Fisheries and Oceans Canada — Pêches et Océans Canada

Science — Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2005/017

Document de recherche 2005/017

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

An estimate of the Western Hudson Bay beluga population size in 2004

Estimation du nombre de bélugas de l'ouest de la baie d'Hudson en 2004

Pierre R. Richard

Fisheries and Oceans /Pêches et Océans
501 University Crescent
Winnipeg, MB
R3T 2N6

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Aerial surveys of belugas were flown in western and southern Hudson Bay between 29 July and 6 August 2004. A combination of aerial visual line-transect surveys and photographic surveys were used to estimate the numbers of belugas present in that region. These estimates were corrected for availability bias based on a correction factor obtained from target experiment and beluga surfacing observations conducted in the similarly-silted waters of the St. Lawrence. These aerial surveys have allowed us to produce a most conservative estimate for this population, represented by the sum of the estimates of the Churchill-Seal and Nelson areas, and rounded to the nearest hundred, of 57,300 (95% C.L.: 37,700-87,100). There were belugas seen in an adjacent stratum but it is unclear if they moved into those areas between surveys. The uncorrected estimate of belugas (i.e.: seen near the surface) in the Churchill-Seal and Nelson areas (27,200) is very similar to the number (25,100) estimated in 1987. We conclude that the population has not experienced a detectable change in numbers since 1987. More than 7,000 belugas were also estimated to occur along the Ontario coast of Hudson Bay but it is difficult to assign them all to a single beluga stock due to a lack of stock identity information. It is also possible that some moved out of the Nelson stratum into that Ontario coast stratum between survey days.

RÉSUMÉ

Des inventaires aériens de belugas ont été effectués dans l’ouest et le sud de la baie d’Hudson entre le 29 juillet et le 6 août 2004. Une combinaison d’inventaires en transects linéaires et de décomptes photographiques ont été utilisés pour estimer le nombre de bélugas occupant la région. Pour pallier aux biais dus à la disponibilité des bélugas qui ont des activités de plongée prolongées, ces estimations ont été corrigées en utilisant un facteur de correction obtenue à partir d’expériences avec des cibles et des observations du temps en surface de bélugas dans les eaux limoneuses du Saint-Laurent, qui sont semblables à celles du secteur à l’étude. Ces inventaires aériens ont permis d’obtenir une estimation conservatrice de la taille de la population en faisant la somme des estimations des strates Churchill-Seal et Nelson. Ce chiffre arrondi à la centaine près est de 57,300 (95% I.C.: 37,700-87,100). Des bélugas ont été observés dans les strates adjacentes mais il n’est pas certain que ces animaux ne se soient pas déplacés d’une strate à l’autre entre les jours d’inventaires. L’estimation sans correction du nombre de bélugas (donc vus à la surface) dans les strates Churchill/Seal et Nelson (27,200) est semblable au nombre (25,100) estimé en 1987. On en déduit que la population n’a pas subi de changement démographique détectable depuis 1987. On estime à plus de 7,000 le nombre de bélugas au large de la côte ontarienne de la baie d’Hudson mais il est difficile de trancher sur leur appartenance à une population ou à une autre par manque d’information sur l’identité des stocks. Il est concevable aussi que certains groupes ont quitté la strate Nelson pour rejoindre la strate de la côte de l’Ontario durant l’intervalle entre les inventaires.

INTRODUCTION

The Western Hudson Bay beluga population's summer distribution centers in the coastal waters of Manitoba, with the largest aggregations in the estuaries of the Seal, Churchill and Nelson rivers. Richard et al. (1990) obtained two surface population estimates of 23,000 (95% CI 10,300-58,300) and 25,100 (95% CI 18,300-32,800) based on visual and aerial photographic surveys conducted in those aggregation areas in 1987. Both of these estimates were negatively-biased because no corrections were made for availability bias (i.e., whales undetectable during dives) for lack of an appropriate method to do so at the time. Also, the surveys may not have covered the entire range of beluga in mid-summer in Hudson Bay. Nevertheless they did cover the highest aggregations. Beluga density is known to be fairly low elsewhere in western Hudson Bay at that time of year. Additional reconnaissance surveys along the Ontario coast yielded a minimum count of 1,299 belugas (Richard et al. 1990) but the stock identity of those whales is not clear. There is evidence that a local population of belugas summers in those areas (Richard et al. 1990) but belugas from the Nelson estuary have been tracked to the Ontario coastal waters in summer (P. Richard, unpublished), so the numbers counted there could be from a mixture of stocks. Further stock delineation research is needed to determine the stock identity of belugas along that coast.

Beluga surveys were conducted from 29 July to 6 August from the Thlewiaza estuary near the Nunavut border to Cape Henrietta Maria at the mouth of James Bay (Fig. 1). These surveys were designed to cover the summer range of belugas in western and southern Hudson Bay as established by past survey efforts (Richard et al. 1990), and by beluga satellite tracking results from the 1990s and early 2000s (Martin et al. 2001; P. Richard, unpubl.). This report presents the results of these surveys and estimates of the population corrected for availability bias.

METHODS

Equipment, crew and visual observation procedure

Surveys were flown in two Cessna 337 Super Skymaster aircraft equipped with bubble windows at the rear seat stations and wide but flat windows at the front seat stations. The flat windows limited the downward viewing angles to about 70° from the horizontal or less. The crew consisted of three observers, two on the right side (one in the co-pilot seat), and one in the left rear seat. Location, ground speed, and altitude were measured by a DGPS and were recorded every two seconds on a GPS. Observers received pre-flight training on the types of observations that were required. Observers were instructed to concentrate their observation effort at closer distances and use peripheral vision for sightings further away from the track line. Observers were paired (front and rear observers) on the right side of the airplane and maintained their seat positions on all flights. Front and back right-side observers were separated by a curtain so rear observers could not be cued by reactions of the front observers when sighting an animal. When a whale group was first seen, the observer called "whale" and then the species and number of individuals in the group were recorded. When the group was abeam, the declination angle was recorded with a Suunto clinometer. If whale sightings occurred in short succession, as was often the case, the observer estimated the position of the animal or group within one of six bands marked on the window corresponding to 200 m wide bands on the water from a 1000 ft 304.8 m) altitude. Observers also recorded sea state (Beaufort scale), ice cover (tenths), fog (%), or glare (%) in the front half of their viewing area.

Timing and survey design

We planned to conduct surveys during the later part of July and early part of August to correspond to the highest level of beluga aggregation in and around the Western Hudson Bay estuaries (Richard et al. 1990). The sampling effort was allocated to cover the areas of high beluga density more intensively than adjacent areas. A systematic line transect design was drawn using Distance 4 (Thomas et al. 2004). Two high-effort survey strata were located around the Churchill/Seal estuaries and the Nelson estuary (Fig.1), based on tracking and survey data from past years. Low-effort survey strata were drawn to cover the remainder of beluga distribution in the area: the western stratum, offshore of the Churchill/Seal and Nelson strata and the eastern stratum along the Hudson Bay coast of Ontario. Transect surveys were flown on 29 July for the Churchill and Western strata and on the 30 July for the Nelson stratum. Originally, because of high beluga aggregation in the Churchill and Seal estuaries, we had intended to photograph the aggregations during the same flights as we did the marine waters transect surveys to obtain a count which could be added to the marine transect surveys; aircraft power problems prevented this however. We therefore did visual counts inside the Churchill estuary. We were able to resolve our power issues and did some camera testing and systematic photographic transect surveys on 01 August.

Photographic system

The aerial photographic system was composed of a Rollei 6008 medium format camera equipped with a Phase One R50 (Phase One A/S Ltd.) and a 40 mm lens. The camera was operated from a desktop computer with Rollei Control6008 v1.1 software, which allows the operator to control the lens opening, the digital back's capture speed, and the interval between pictures. It also logs the settings used for each picture. The pictures were acquired on a large hard drive in PhaseOne proprietary compressed format and later decompressed into TIF images for analysis using Phase One's CaptureOne v2.9RC1 software.

Survey conditions

Pilots maintained an altitude of 304.8 m during all line transect surveys. Glare conditions were light in most transects. Fog was absent and ice cover was absent or light in all but the eastern parts of the Nelson stratum where ice cover reached 30%-40% and in the offshore portion of the eastern stratum where it reached 50%-80%. Sea state conditions were very good (Beaufort seas states <3) for observations throughout the surveys.

Line transect estimation methods

For the line transects we estimated the probability of detecting beluga groups using the distance sampling method described by Buckland et al. (2001), and partly in Innes et al. (2002). A conventional line transect estimate of abundance was obtained from left and right sightings. That estimate assumes that all belugas on the flight line are seen (g(0)=1). Because visibility is reduced near the track line to about 200 m, the line (x=0) here is offset 200m for the analysis. The line transect analysis was conducted using Distance 5 beta 4 software (Thomas et al. 2005). Various detection functions were examined. The function parameters were fitted by likelihood methods. The “best” fitting function was selected on the basis of the lowest Akaike Information Criterion (Burnham and Anderson 1998). Because there were too few samples to obtain reliable bootstrap estimates, variance was estimated with the empirical method detailed in Buckland et al. (2001). Estimates of population sizes extended to the entire area, corrected for missing distance data, and their respective variances were obtained using methods described below (Innes et al. 2002).

