.37	0.050	450	0.662
1 Aug. 2009	W	25	0.245	2.37	0.050	59	0.432
Total						788	0.513

Table 7. Sum of abundance estimates of Clearwater Fiord photo surveys and North stratum visual surveys on days when both survey types were conducted. Error ranges of the estimates are given by 0.025 and 0.975 percentiles (pc) of bootstrapped estimates.

Date	2.5 pc	Estimate	97.5 pc
8 Aug. 1990	989	1,087	1,202
6 Aug. 1999	1,877	2,207	2,554
7 Aug. 1999	1,837	1,977	2,197
2 Aug. 2009	279	728	1,600

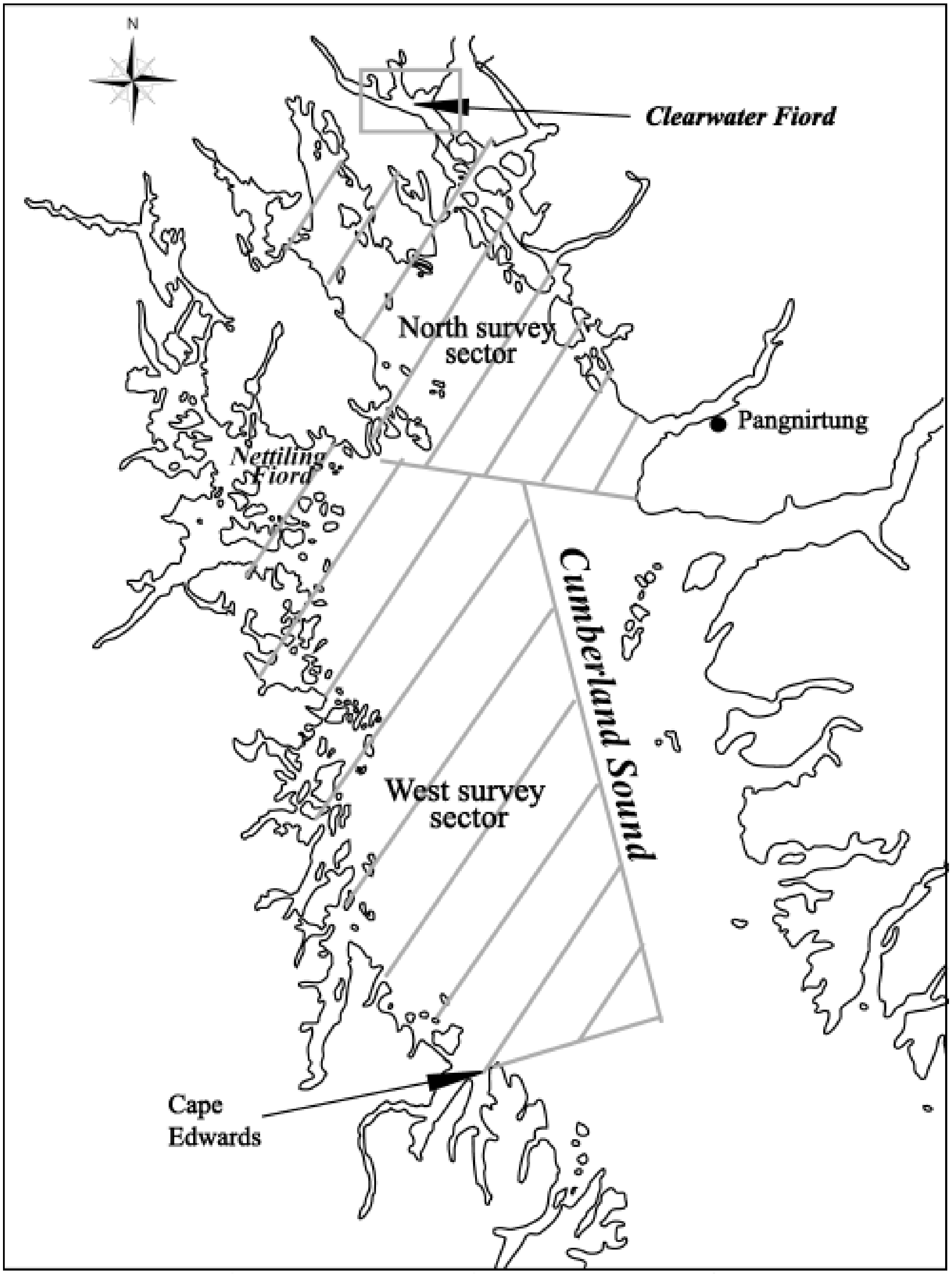


Figure 1. Study area based on summer range of the Cumberland Sound beluga population and delimitation of survey strata (Clearwater Fiord, North and West strata).

