Abstract—Aerial surveys to estimate the numbers of beluga whales, *Delphinapterus leucas*, were flown in James Bay, eastern Hudson Bay, and Ungava Bay in Canada in the summer of 1993 on transects systematically spaced 5 or 10 nmi apart. In James Bay and eastern Hudson Bay line-transect methods were used. In Ungava Bay strip transects were used, and off-transect sightings were also recorded. Beluga whales were also counted on coastal flights in eastern Hudson Bay and Ungava Bay. James Bay and eastern Hudson Bay were surveyed in August; Ungava Bay in July and again in August. Watches were kept from land at estuaries in eastern Hudson Bay in 1993 and in Ungava Bay in 1992 and 1993.

The estimates of detectable beluga whales (uncorrected for diving and observer errors) were 3141 (SE=787) in James Bay and 1014 (SE=421) in eastern Hudson Bay. A further 115–148 beluga whales were seen near the coast of eastern Hudson Bay during the coastal survey, but mostly away from traditionally used estuaries. The estimate for James Bay was nearly three times the previous estimate, made in 1985, possibly because ice cover in James Bay was much lower in 1993 than in the 1985 survey. The 1993 estimate for eastern Hudson Bay was close to that for 1985. No beluga whales were seen during aerial transects in Ungava Bay, but they were seen off-transect and on coastal flights, mostly in or near the Whale River estuary in southern Ungava Bay. The largest group sighted and the greatest number seen in any day consisted of 20 individuals, a minimum size for the summer population in Ungava Bay. An upper 90% confidence limit for summer numbers is imprecisely estimated at 150.

Neither the coastal surveys nor the land-based observations in Hudson Bay and Ungava Bay indicated the presence of large, dense herds that might have been inefficiently sampled by transect survey.

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Numbers and distribution of beluga whales, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay, and Ungava Bay in Canada during the summer of 1993

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James, Hudson and Ungava bays are summering areas for stocks of beluga whales (*Delphinapterus leucas*) (Sergeant and Brodie, 1975; Finley et al., 1982; Smith and Hammill, 1986; Richard et al., 1990). There are several apparently separate summer groups, which include a summer group of ~23,000 individuals in western Hudson Bay, a group of 1500 individuals in the eastern Hudson Bay arc, and a few individuals in Ungava Bay (Smith and Hammill, 1986; Richard et al., 1990). Beluga whales, probably composing other separate groups, also summer in southern Hudson Bay (Richard, 1993) and James Bay (Smith and Hammill, 1986).

A land claim agreement was signed between the Inuit of the central and eastern Canadian Arctic and the Government of Canada in 1990 (Anonymous, 1993). In eastern Hudson Bay, this land agreement defined a marine area around the Belcher Islands (the "Nunavut Settlement Area") for the use of the beneficiaries of that agreement (Figs. 1 and 2). It also defined an area north and east of the settlement area (the "Equal Use and Occupancy Area") to be shared by the Inuit of Nunavut and those of northern Quebec. Other provisions of the agreement, and of the earlier James Bay and Northern Quebec Agreement, assured the aboriginal people of a right to hunt beluga whales in these waters.

The hunting of beluga whales is valued by Inuit in northern Canada as a means of procuring food, as a tradition helping to define their culture, and as a recreation. Maintaining beluga whale hunting, and stocks adequate to support it, are important objectives for the Inuits. Commercial hunting in the 19th century severely reduced numbers of beluga whales on the eastern coast of Hudson Bay and in Ungava Bay and they have not yet recovered (Reeves and Mitchell, 1987a; 1987b; 1989). These stocks were listed as "threatened" and "endangered," respectively, by the Committee on the Status of Endangered Wildlife in Canada (Campbell, 1993), and exploitation still occurs (DFO, 1996; NAMMCO, 1999) A low reproductive rate limits the species's potential for increase (Sergeant, 1981; Kingsley, 1989); therefore careful monitoring and management of stocks are appropriate.

Population management requires periodic evaluations of stock size, as a basis for setting harvest levels and for estimating the effect of harvest on the population trend. Beluga whale stocks are evaluated by aerial survey in their summering areas. The previous, and first, offshore aerial survey of James Bay, eastern Hudson Bay, and Ungava Bay was flown in summer 1985 (Smith and Hammill, 1986), and the development in the early 1990s of a beluga whale management plan for northern Quebec rendered it timely to update information on the population.