Adjustment for missing distances

A perpendicular distance was not always recorded for each observation. We assumed that the observations with missing perpendicular distance were a random sample of all observations and adjusted the estimated abundance in the following manner (Innes et al. 2002):

$$\hat{N}^* = \hat{N}\left(1 + \frac{n_m}{n}\right)$$

where n_m is the number of observations with a missing perpendicular distance and n is the total number of observations with a recorded distance including those beyond truncation limits. We estimated the variance as:

$$\hat{\text{var}}(\hat{N}^*) = \hat{\text{var}}(\hat{N})\left(1 + \frac{n_m}{n}\right)^2$$

Photo strip transect estimation methods

The estimates obtained from systematic digital photographic strip transects were analysed using methods described in Kingsley (1996). The expansion factor is obtained from the ratio of the transect spacing and the photo width. The estimate is then the sum of transect counts, totalling the non-overlapping portions of the consecutive photos, multiplied by the expansion factor. Kingsley and Smith's (1981) serial difference method for variance estimation for systematic surveys (based on Cochran 1977) was used to calculate the variance of the photo survey estimates.

Estimation and adjustment for availability bias

The correction factor to account for the number of belugas that were submerged as the survey aircraft flew over ('availability bias' cf. Marsh and Sinclair 1989) is based on target detection and beluga surfacing observations in the St. Lawrence (Kingsley and Gauthier 2002) and from retrievable time-depth-recorders deployed on belugas in the high Arctic (Innes et al. 2002). Similar TDR data was acquired in the Nelson estuary in 2002-2004 but results are not yet analysed.

Richard et al. (1994) found that submerged beluga models recorded on analog aerial photographs could be detected and correctly identified to species to a depth of approximately 4 m in clear offshore water. It is assumed that, in the less transparent estuaries, that detection could be reduced to 2 m of depth or even less. Studies of 11 belugas in the High Arctic showed that the proportion of belugas swimming as depths less than 4 m in marine waters is 54% CV: 1.4%) and less than 2 m in estuaries is 87% (CV = 3.2%) during August (Innes et al. 2002). Kingsley and Gauthier (2002) suggest an availability factor for lightly-silted waters of 47.8% (CV = 13.1%). Silt conditions in the inshore areas of western Hudson Bay where most of the observations were made are similar to those of the Saint-Lawrence. One exception is the upper part of the Nelson estuary which is highly silted but where depths are probably less than 2 m. There the animals are visible only when they break the surface but they are in very shallow water and must break the surface more frequently presumably making up for the lack of sightability. In the absence of better data, we used the St. Lawrence 47.8% (CV = 13.1%) estimate in all corrections for availability bias. The proportion of beluga whales that were available to be seen or photographed (p_a) was estimated as the mean of values for individual whales over selected periods and depth ranges. The var(p_a) was the squared standard error of the mean p_a of the tagged whales.

Following Innes et al. (2002), the abundance estimate was corrected for availability bias by dividing the estimated abundance ($\hat{N}^*$) by the availability bias:

$$\hat{N}^{**} = \frac{\hat{N}^*}{p_a}.$$

The variance of the corrected abundance estimate was computed as:

$$\hat{\mathrm{var}}(\hat{N}^{**}) = \left(\hat{N}^{**}\right)^2 [cv^2(\hat{N}^*) + cv^2(p_a)] \quad ,$$

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

Finally, ninety-five percent confidence limits were calculated after log transformation of variance estimates following Buckland et al. (2001) where the lower and upper confidence limits are N/V and N*V and

$$V=\exp[1.96*\mathrm{sqrt}(\ln[1+var(N)/N^2])]$$

Regional population estimation

Regional population estimates were obtained by summing stratum estimates and photo surveys. The standard errors of these summed estimates were obtained by empirical bootstraps of the sums of their lognormal distributions. The empirical bootstraps were conducted in Analytica 3.1 (Lumina Decision Systems, www.lumina.com) using the LogNormal_m_sd function, a Median Latin HyperCube resampling and 3000 replicates.

RESULTS

Churchill stratum 29 July

We surveyed the Churchill stratum on 29 July (Fig. 2). Most belugas (89%) were seen on the two westernmost transects around the Seal estuary. In addition, a large herd was found in the Churchill estuary's middle channel. There were only a few beluga sightings east of Churchill.

Recorder malfunction caused the loss of data on the left side during the first transect so the estimate could only be obtained from the right observer's sighting data. A multiplier of two was applied to the density calculation because Distance software assumes data input from both sides of a survey track when it calculates an estimate from the estimated effective strip width. The factor of two therefore yields a density estimate based on the area viewed from one side.

A hazard rate function was fitted to the sighting data grouped in 200 m intervals and left-truncated at 200 m (Fig. 3). The resulting near-surface estimate is 12,027 (CV=96.0%) belugas (Table 1). In addition, there were counts made by both right side observers along the mid-channel inside the Churchill estuary. The counts totalled 680 and 928 (mean: 804). These estuarine counts are approximations because it is very difficult to accurately count visually hundreds of animals over such a short distance during an aerial survey. Counts were made in 10s when animals were too aggregated and it is probable that some groups or individuals were missed in the count.

Correcting the stratum estimate for missed distances, adding the estuary mean count and correcting for availability bias yielded a very imprecise total Churchill stratum estimate of 27,514 (95% C.L. = 5,096-148,563) belugas (Table 2).

Western stratum 29-30 July

The Western stratum covers the inshore and offshore adjacent to the two high-density strata. Belugas were seen in only four transects (Fig. 4; sightings numbered from 1-4 for visibility) and most sightings (Fig. 4, number 3) were made on one transect near shore adjacent to the northwest corner of the Nelson stratum. A hazard rate function was fitted to the sighting data grouped in 200 m intervals and left-truncated at 200 m (Fig. 5). Because of the paucity of sightings and high clumping on one transect, the near-surface beluga population estimate has an imprecise value of 1,753 (CV=79.9%) (Table 1). Correcting the stratum estimate for missed distances and for availability bias yielded a total western stratum estimate of 3,667 with wide confidence limits (95% C.L. = 912-14,748) (Table 2).

Nelson stratum 30 and 31 July

The Nelson stratum (Fig. 6) is the second high-density stratum in western Hudson Bay. It was first surveyed on 30 July. Sightings were made in all but the southernmost transect, up the estuary. A hazard rate function was fitted to the sighting data grouped in 200 m intervals and left-truncated at 200 m (Fig. 7). The near-surface beluga population is estimated to be 12,591 (CV=40.0%) (Table 1).

We surveyed the Nelson stratum a second time on 31 July because it was the largest aggregation in 1987 (Richard et al. 1990). The number of beluga sightings was higher than in the first survey (Fig. 8). A hazard rate function was fitted to the sightings data grouped in 200 m intervals and left-truncated at 200 m (Fig. 9). The resulting near-surface estimate is 22,498 (CV=43.1%) (Table 1).

Using both surveys as replicates and fitting a hazard rate function yielded a more precise mean estimate of 17,544 near-surface belugas (CV=28.2%) for that stratum (Table 1). Correcting that estimate for missed distances, adding the estuary mean count and correcting for availability bias yielded a total Nelson stratum estimate of 37,122 (95% C.L. = 20,137-68,435) belugas (Table 2).

Churchill and Seal Photo estuary surveys 31 July

On 31 July, using a power unit for the aerial camera built from two 12 V batteries in parallel, we attempted to conduct a combined photographic and visual survey of the Churchill stratum at 1000 ft (305 m). This survey was aborted at the first transect because sea states exceeded Beaufort 3 as soon as we left the inshore region. We decided to test the resolution of the camera at varying altitudes over both estuaries and to try again the following day.

We photographed a large herd of belugas close to shore near the Seal estuary. We aligned the aircraft over the concentration along the shore and into the estuary and did two passes at different altitudes: 1000 ft (305 m), 3000 (914 m) and 5000 ft (1524 m). The 1000 ft pass was too low to encompass the aggregation. The other two passes seemed to capture most of the beluga aggregation but it is possible that we missed some more dispersed pods at the periphery of the aggregation. The resulting photo counts at 3000 ft and 5000 ft yielded counts of 4,074 and 5,253 belugas (Table 1).

A similar set of photographic passes was done at both altitudes over the Churchill estuary and yielded a photo count of 1,720 and 1,872 at 3,000 ft and 5,000 ft, respectively. Here too, we oriented the aircraft to pass over the aggregation as best we could but it is possible that we missed some scattered pods in the shallows surrounding the estuary's mid-channel occupied by the main herds. Consequently, these counts may be underestimates but the 5,000 ft passes did capture a large proportion of the whales. Once corrected for diving animals, the estimates are 10,571 (95% C.L. = 8,186-13,651) for the Seal estuary and 3,916 (95% C.L. = 3,033-5,057) for the Churchill estuary (Table 2).

A third pass was done at 10,000 ft (3048 m) to determine if it would be possible to count belugas at that altitude but it proved too difficult to distinguish belugas from wavelets, sun glare shimmer, or submerged white rocks at that altitude. The 10,000 ft pass was nevertheless useful to determine the coverage of the 3,000 ft and 5,000 ft passes.