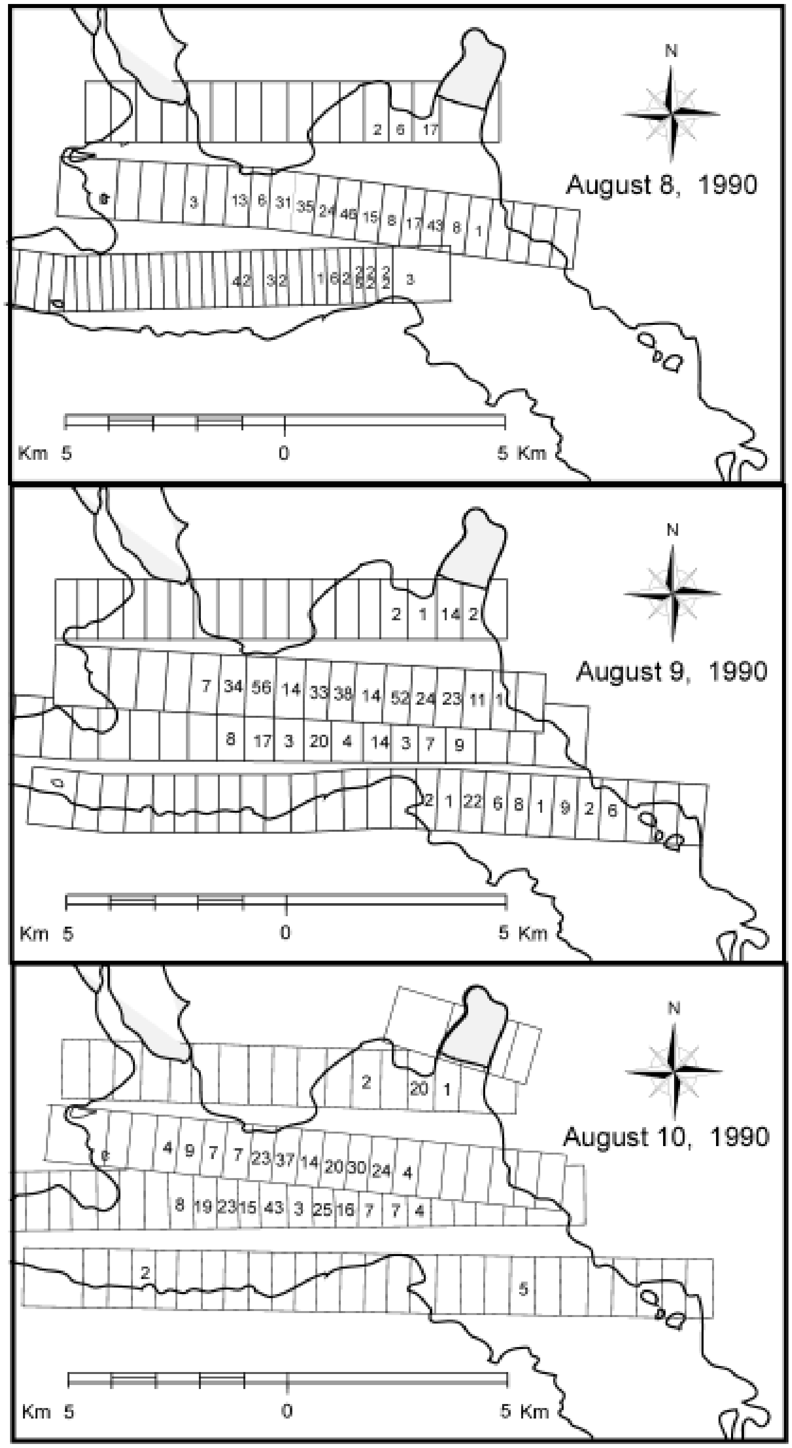


Figure 2. Photographic surveys of the Clearwater Fiord beluga aggregation, August 1990. Numbers in photo cells represent the total number of belugas (near the surface) counted in the non-overlapping portion of each photo.

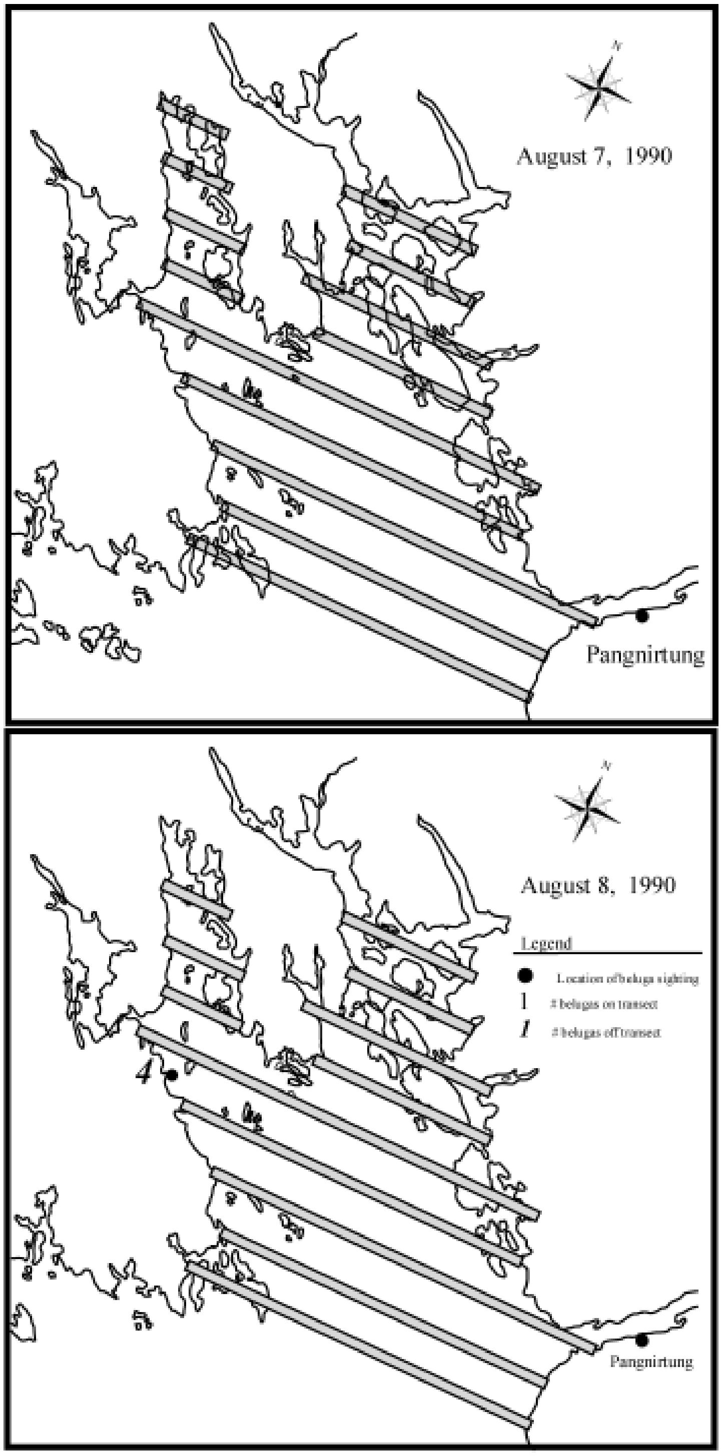


Figure 3a. Systematic visual strip surveys for the North stratum of Cumberland Sound on 7 and 8 August 1990. Numbers of belugas sighted are indicated. Note: strip width is not to scale.