This article reports the results of aerial surveys flown in summer 1993. A

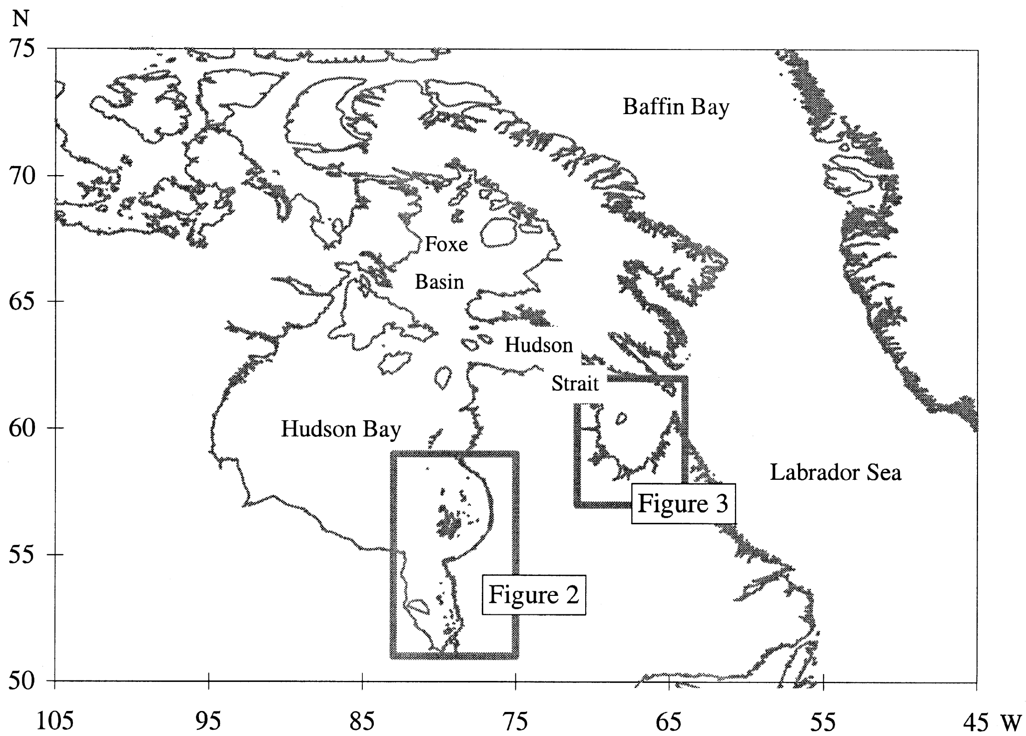

Figure 1

Map of northeastern Canada, showing the locations of the 1993 beluga whale aerial surveys in James Bay, eastern Hudson Bay, and Ungava Bay.

systematic transect survey was flown over offshore areas of James Bay, eastern Hudson Bay, and Ungava Bay (Figs. 1–3). However, summering beluga whales often form dense coastal concentrations, which are inefficiently estimated by sample survey. Therefore, coastal surveys were also flown in eastern Hudson Bay and Ungava Bay to check whether large numbers in concentration areas might have caused serious errors in the results of sample surveys. To the same end, watches were kept over known estuarine concentration areas from vantage points on land in 1992 and 1993.

Methods

Beluga whales concentrate in and around the mouths of rivers in summer, and this habit largely defines accepted stocks (Brown Gladden et al., 1997). Therefore aerial surveys for stock assessment are normally carried out in summer in these areas. The survey area for this study comprised James Bay, the eastern Hudson Bay arc north to 59°N and as far west as 80°20′W, and Ungava Bay. This area was similar to that covered by the previous aerial survey of these stocks in 1985 (Smith and Hammill, 1986). Beluga whales are uncommon in summer along the northern part of the eastern coast of Hudson Bay and the southern coast of Hudson Strait (Finley et al., 1982; Smith and Hammill, 1986); therefore the survey did not include these areas.