Systematic photo surveys of the Seal and Churchill estuaries 01 August

The photographic passes conducted on 31 July suggested that excellent counts could be obtained from 3000 ft passes in most conditions while 5000 ft were also feasible in good sighting conditions, i.e., when sea state and sun glare were reduced. Because of the extreme clumping of belugas noticed in previous days in the inshore portion of the Churchill stratum and both estuaries, we thought there would be little value in conducting the same visual systematic surveys that were done on 29 July. Instead, we decided to conduct a photographic survey of large beluga aggregations. First, we completed a reconnaissance survey along the Churchill stratum transects with both aircraft throughout the Churchill stratum to determine the locations of aggregations. Three aggregations of several thousand belugas were located: one in the Churchill estuary, one in the Seal estuary, and a third between the two, in the waters adjacent to the Knife Delta. Belugas were otherwise scattered in small groups in a few other transects, as had been seen on 29 July. In addition, a pod of seven killer whales was observed at the offshore end of the easternmost stratum of the Churchill stratum, north of Cape Churchill.

The three aggregations were delimited by DGPS coordinates and survey grids were flown to cover them almost completely with no overlap between adjacent photo transects. The larger Seal River aggregation was surveyed first using 11 lines (Fig. 10), and yielded an estimate of 7,589 (CV= 17.3%) whales (Table 1). Once corrected for availability bias this results in an aggregation of 15,887 (95% C.L. = 10,427-24,174) (Table 2). The second aggregation could not be found subsequently and we supposed that it had merged with the one in the Seal River since it was travelling in that direction when spotted during the morning reconnaissance surveys. The Churchill estuary aggregation was photographed following a grid with six lines but the tide was low and only four lines were needed to cover the water occupied by the belugas (Fig. 11). One transect had most of the animals and the survey yielded an estimate of 2,076 with a high CV (40.6%) (Table 1). Once corrected for availability bias, the estuary's was estimated to contain 4,343 belugas (95% C.L. = 1,949-9,680) (Table 2).

Eastern stratum 2 and 6 August

We started surveying the eastern stratum on 2 August. Sightings were made throughout most the western transects (Fig. 12). In the offshore small flow pack ice made sighting belugas very difficult so we terminated transects when ice cover exceeded 50%. Left and right side counts totalling 63 belugas were also obtained off transect in the Severn estuary. We had to stop surveying just before the Winisk estuary because of low fog. For line transect estimation, the survey stratum area and transect lengths were adjusted according to the actual transect distances covered (solid lines in Fig. 12). The stratum was post-stratified to reflect the coverage accomplished on 2 August (the thick black line in Fig. 12 delimits the post-stratification into an east and west post-stratum). A halfnormal function was fitted to the sighting data grouped in 200 m intervals and left-truncated at 200 m (Fig. 13). The resulting near-surface estimate is 6,866 (CV=36.3%) belugas for the 2 August post-stratum (Table 1).

We were able to resume surveys of the easternmost transects on 6 August. On 6 August, no sightings were done to the east, except in the Winisk estuary where we made two counts on the same side of the aircraft: 140 and 150 (average =145) (Fig. 12).

Correcting that estimate for missed distances, adding the Severn and Winisk estuarine counts and correcting for availability bias yielded a total Eastern stratum estimate of 14,799 (95% C.L. = 7,126-30,734) belugas (Table 2).

DISCUSSION

The Churchill stratum surveys showed considerable inshore aggregation of beluga whales, particularly at the river mouths of the Churchill and Seal rivers. There were relatively few whales in the adjacent Western stratum. The extreme clumping resulted in a very high CV for the 29 July estimate of the Churchill stratum (Tables 1 and 2). The photographic survey estimates of 1 August (systematic photographic surveys of Seal and Churchill estuaries), which covered only a fraction of the inshore area of the line transect stratum yielded a total mean estimate 9,665 belugas visible at the surface (Table 1) and once corrected for availability bias a mean estimate of 20,220 (Table 2). This illustrates the high degree of inshore clumping in that stratum. In fact, due to the presence of killer whales, it is possible that most if not all belugas in the Churchill stratum were recorded by the photographic survey. We noticed a higher degree of clumping on the morning reconnaissance surveys of the stratum. There were essentially three herds of belugas: one in the Churchill estuary and two to the west of it. These two herds had probably merged into one at the mouth of the Seal estuary when we photographed it on the afternoon of 1 August. The 1 August photographic estimates total to a value that is larger than the sum of 5000 ft photographic counts done on 31 July. Finally, given the degree of beluga aggregation, the estimates from the systematic photographic surveys of the Churchill and Seal estuaries done on 1 August, and which targeted the aggregations, are much more precise (CVs= 43% and 22%;Table 2) than the 29 July estimate of the Churchill stratum (CV= 105%;Table 2).

The extreme aggregation of belugas in the Churchill stratum is probably the result of the presence of the pod of seven killer whales sighted offshore of Cape Churchill. Belugas in the Churchill stratum were probably herding into the shallow Churchill and Seal rivers to avoid predation. There are many Inuit tales of belugas and narwhals hugging the shoreline when killer whales are present in an area. It has recently been shown that it does not take a large number of killer whales to cause a noticeable reduction in a marine mammal population (Williams et al. 2004) so belugas may have adapted to seek shelter in shallow waters at times when there is no pack ice in which to hide from killer whales.

The two Nelson stratum visual surveys done on July 30-31 yielded different (but not significantly so) surface population estimates. The group size estimates were identical but during the second survey the beluga sighting rate was 1.5 times higher and the effective strip width smaller by 80 m, which accounts for the difference in the estimates. While the two surveys were done by different observer crews, this difference is too large to be attributed to differences in observer efficiency. Both sets of observers had similar survey experience: all but one, whose data was not used here, had done at least three beluga surveys in the past. In effect, the 31 July crew saw beluga pods more frequently than on the 30 July one and, as a result, their effective strip width shrunk as they struggled to record the sightings closer to the aircraft first. A factor affecting sightings could be that the 31 July survey was done at high tide when water clarity would have been better than during the 30 July survey which was flown at low tide in more turbid water conditions. Another factor could be movement into the Nelson stratum from the adjacent portions of the Western stratum. The largest sightings in the Western stratum on 29-30 July were very close to the Nelson stratum boundaries. However, the two survey estimates are not significantly different from one another since their confidence limits widely overlap. The mean estimate (37,122; Table 2) derived from the two surveys of the Nelson stratum is a better and more precise measure of the abundance of belugas in that stratum.

To obtain a total regional estimate for the Western Hudson Bay, we must make a number of assumptions before summing the stratum estimates. One assumption is that there could be movement of belugas between strata during the several days that these surveys were conducted. This is reasonable since we saw belugas in three large herds on the morning of the 1 August, one of which was moving towards the Seal River and apparently had merged with the herd already in that estuary by the afternoon.

If we assume that there were beluga movement between strata, the most conservative estimate of the Western Hudson Bay population is the sum of the Nelson strata's mean estimate (30-31 July) added to the sum of photo survey estimates (1 August, Churchill and Seal estuaries). Both surveyed areas are too far apart (176 km along the coast from the Churchill estuary to the northwest corner of the Nelson stratum) for belugas to move from one to the other in a day or two. They also encompass the highest densities of belugas in the region. Summing those two surveys, the resulting Western Hudson Bay population size is thus 57,342 (95% C.L.: 37,763-87,071) (Table 3). Alternately, the sum of the Nelson mean estimate and the 29 July Churchill line transect estimate is also a plausible, albeit much less precise, 64,636 belugas (95% C.L.: 26,515-157,565; Table3).

Both these estimates are derived from coverage similar to the areas surveyed in late July 1987 (Richard et al. 1990). The uncorrected estimate of belugas (i.e.: seen near the surface) in the Churchill-Seal and Nelson areas (27,200) is very similar to the number (25,100) estimated in 1987, indicating that there has not been a detectable change in beluga numbers since those earlier surveys.

If we assume that there was no movement between the West stratum and the Nelson stratum, we obtain a partial estimate for Western Hudson Bay population (without East stratum) of 61,009 whales (95% C.L.: 40,683-91,490) from the sum of the West stratum, the Churchill-Seal photographic survey and the Nelson stratum mean estimates (Table 3). This assumption is more risky because most of the sightings in the West stratum were outside the periphery of the Nelson stratum (Fig. 3, sighting groups labelled 3 and 4).

Finally, if one assumes that the East stratum belugas did not come from the Nelson or West stratum, we can derive a total Western Hudson Bay population of 75, 808 belugas (95% C.L.: 53,038-108,354) (Table 3). This is a difficult assumption to make because tracking data shows that belugas tagged in the Nelson estuary move out of that area in the month of August, proceeding eastward into the East stratum. Another problem is that there is evidence that belugas that aggregate in the Severn and Winisk estuaries are there early in the spring and remain in or near these estuaries all summer (Richard et al. 1990). The stock identity of those animals is still unclear but we may be counting animals from more than the Western Hudson Bay stock.

In summary, these aerial surveys have allowed us to estimate that there are several tens of thousands of belugas in Western Hudson Bay. The most conservative estimate, obtained by the sum of the estimates of the Churchill-Seal and Nelson areas and rounded to the nearest hundred, is 57,300 belugas (95% C.L.: 37,700-87,100). There were belugas seen in an adjacent stratum but it is unclear if they moved into the survey areas in between survey periods. The estimates of belugas seen near the surface in the Churchill-Seal and Nelson areas are very similar to the numbers obtained in 1987. We conclude that the population has not experienced a detectable change in numbers since 1987. More than 7,000 belugas were also estimated to occur along the Ontario coast of Hudson Bay but it is difficult to assign them all to a single beluga stock for lack of stock identity information. It is also possible that some of these whales moved out of the Nelson stratum into that stratum between survey days.