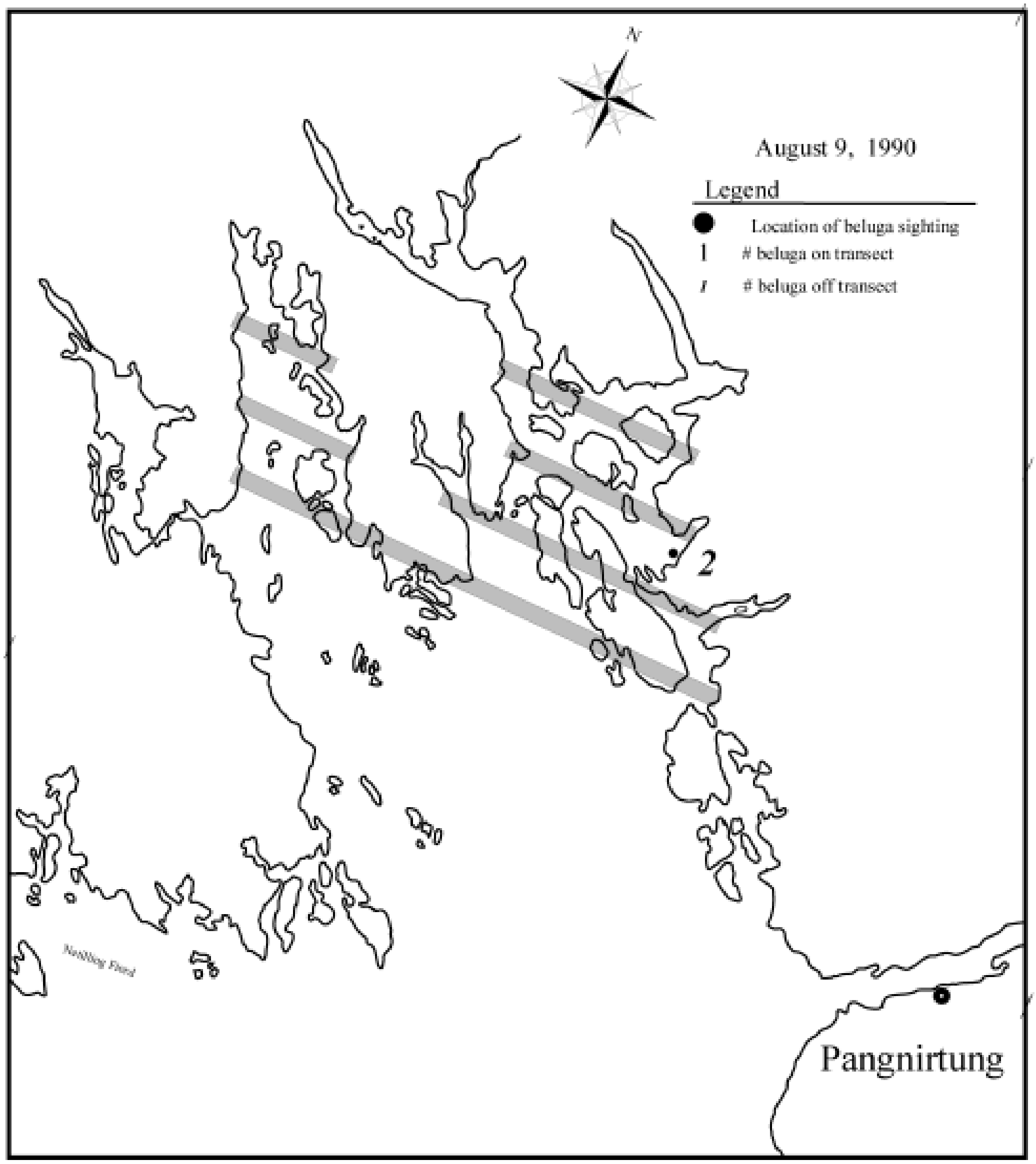


Figure 3b. Systematic visual strip surveys of the North stratum of Cumberland Sound on 9 August 1990. Numbers of belugas sighted are indicated. Note: strip width is not to scale.

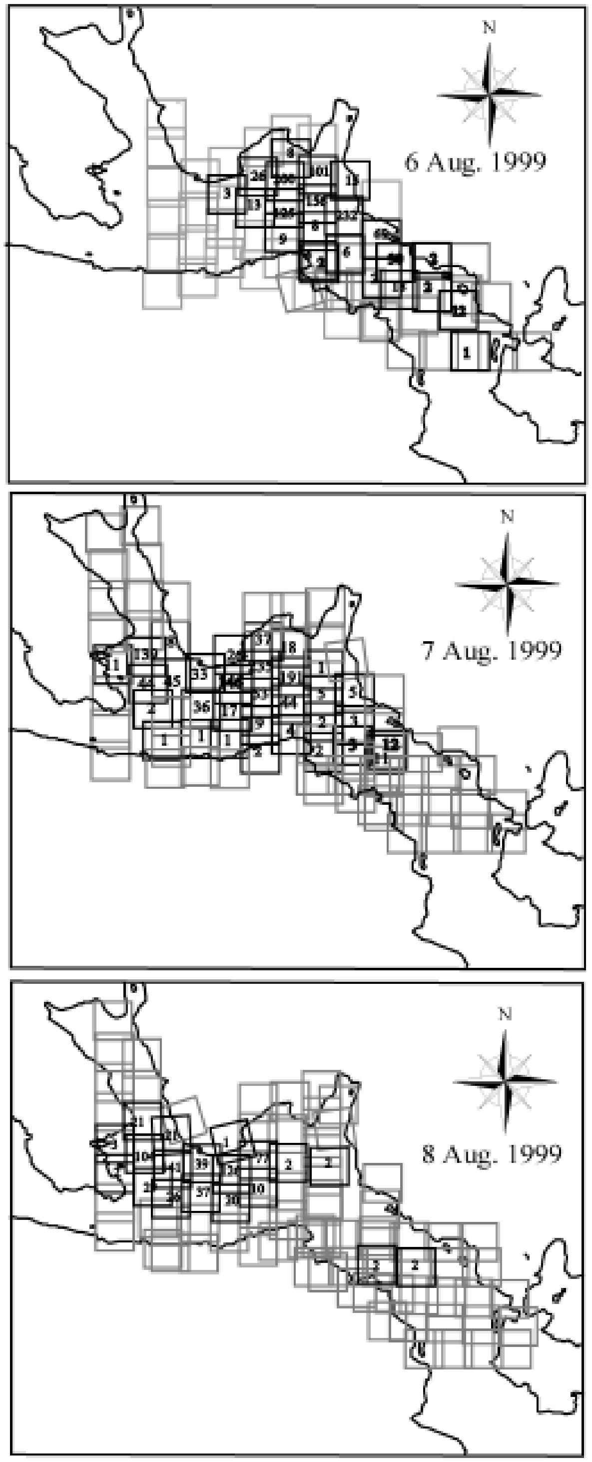


Figure 4. Photographic surveys of the Clearwater Fiord beluga aggregation, August 1999. Numbers in photo cells represent the total number of belugas (near the surface) counted in each photo.