The transects in James Bay and eastern Hudson Bay were systematically spaced east–west lines similar to those used in 1985 (Smith and Hammill, 1986) (Fig. 2). They were on exact 10′ lines of latitude (i.e. 18.52 km apart) from the southern end of James Bay at 51°10′N as far as 58°50′N near Inukjuak, and additional lines were interpolated at 5′ (9.26-km) intervals between 55°35′N and 57°35′N, i.e. in the central part of the Hudson Bay arc.

The survey of Ungava Bay was also based on systematic designs (Fig. 3). South of 59°30′N, the initial design had north–south transects on every 15th minute of longitude, a spacing approximately equal to 7.5 minutes of latitude (13.9 km). North of this line the transects lay east–west on every tenth minute of latitude, i.e. 18.52 km apart.

Earlier surveys of Ungava Bay had detected few beluga whales (Finley, 1982; Smith and Hammill, 1986). Inuk hunters had suggested that flying at different times in the summer might produce different results; therefore the Ungava Bay survey was flown twice: in mid-July and in late August. In both surveys, sections of the coastline were followed and surveyed when ferrying to and from transect blocks, so that the coastline, particularly near the logistic base at Kuujjuak, was repeatedly covered.

The transect survey of James Bay and eastern Hudson Bay was flown in a Cessna 337 aircraft, at 1500 feet (457 m) above sea level at about 130 knots, (67 m/s), and navigated by GPS. The aircraft was equipped with flat windows. Observers sat in the two seats behind the pilot. Line-transect survey methods were used, in which all sightings were recorded with their distance from the transect line, and a sighting curve was subsequently calculated to correct for the decreasing detectability of targets with distance.

The angle of view from the horizontal was measured with Suunto inclinometers. Records were made with time-coding tape recorders and were transcribed daily. Ground speeds were calculated from the elapsed time on the transect and sighting positions were interpolated along transects. The state of the sea was assessed and recorded by using the Beaufort Scale of wind force; survey plans included not flying in conditions over Beaufort 4 (i.e. over 10 knots or 5.14 m/s).

The coastline of the eastern Hudson Bay arc was surveyed once, on 21 August, in a flat-windowed "Twin Otter" aircraft flying at 500–1000 ft (152–305 m). The observers, two to seven in number depending on the survey segment, were members of local hunters' and trappers' associations; they sat behind the pilots and recorded observations directly onto sighting maps. The flight line from Kuujjuaraapik followed the mainland coastline northbound to Inukjuak. The southbound leg was flown on the offshore side of the chains of islands close to the coast, and the plane made a detour to survey Richmond Gulf. It flew as far south as the Vauquelin River before returning to end at Kuujjuaraapik (Fig. 2).

The Ungava Bay surveys used strip-transect methods. A "Twin Otter" aircraft was flown at an altitude of 1500 feet (457 m). The transect survey used a systematic design with a strip width of 600 m on each side of the aircraft, but sightings were so few that all were recorded, on- or off-effort and on- or off-transect. Ferry flights to the start of and from the end of each day's transect pattern followed the coastline, detouring to search the largest bays and estuaries. The entire coast was covered in this way, some stretches several times.

Observations made from land at estuaries frequented by beluga whales in summer were a supplementary source of information from which it was possible to assess the probability that large estuarine concentrations had been inefficiently estimated by transect sample survey. Local observers manned camps at the Little Whale River and at the Nastapoca River in eastern Hudson Bay in 1993,[1] and in southern Ungava Bay in 1992[2] and 1993[3] (Fig. 3). From vantage points, the estuary areas were scanned regularly for beluga whales. The estuaries of the Little Whale and Nastapoca rivers are less than 1 km long, and easily covered, but the Whale River estuary in southern Ungava Bay could not be completely covered. The objective was to scan five times a day, at three-hour intervals; but weather sometimes interfered with this schedule. Not only numbers, age class, and behavior of beluga whales were noted, but also boat and air traffic, visibility, wind, weather, and tide.