ACKNOWLEDGEMENTS

Funding was provided by the Nunavut Wildlife Research trust Fund and the department of Fisheries and Oceans Nunavut Implementation Fund. I am very grateful for the logistic and accommodation support provided by the staff of the Churchill Northern Studies Center. Thanks to Natalie Asselin, Jean-François Gosselin, Pierre Carter, Klaus Hocheim and Courtenay O'Brien-Moran who served as survey observers. I am especially grateful to Klaus who operated the digital camera, and did the painstaking digital image mosaicing and counts of belugas off those images. Thanks to Courtenay and Natalie for their assistance in the visual survey data processing and mapping. I also thank the pilots and staff of Hicks & Lawrence for their assistance.

REFERENCES

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers and L. Thomas. 2001. Introduction to distance sampling. Estimating abundance of biological populations. Oxford University Press, 432 pp.

Burnham, K. P. and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA.

Cochran, W.G. 1977. Sampling Techniques. Wiley, New York. 429 p.

Innes, S., D.C.G. Muir, R.E.A. Stewart, M.P Heide-Jørgensen and R. Dietz. 2002. Stock identity of beluga (*Delphinapterus leucas*) in Eastern Canada and West Greenland based on organochlorine contaminants in their blubber. NAMMCO Scientific Publications 4.

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 + 42 p.

Kingsley, M.C.S. and G.E.J. Smith. 1981. Analysis of data arising from systematic transects surveys p 40-48. *In*: F.L. Miller & A. Gunn [eds] Proc. Symp. Census and Inventory Methods for Populations and Habitats, Banff, April 1980.

Kingsley, M.C.S. and Gauthier. 2002. Visibility of St. Lawrence belugas to aerial photography, estimated by direct observation. NAMMCO Scient. Publ. 4:259-270.

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.

Martin, A.R., P.Hall and P.R. Richard. 2001. Dive behaviour of belugas (*Delphinapterus leucas*) in the shallow waters of western Hudson Bay. Arctic. 54:276-283.

Richard, P.R., Weaver, P.A., Dueck, L.P., and Barber, D.G 1994. Distribution and numbers of Canadian high Arctic narwhals (*Monodon monoceros*) in August 1984. *Meddelelser om Grønland* - Bioscience. 39:41-50.

Richard, P.R., Orr, J.R., and Barber, D.G. 1990. The distribution and abundance of belugas, *Delphinapterus leucas* , in eastern Canadian subarctic waters:a review and update. p. 23-38. *In*: T.G. Smith, D.J. St.Aubin, and J.R. Geraci [eds.] Advances in research on the beluga whale, *Delphinapterus leucas* . Can. Bull. Aquat. Sci. 224.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. 2004. Distance 4.1 Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. 2005. Distance 5.0 Release “beta 4”. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

Williams, T.M. J.A. Estes, D.E. Doak, and A.M. Springer. 2004. Killer appetites:Assessing the role of predators in pcological communities. Ecology 85(12):3373-3384.

Table 1: Near-surface estimates of beluga whale numbers from line and photographic transect surveys flown in 29 July to 06 Aug 2004 in Western and southern Hudson Bay.

Line Transect Surveys	Date	# lines	Effort (km)	ESW (m)*	Sightings	Sighting rate	E(S) **	Number (CV)
Churchill stratum transects (Hz)	29-Jul	11	346	360.8	73	0.211 (93.1)	6.2 (21.2)	12027(96.0)
Churchill estuary counts (+)	29-Jul	1	13	-	-	-	-	680-928
Nelson line transects (Hz)	30-Jul	7	551	534.9	613	1.112 (39.7)	1.86 (2.6)	12591 (40.0)
Nelson line transects (Hz)	31-Jul	7	551	452.3	917	1.664 (3.3)	1.9 (2.1)	22498 (43.1)
Average Nelson line transects (Hz)	30-31 Jul		-	-	-	-	-	17544 (28.2)
Western line transects (Hz)	29&30-Jul	14	1365	633.9	17	0.0125 (24.3)	4.4 (34.1)	1753 (79.9)
Eastern stratum –west post-strat (Hn)	02-Aug	10	495	403	53	0.107(25.8)	3.2 (18.7)	6866 (36.3)
Eastern stratum –east post-strat	06-Aug	9	463	-	0	-	-	0
Severn estuary (+)	04-Aug	1	~10	-	-	-	-	63
Winisk estuary (+)	06-Aug	1	~10	-	-	-	-	145
Photo Surveys		**# lines**	**Photo width (km)**	**Spacing (km)**	**Count**			**Number (CV)**
Churchill 3000 ft (+)	31-Jul	1	0.817	-	1720			1720
Churchill 5000 ft (+)	31-Jul	1	1.362	-	1872			1872
Seal 3000 ft (+)	31-Jul	1	0.817	-	4074			4074
Seal 5000 ft (+)	31-Jul	1	1.362	-	5253			5253
Seal systematic 3000 ft	01-Aug	11	0.817	1.463	4240			7589 (17.3)
Churchill systematic 3000 ft	01-Aug	4	0.817	1.103	1538			2076 (40.6)

* ESW: effective strip width estimated by fitted detection function
** E(S): estimated pod size
(+): a single pass over aggregation (2 observers)
(Hz): Hazard rate model
(Un): Uniform model
(Hn): Half-normal.

Table 2: Estimates of beluga population size in 2004 Western and Southern Hudson Bay visual strata and photo surveys.

Survey		Estimate	CV	Proportion missing distances	Adjustment for missing distances	+ estuarine count (*)	Proportion whales seen	Total estimate	Error Prob. with alpha 5%	Confidence limits	CV
Churchill stratum 29 Jul	**Mean**	12,027		2.7%	12,348	13,152	47.8%	27,514	2.5%	5,096	
	SE	11,546	96.0%		12,828	12,828	6.3%	28,810	97.5%	148,563	105%
Nelson Stratum mean 30-31 Jul	**Mean**	17,544		1.1%	17,744		47.8%	37,122	2.5%	20,137	
	SE	4,947	28.2%		5,177		6.3%	11,873	97.5%	68,435	32%
West stratum 29-30 Jul	**Mean**	1,753			1,753		47.8%	3,667	2.5%	912	
	SE	1,401	79.9%		1,401		6.3%	2,969	97.5%	14,748	81%
Churchill Photos 31 Jul	**Mean**	1,872			1,872		47.8%	3,916	2.5%	3,033	
	SE				0		6.3%	513	97.5%	5,057	13%
Seal Photos 31 Jul	**Mean**	5,053			5,053		47.8%	10,571	2.5%	8,186	
	SE						6.3%	1,385	97.5%	13,651	13%
Seal systematic Photo survey 01 Aug	**Mean**	7,589			7,589		47.8%	15,877	2.5%	10,427	
	SE	1,313	17.3%		1,313		6.3%	3,445	97.5%	24,174	22%
Churchill systematic Photo survey 01 Aug	**Mean**	2,076			2,076		47.8%	4,343	2.5%	1,949	
	SE	843	40.6%		843		6.3%	1,853	97.5%	9,680	43%
East Stratum 02-06 Aug	**Mean**	6,866			6,866	7,074	47.8%	14,799	2.5%	7,126	
	SE	2,494	36.3%		2,494	2,494	6.3%	5,715	97.5%	30,734	39%

(*) Counts were averages of 680 and 928 belugas in Churchill estuary on 29 July; the sum of 35 and 28 in Severn on 2 August; and the average of 140 and 150 in Winisk estuary on 6 August

Table 3: Sum of 2004 estimates of beluga population size in Western and Southern Hudson Bay.

Strata or survey combined		Total estimate	Error Prob. alpha = 5%	Conf. limits	CV
Sum of Churchill stratum (29 July)	**Mean**	64,636	2.5%	26,515	
+ Nelson stratum mean (30-31 July) (*)	**SE**	30,971	97.5%	157,565	48%
Sum of Churchill-Seal photo survey	**Mean**	57,342	2.5%	37,763	
+ Nelson stratum mean (*)	**SE**	12,360	97.5%	87,071	22%
Sum of Churchill-Seal photo survey +	**Mean**	61,009	2.5%	40,683	
Nelson stratum mean + West stratum (29-30 July)	**SE**	12,749	97.5%	91,490	21%
Sum of Churchill-Seal photo survey + Nelson	**Mean**	75,808	2.5%	53,038	
stratum mean + West stratum + East stratum (2-6 August)	**SE**	13,931	97.5%	108,354	18%

(*) These combined estimates are most comparable in their coverage with the 1987 estimates (Richard et al. 1990).