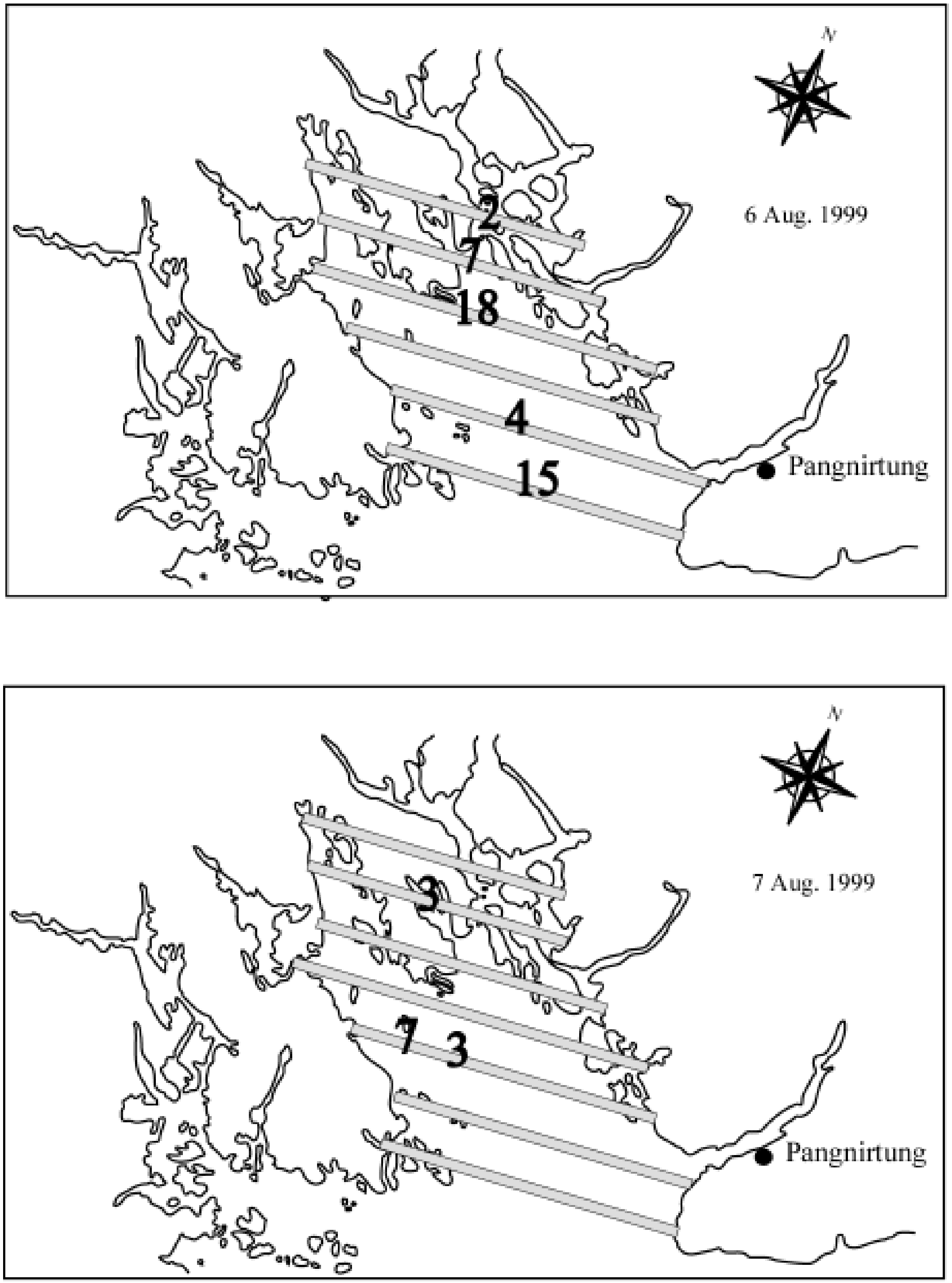
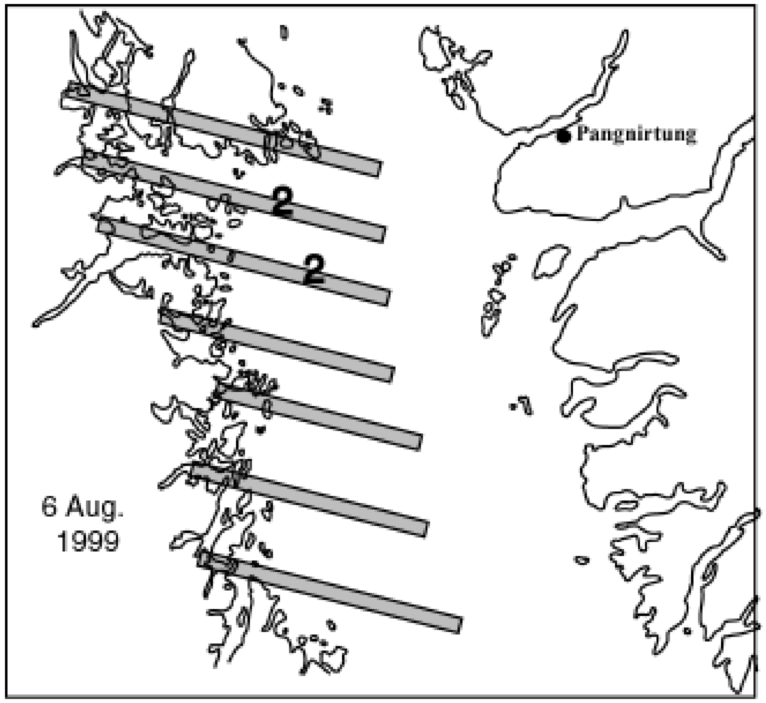


Figure 5. Systematic visual strip surveys of the North stratum of Cumberland Sound on 6 and 7 August 1999. Numbers of belugas sighted are indicated. Note: strip width is not to scale.



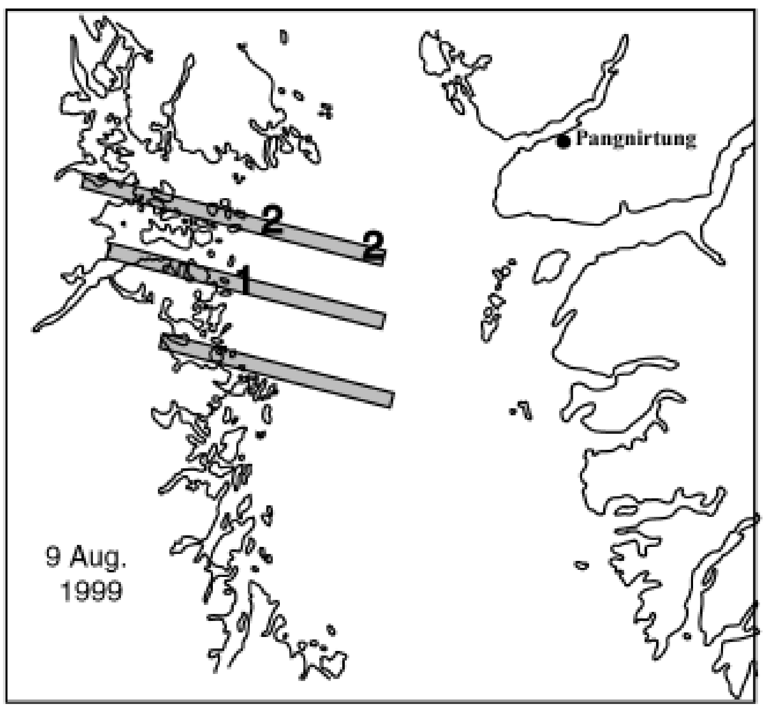


Figure 6. Systematic visual strip surveys of the West stratum of Cumberland Sound on 6 and 9 August 1999. Numbers of belugas sighted are indicated. Note: strip width is not to scale.

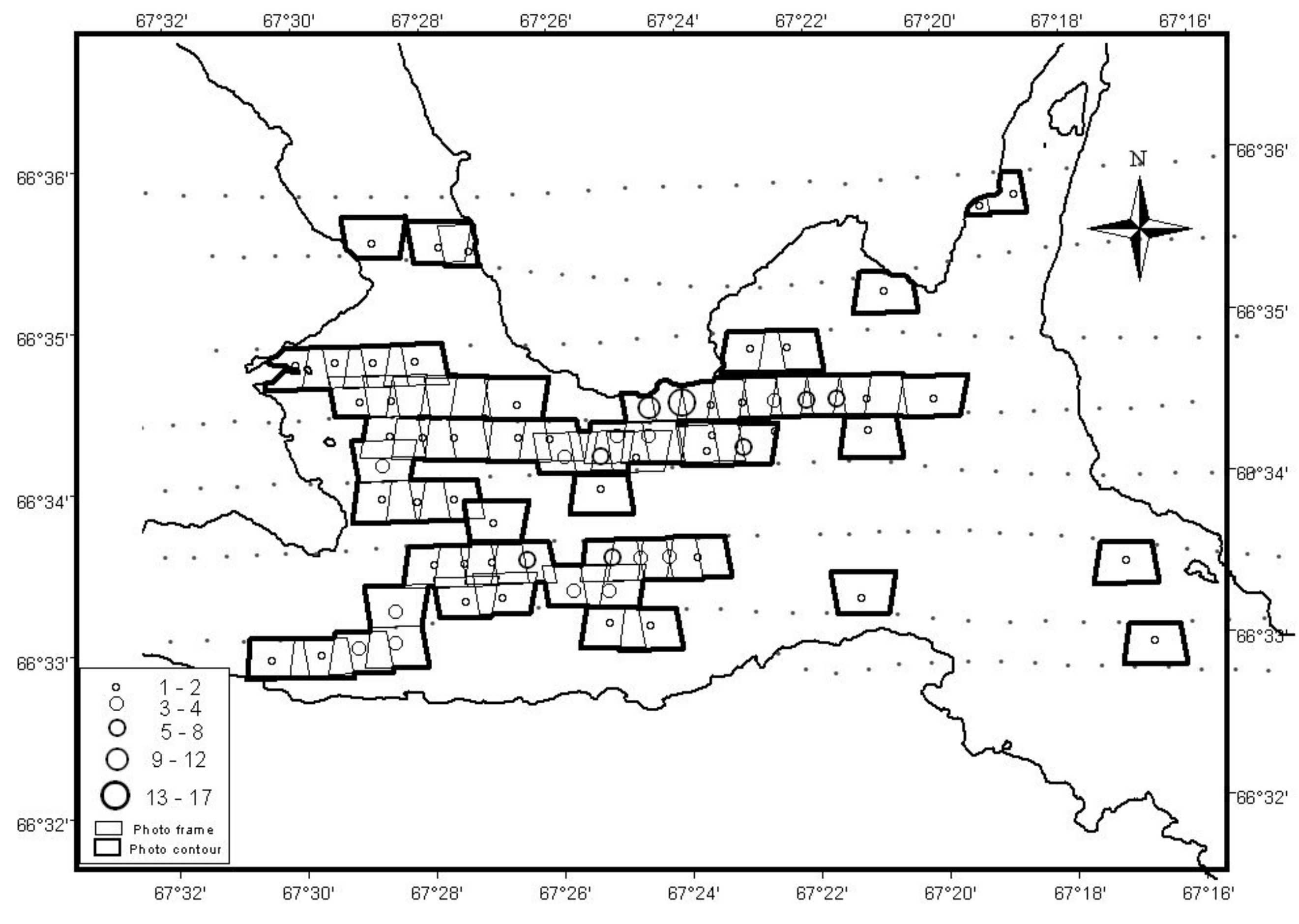


Figure 7. Photographic surveys of the Clearwater Fiord beluga aggregation on 2 August 2009.

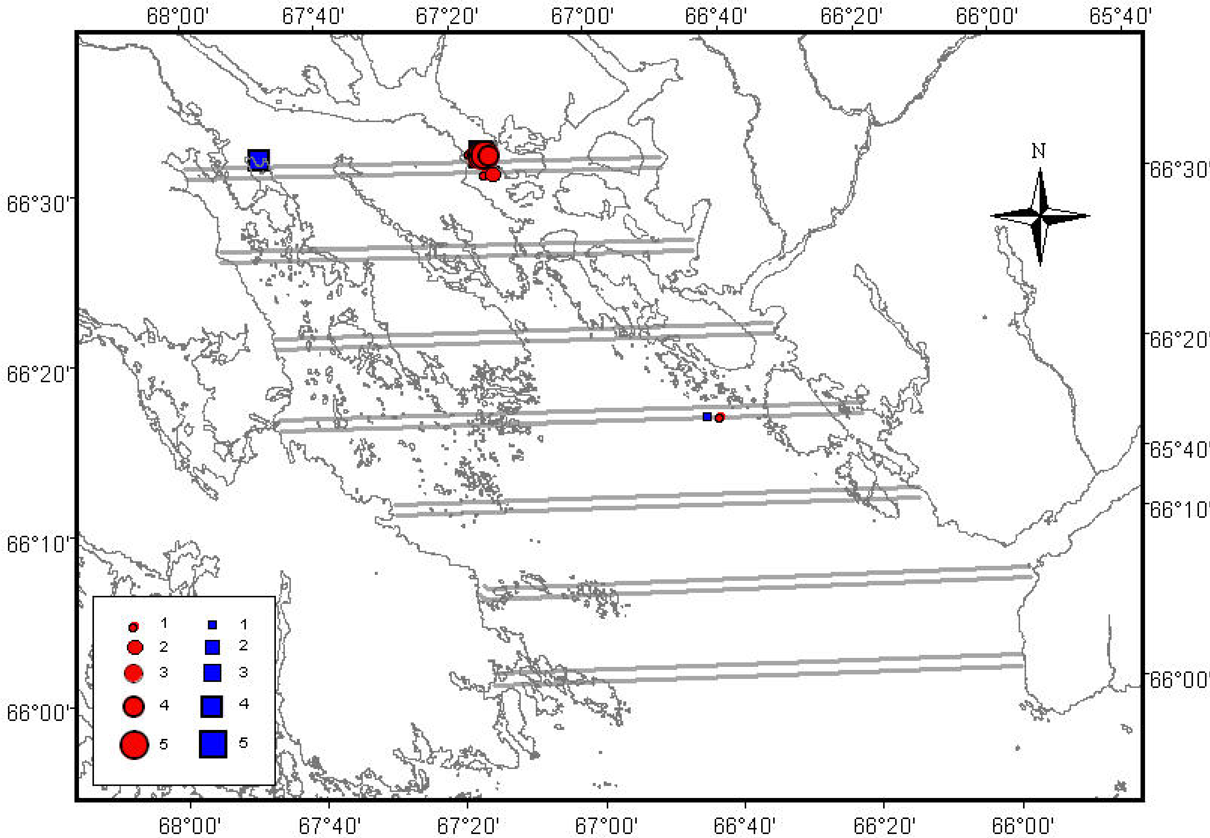


Figure 8. Systematic visual strip transect surveys of the North stratum of Cumberland Sound on 2 August 2009. The red circles and blue squares represent primary and secondary observers' observations, respectively. Note: strip width is not to scale.