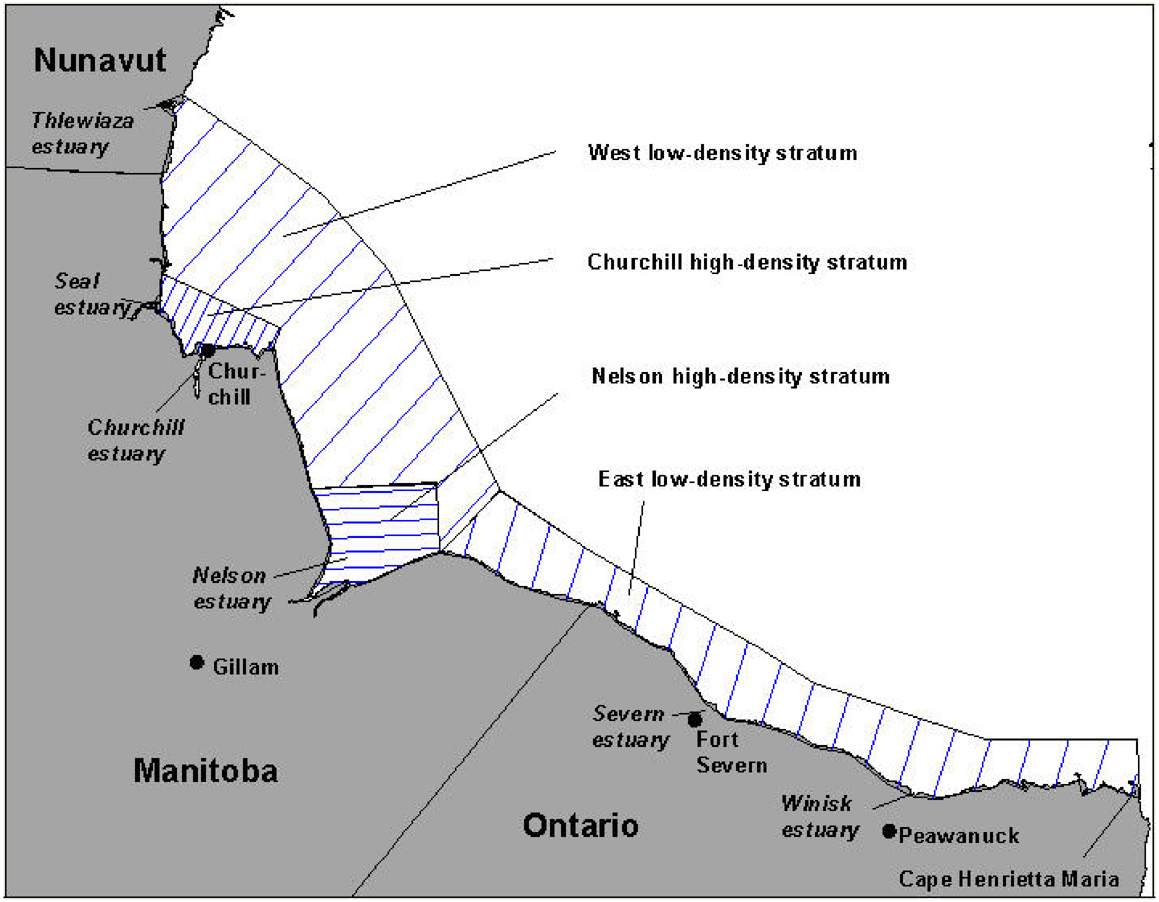

Fig. 1: Study area of 29 July - 6 August Western and Southern Hudson Bay surveys (planned survey strata and lines are illustrated).

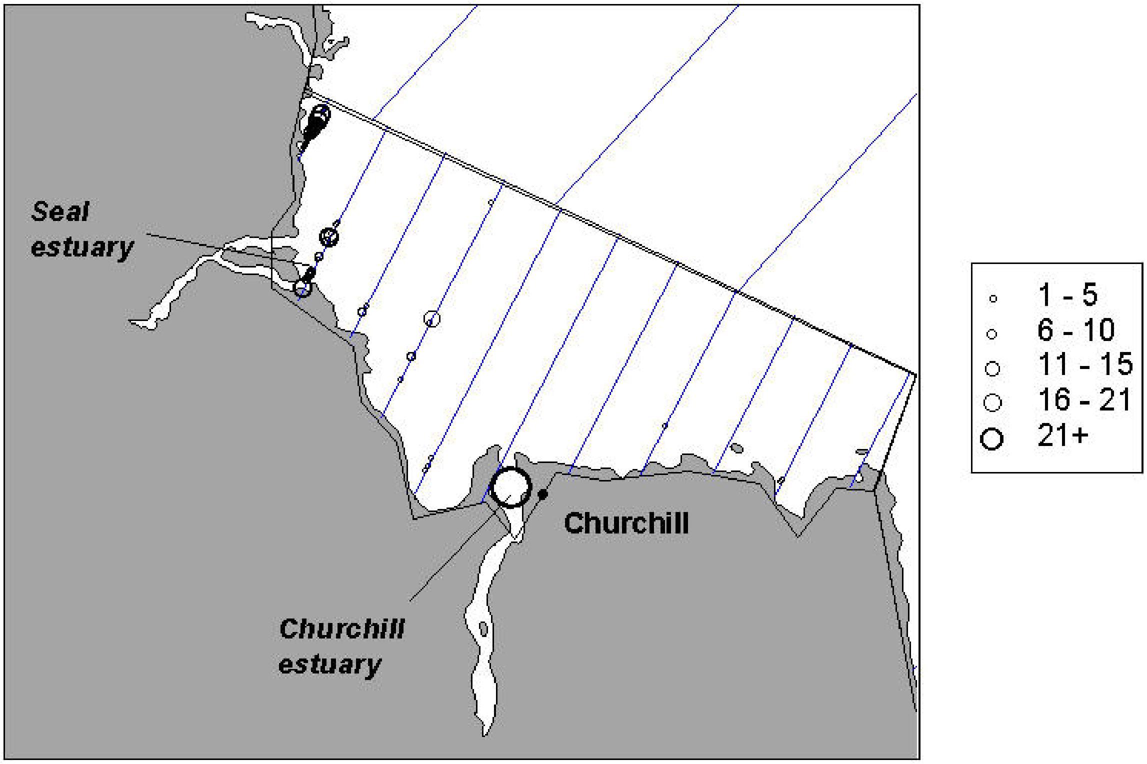

Fig. 2: Beluga survey transects conducted in the Churchill survey stratum on 29 July 2004 (right observer sightings are shown; the Churchill estuary aggregation is also illustrated with a wide open circle).

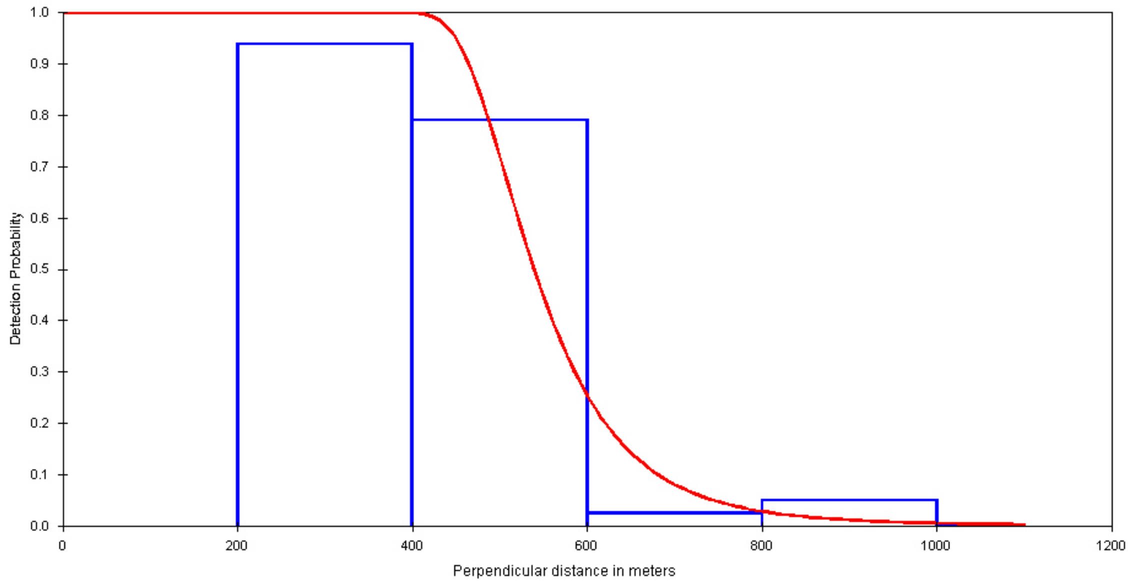

Fig. 3: Detection function for sightings data from the beluga surveys in the Churchill stratum on 29 July 2004.