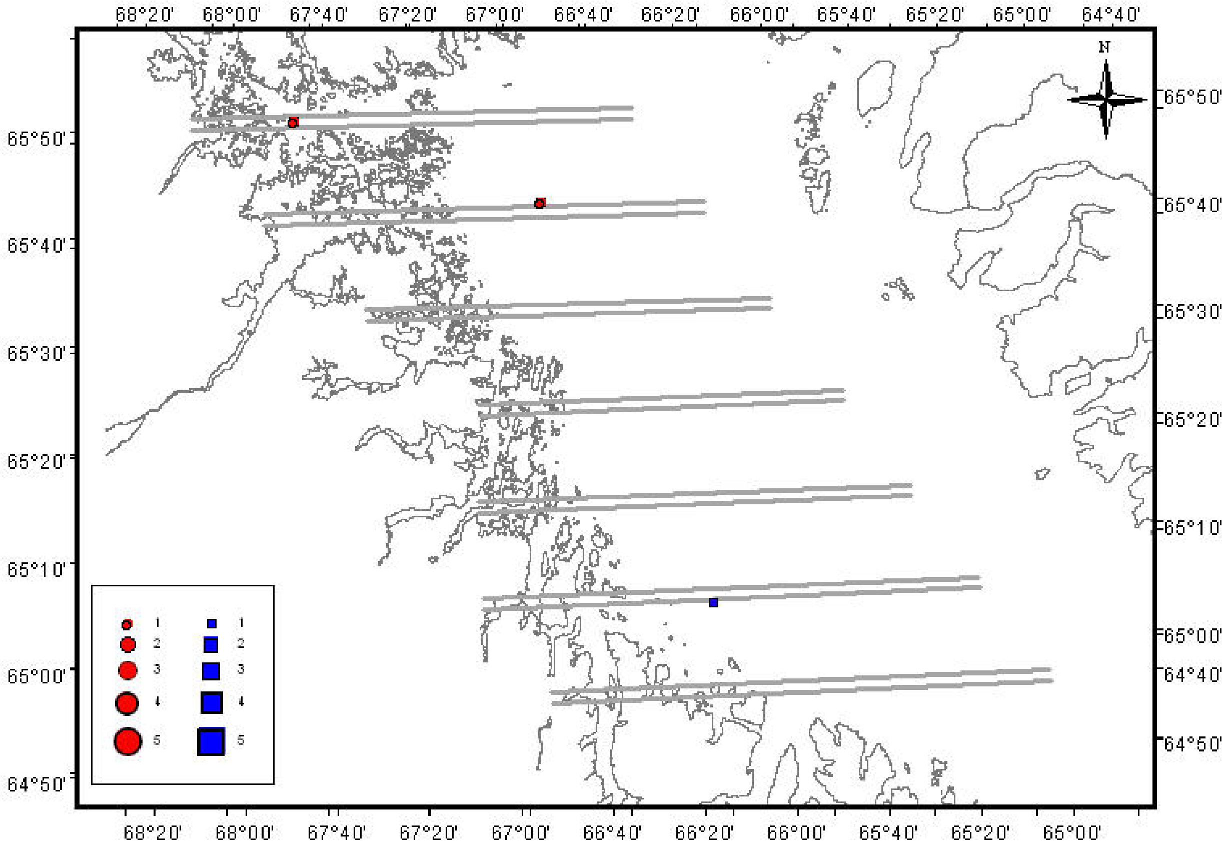


Figure 9. Systematic visual strip transect surveys of the West stratum of Cumberland Sound on 1 August 2009. The red circles and blue squares represent primary and secondary observers' observations, respectively. Note: strip width is not to scale.

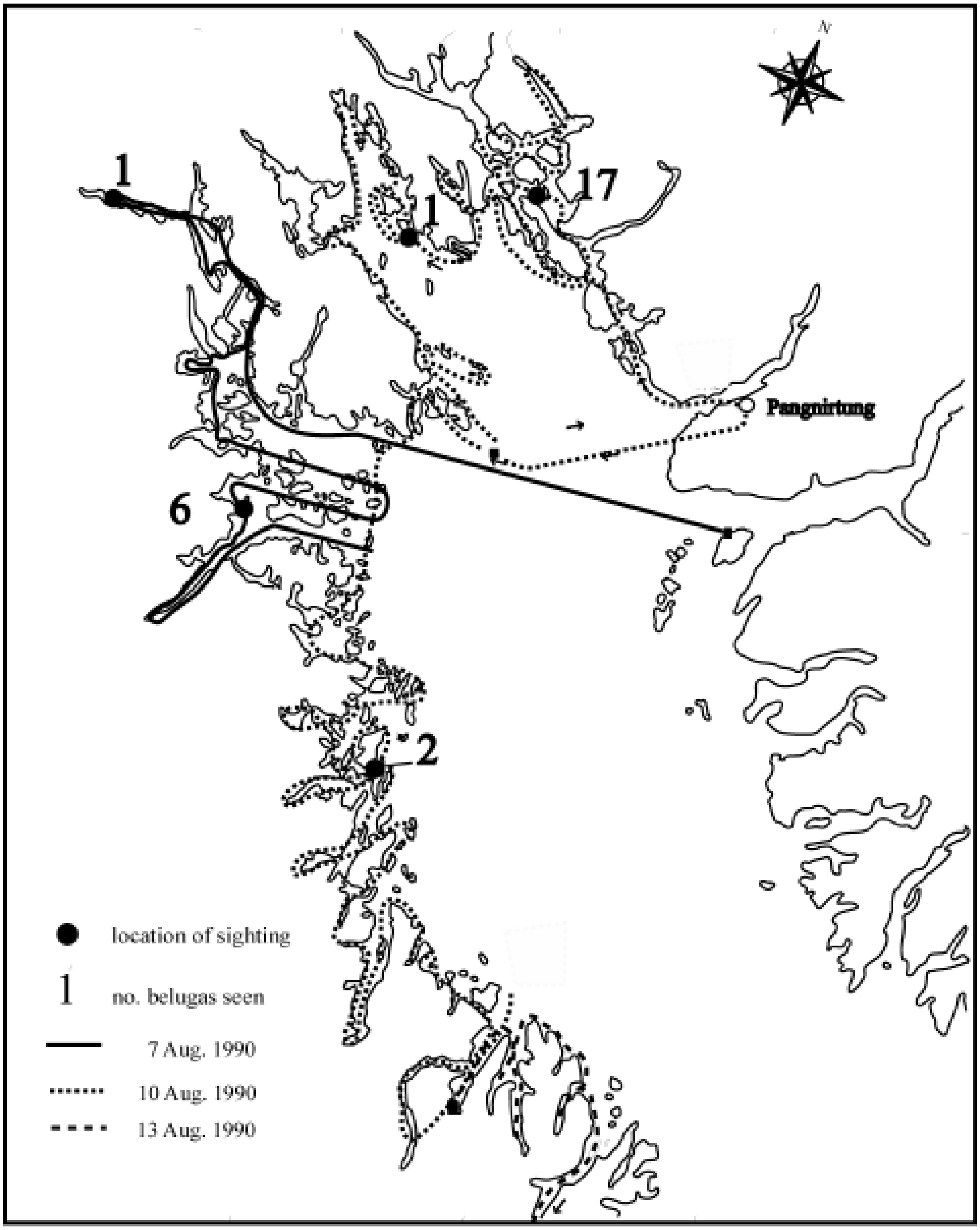


Figure 10. Reconnaissance surveys of the coast of western Cumberland Sound, August 1990. Numbers of belugas sighted are indicated.

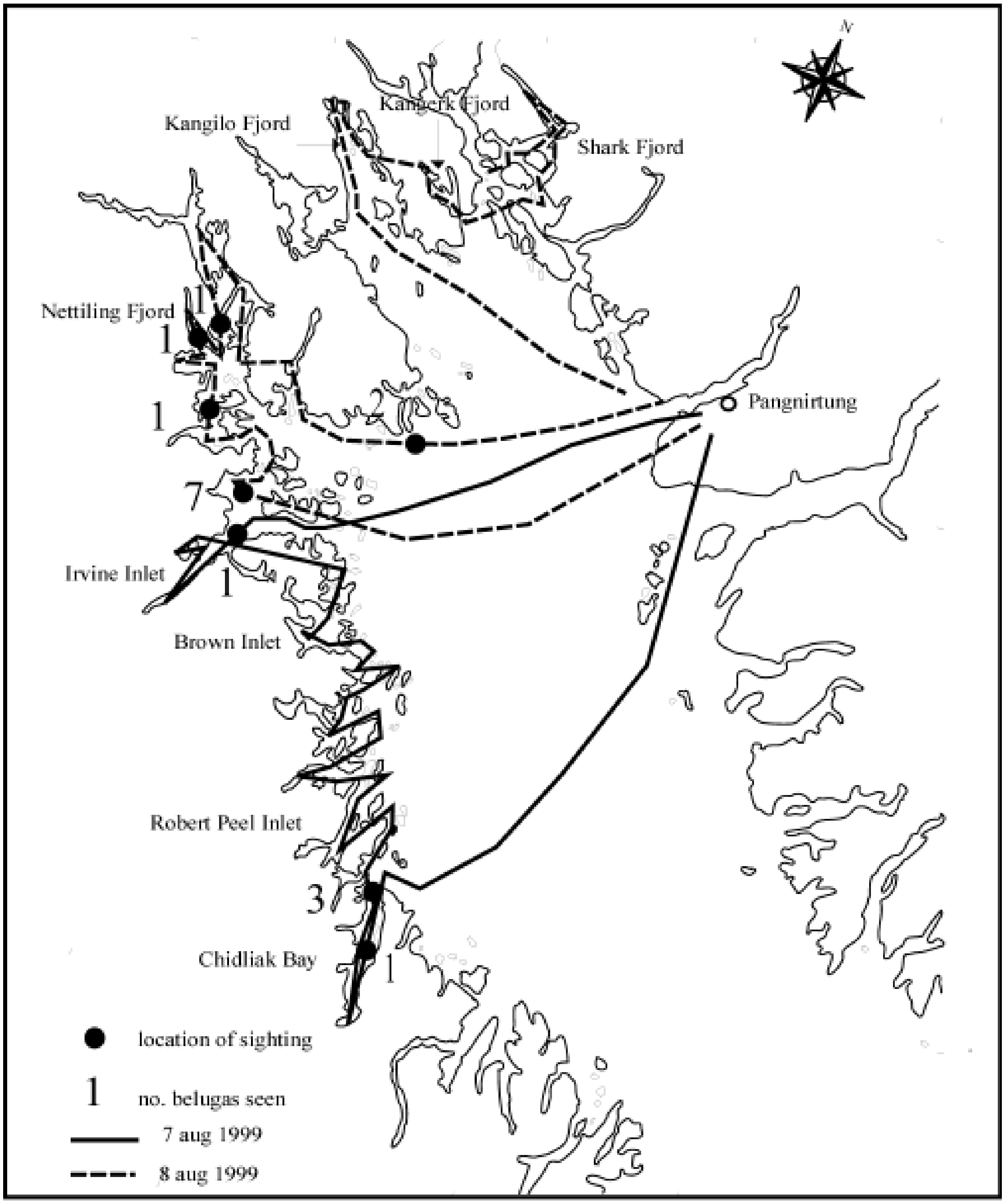


Figure 11. Reconnaissance surveys of the coast of western Cumberland Sound, August 1999. Numbers of belugas sighted are indicated.