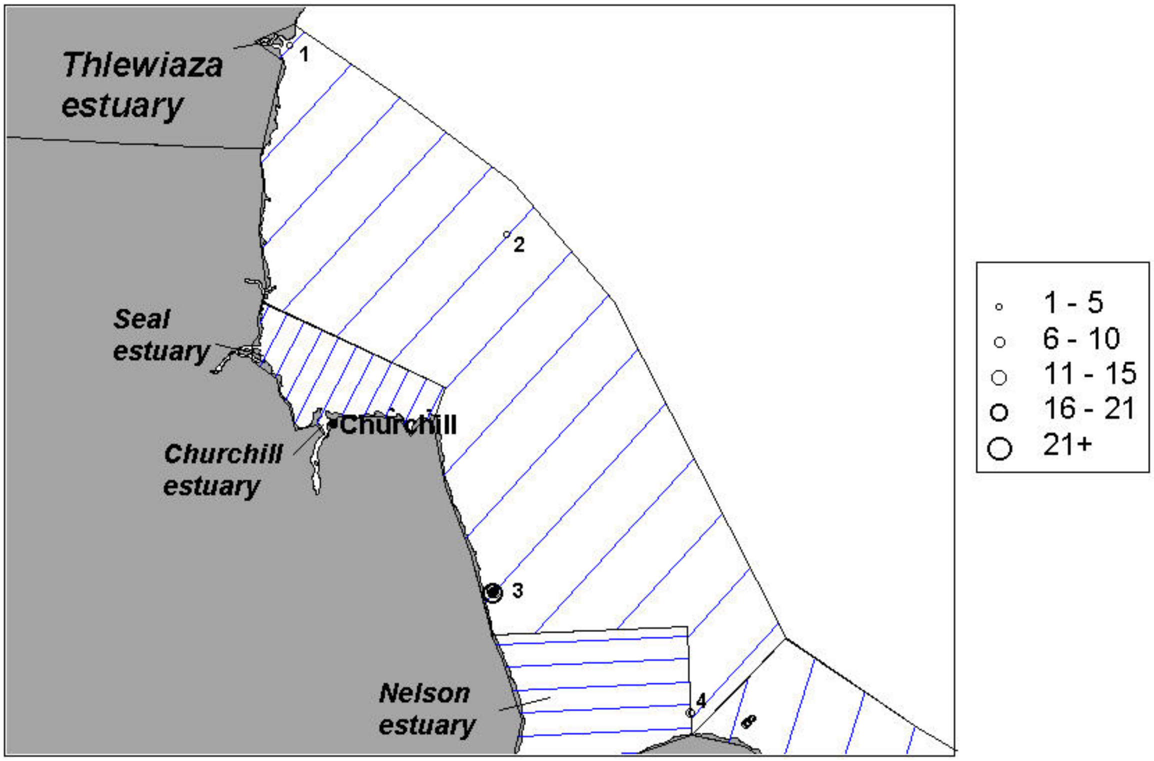

Fig. 4: Beluga survey transects conducted in the Western survey stratum on 29-30 July 2004 (left and right observer sightings are shown).

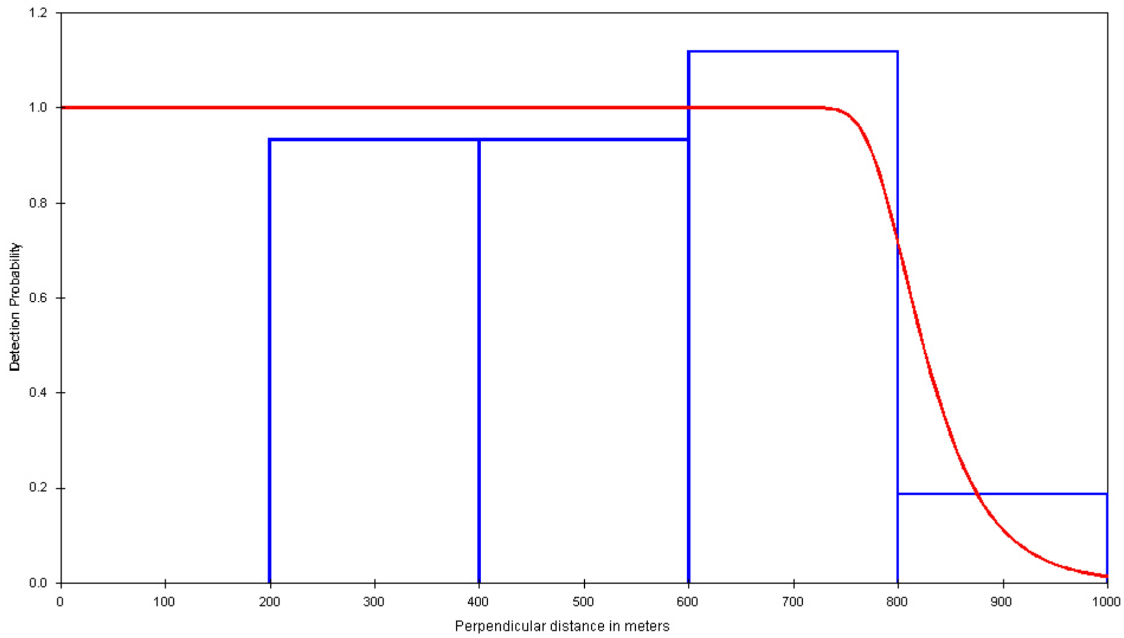

Fig. 5: Detection function for sightings data from the beluga surveys in the Western stratum survey on 29-30 July 2004.

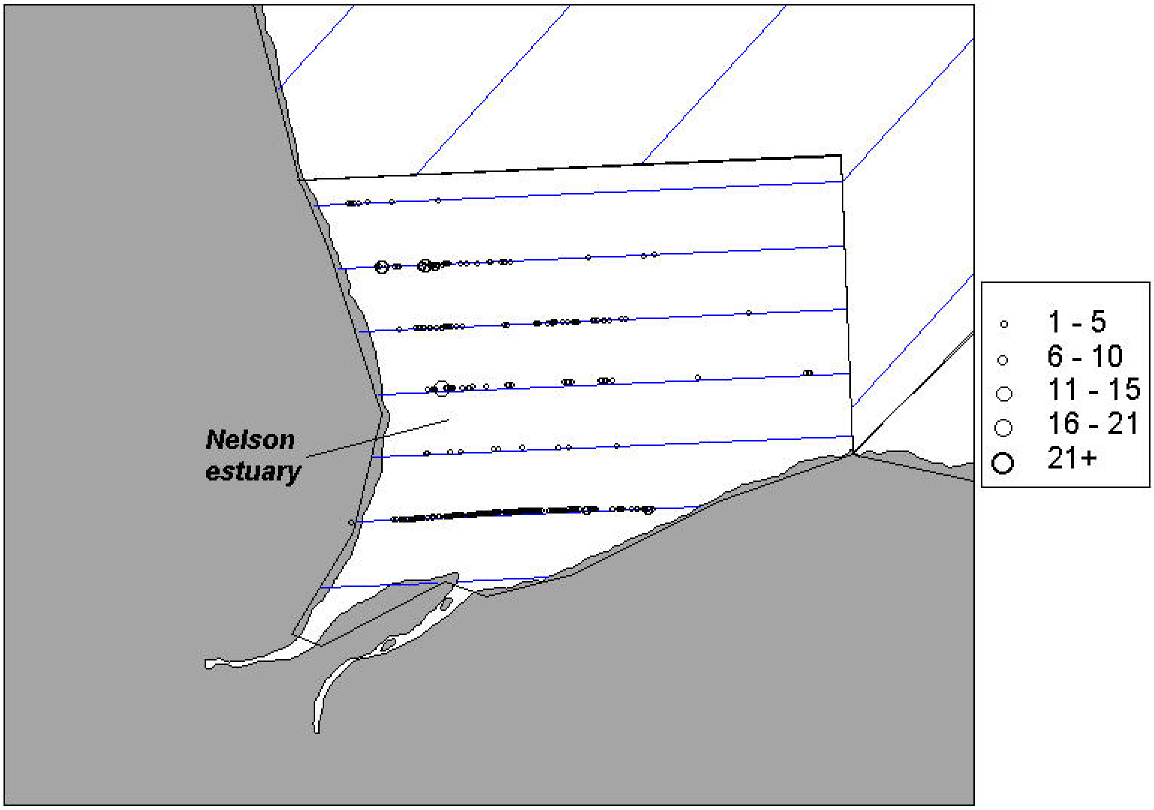

Fig. 6: Beluga survey transects conducted in the Nelson survey stratum on 30 July 2004 (left and right observer sightings are shown).

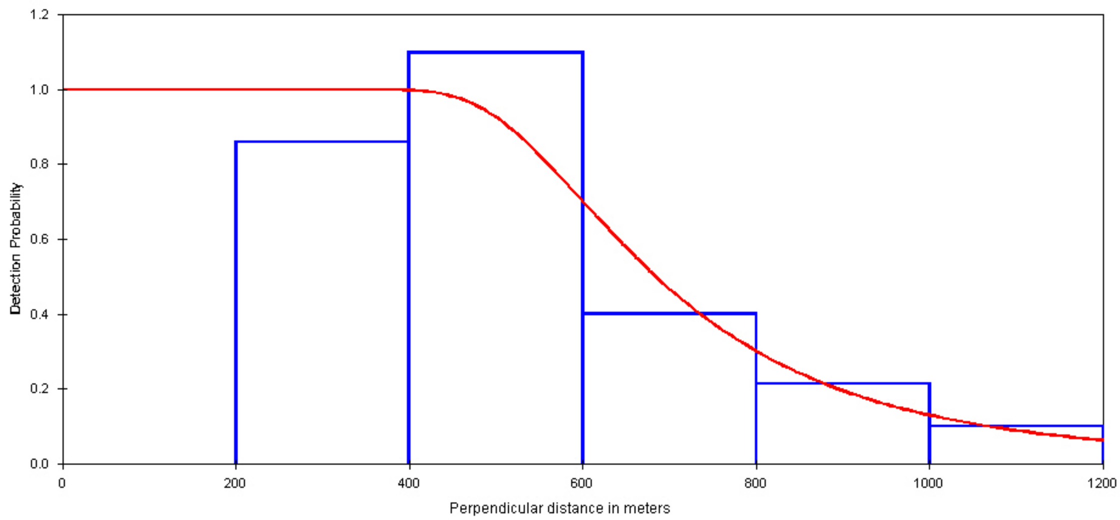

Fig. 7: Detection function for sightings data from the beluga surveys in the Nelson stratum on 30 July 2004.