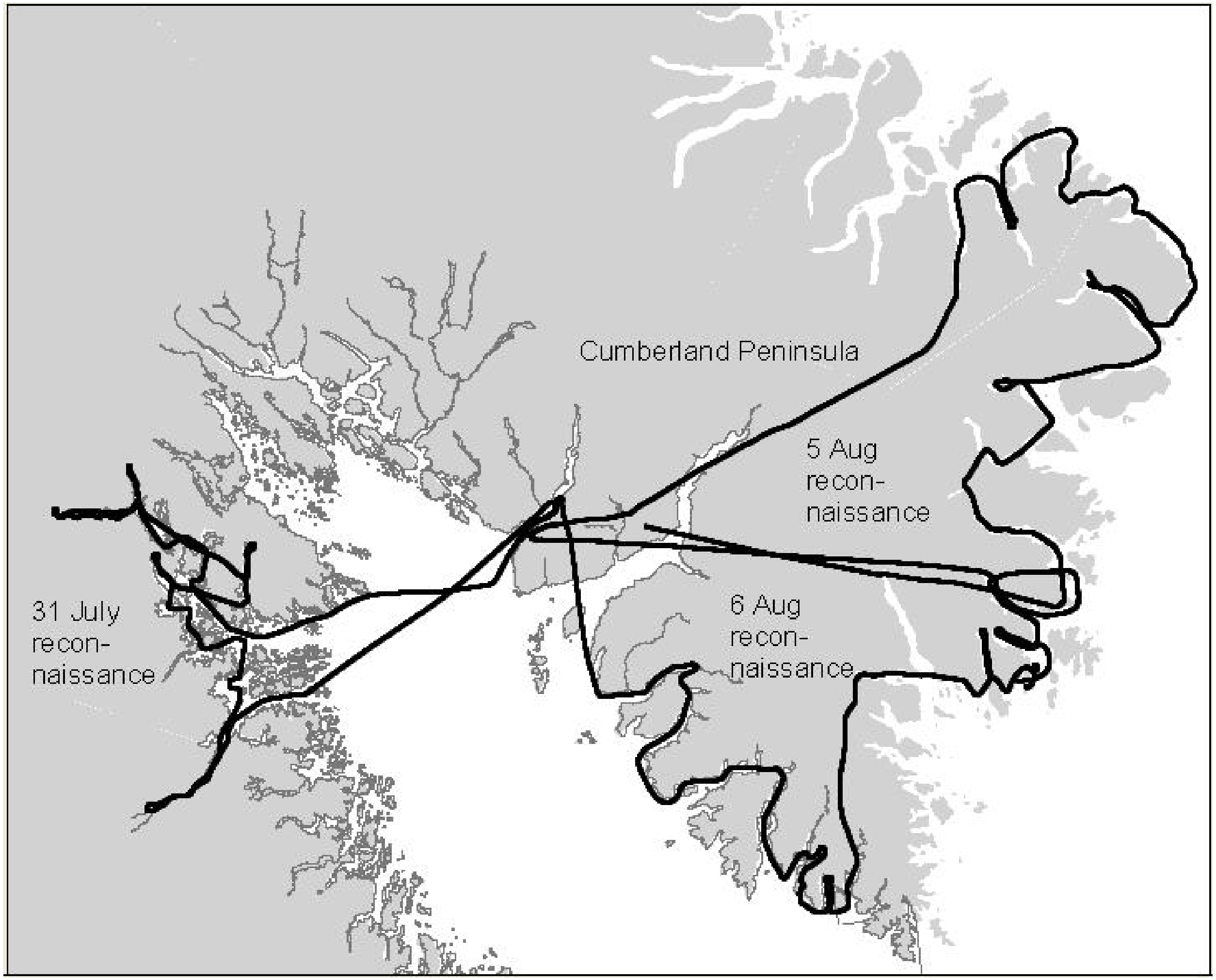


Figure 12. Reconnaissance surveys conducted on 31 July to 6 Aug 2009. No belugas were sighted.

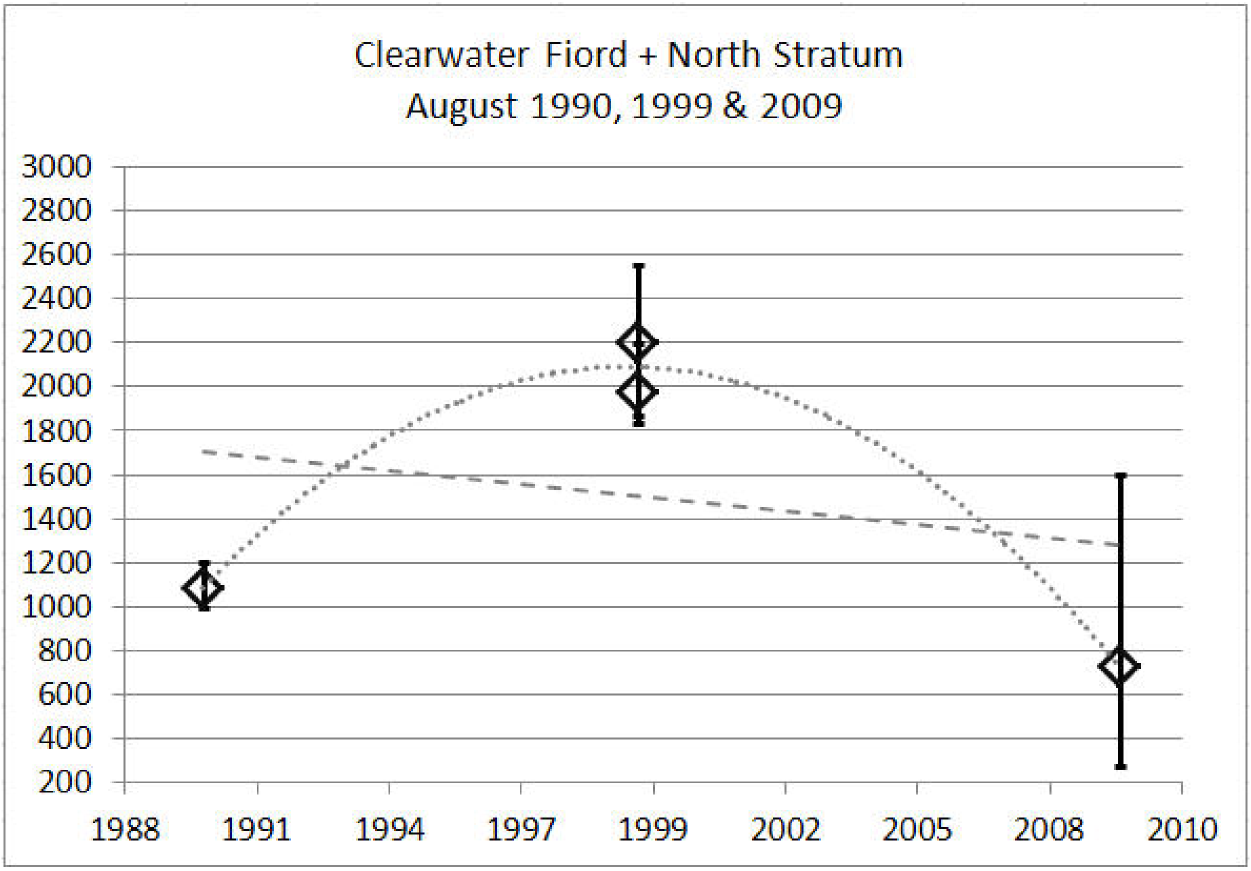


Figure 13. Trend in the sums of dive-corrected estimates from Clearwater Fiord photo counts and dive-corrected visual estimates of the North stratum flown on the same day, for August 1990, 1999 and 2009. 2.5 and 97.5 percentiles of bootstrapped estimates are given around the mean estimate. A linear fit (short dashed line) and a second-order polynomial fit (long dashed line) are also shown.

APPENDICES

Appendix 1. Aerial surveys conducted for belugas in Cumberland Sound in 1990, 1999 and 2009.

Survey date	Stratum/location	Survey type
07-Aug-90	North	Visual
	Western bays and fiords	Reconnaissance
08-Aug-90	Clearwater Fiord	Photo*
	North	Visual*
09-Aug-90	Clearwater Fiord	Photo
	North	Visual
10-Aug-90	Clearwater Fiord	Photo
	Northern bays and fiords	Reconnaissance
13-Aug-90	Western bays and fiords	Reconnaissance
06-Aug-99	Clearwater Fiord	Photo*
	North	Visual*
	West	Visual
07-Aug-99	Clearwater Fiord	Photo*
	North	Visual*
	Western bays and fiords	Reconnaissance
08-Aug-99	Clearwater Fiord	Photo
	Northern bays and fiords	Reconnaissance
09-Aug-99	West	Visual
30-Jul-09	North	Photo
31-Jul-09	Western bays and fiords	Reconnaissance
01-Aug-09	West	Visual*†
02-Aug-09	Clearwater Fiord	Photo*†
	North	Visual†
03-Aug-09	Clearwater Fiord	Photo
	North	Visual
05-Aug-09	North Cumberland Peninsula	Reconnaissance
06-Aug-09	South Cumberland Peninsula	Reconnaissance

* Survey data used to calculate abundance estimates for between-year comparisons

† Survey data used to calculate abundance estimate for that year