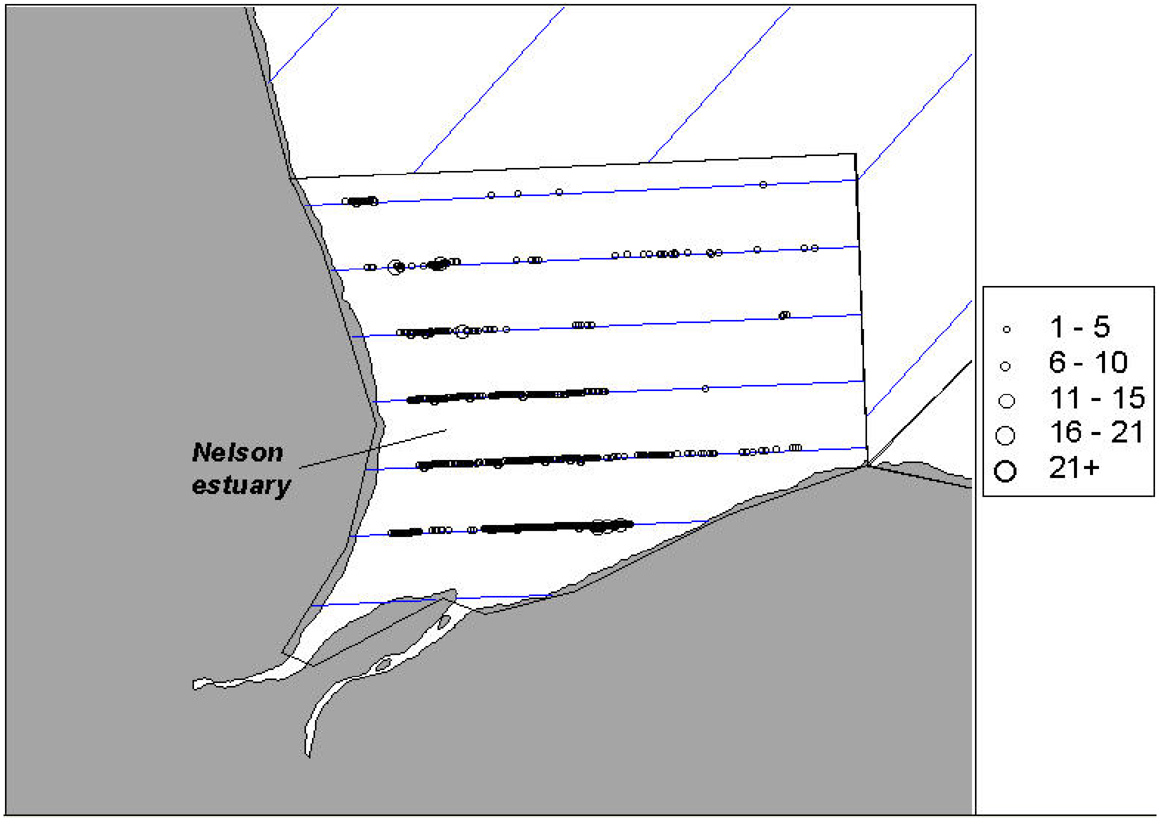

Fig. 8: Beluga survey transects conducted in the Nelson survey stratum on 31 July 2004 (left and right observer sightings are shown).

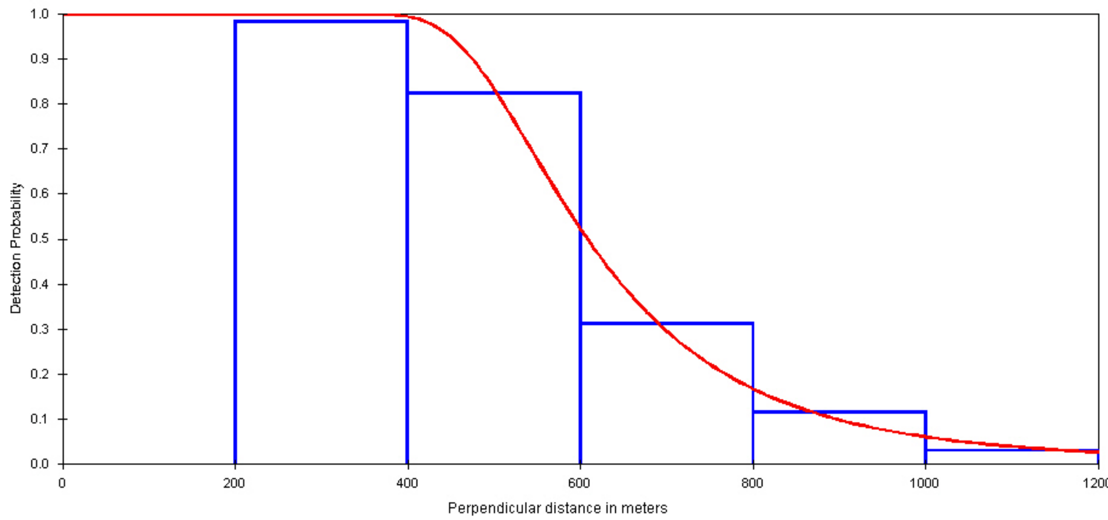

Fig. 9: Hazard Rate detection function for sightings data from the beluga surveys in the Nelson stratum survey on 31 July 2004.

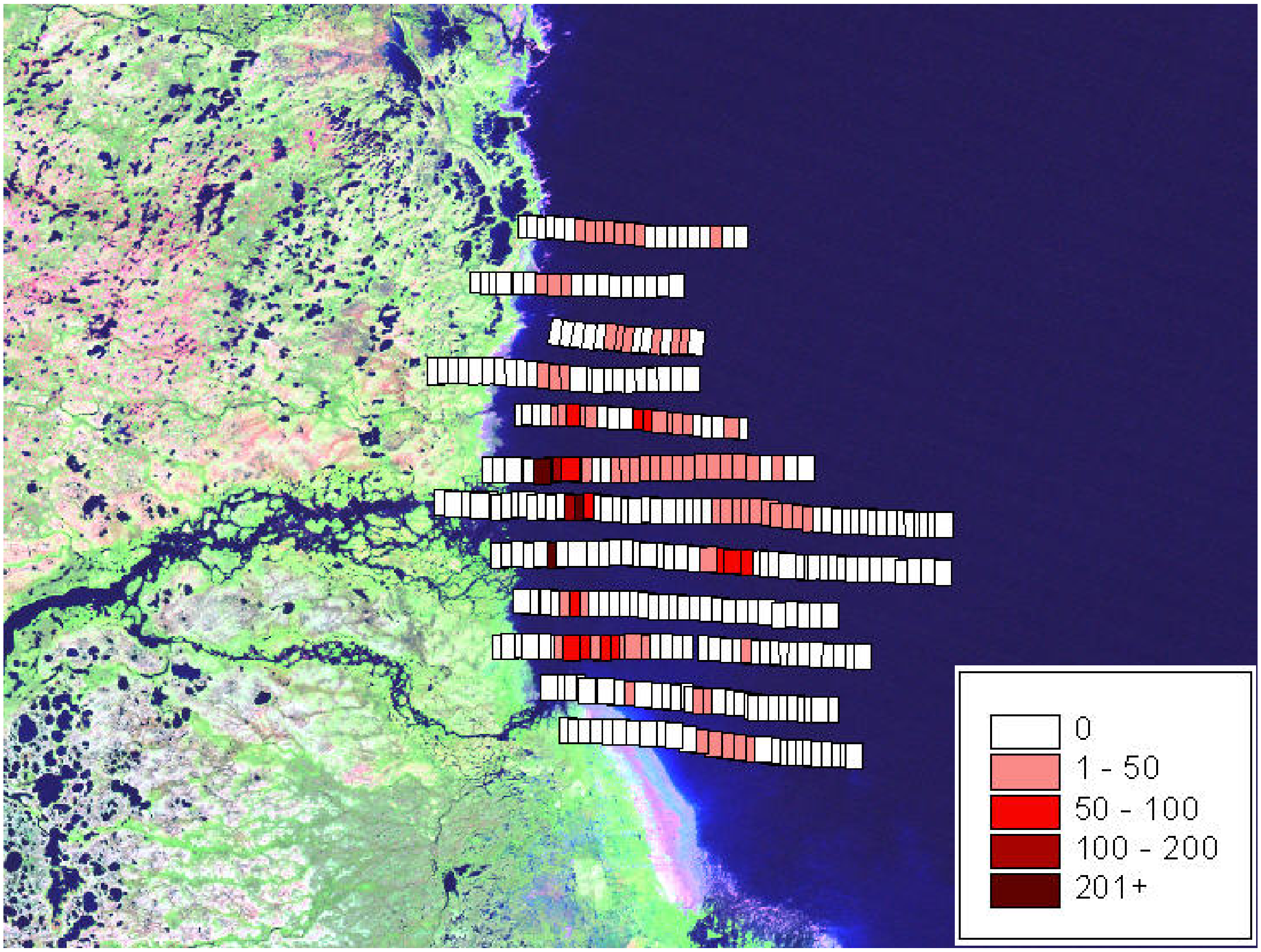

Fig. 10: Beluga photo surveys conducted in the Seal estuary on 1 August 2004.

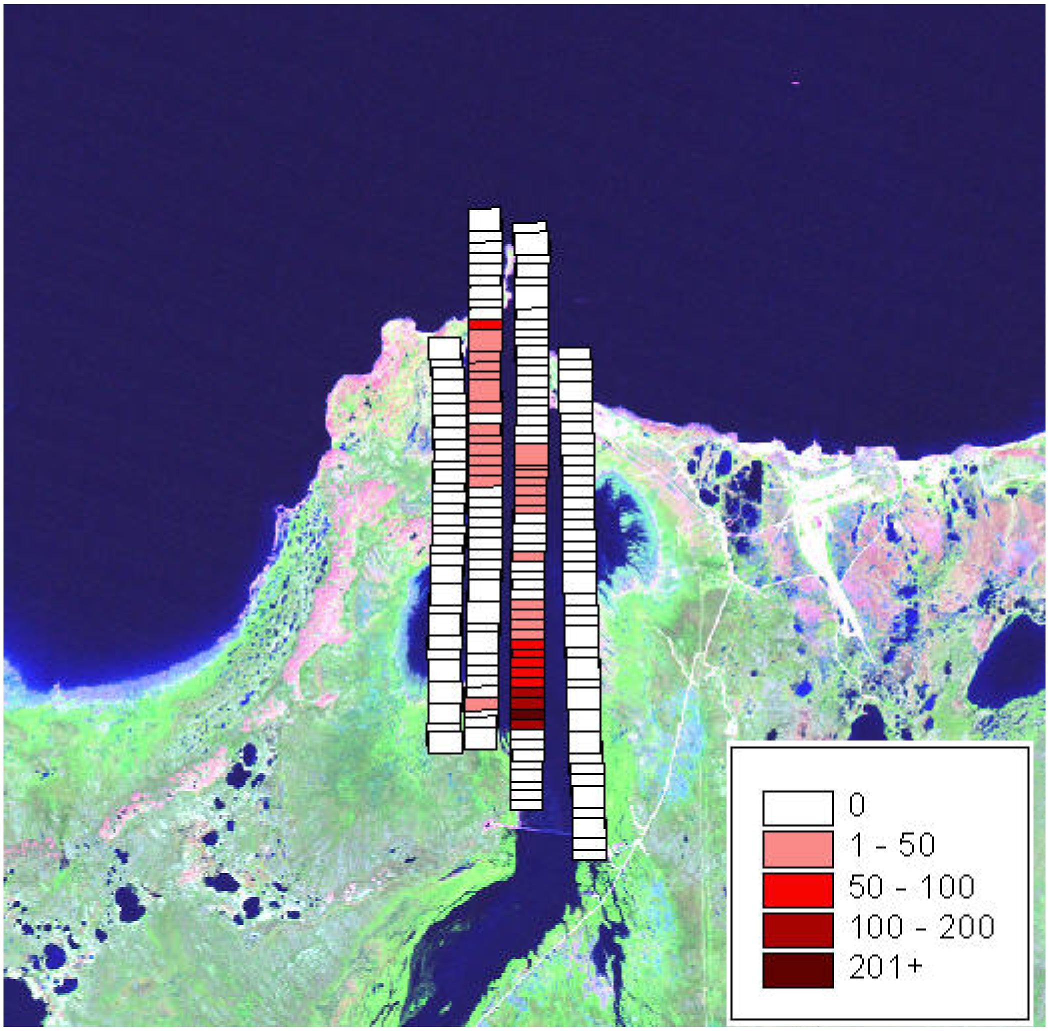

Fig. 11: Beluga photo surveys conducted in the Churchill estuary on 1 August 2004.

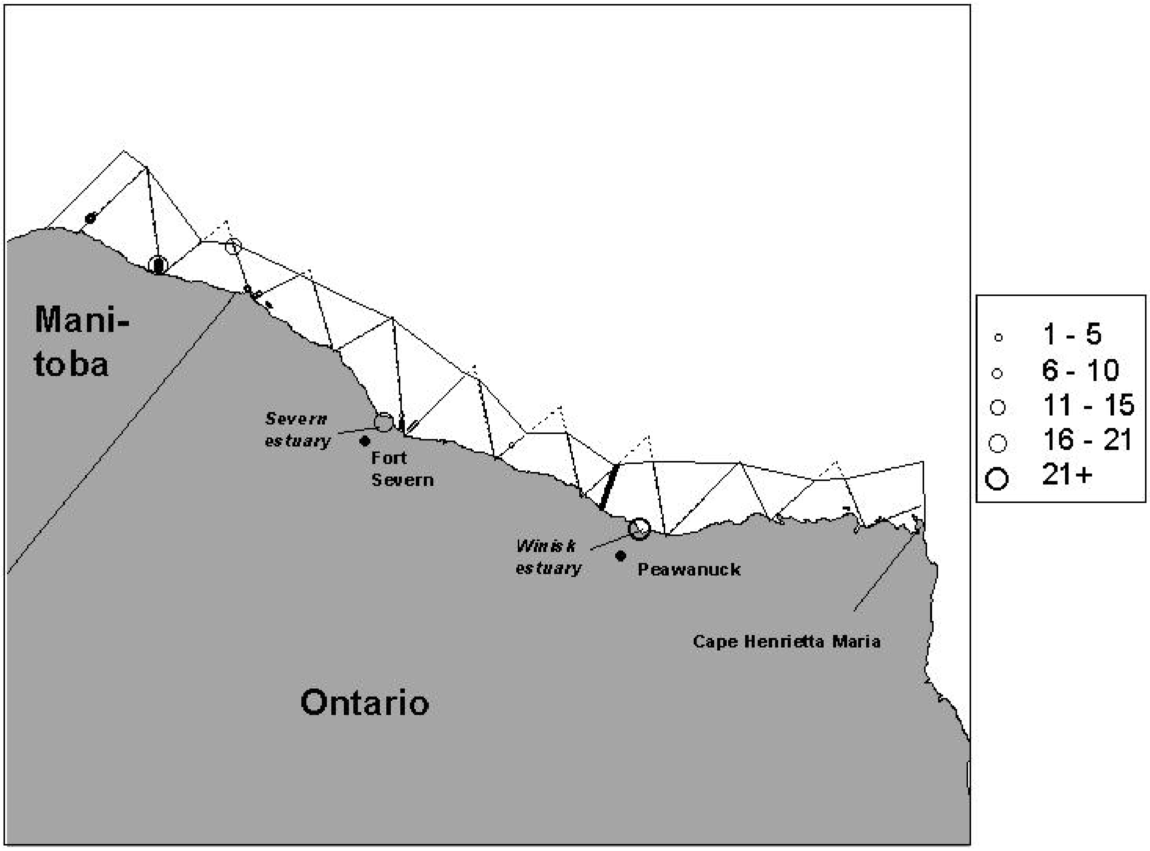

Fig. 12: Beluga survey transects and estuarine counts conducted in the Eastern survey stratum on 2 and 6 August 2004 (left and right observer sightings are shown; dotted lines indicate the portions not surveyed due to ice cover; thick black line delimits the post-stratum boundary).

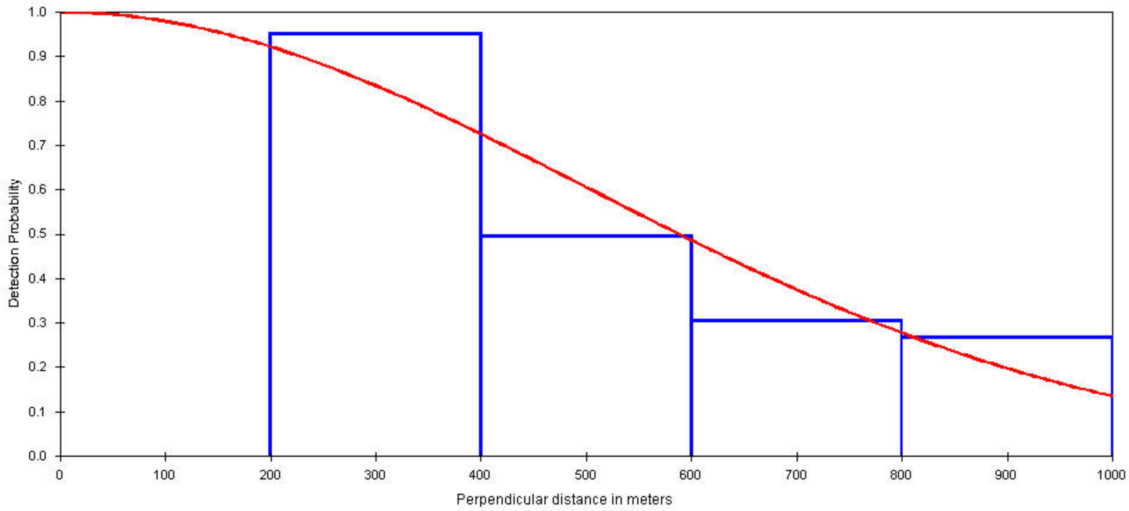

Fig. 13: Half Normal detection function for sightings data from the beluga surveys in the western post-stratum of the eastern stratum on 2 August 2004.