Line-transect methods were used to analyze the data from James and Hudson Bays. Such methods involved fitting to the sighting data a sighting probability curve $g(x)$, i.e. the probability that an animal group at distance x from the

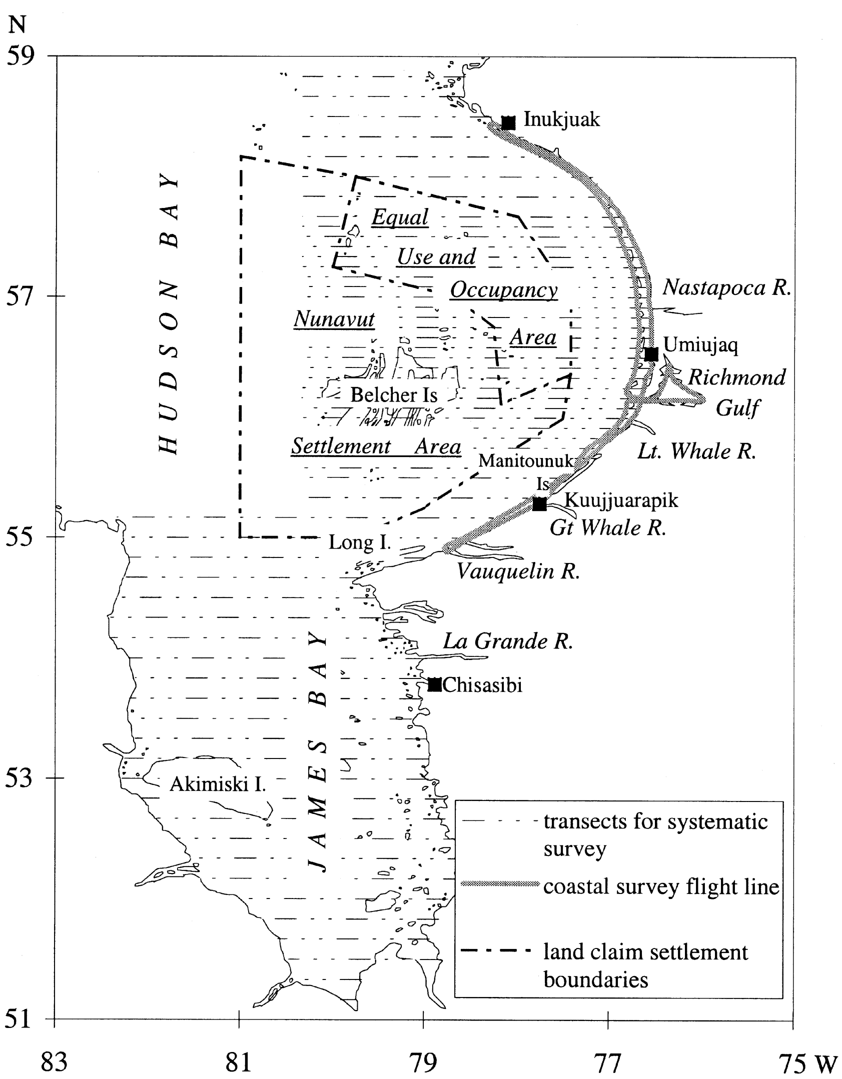

Figure 2

Systematic design for aerial transect survey of beluga whales in James Bay and eastern Hudson Bay, August 1993.

[1] Doidge, D. W. 1994. Land-based observation of beluga whales at the Little Whale and Nastapoka rivers, eastern Hudson Bay, summer 1993. Report prepared by Makivik Corp., C.P. 179, Kuujjuaq, P.Q. J0M 1C0 Canada, 30 p.

[2] Makivik Corp. 1993. Land-based observations of belugas in Ungava Bay, summer 1992. Report prepared by Makivik Corp., C.P. 179, Kuujjuaq, P.Q. J0M 1C0 Canada. 7 p.

[3] Doidge, D.W., and A. H. Gordon. 1994. Land-based observations of beluga at Tuututuup Nuvunga, southern Ungava Bay, summer 1993. Report prepared by Makivik Corp., C.P. 179, Kuujjuaq, P.Q. J0M 1C0 Canada, 13 p.

track-line is detected. Commonly, line-transect analysis assumes that 1) $g(0)$ is unity and 2) $g(x)$ is never increasing with x. An associated shape criterion, which improves the behavior of estimates obtained by line-transect survey (Burnham et al., 1980; Buckland, 1985), suggests that the sighting curve should have a "shoulder" or plateau at small x.

Richards' (1959) sigmoidal growth curve, reversed left-to-right, was chosen for its flexibility to fit $g(x)$. The ordinate at the point of inflection was constrained to be less than 0.9. Because of difficulty in seeing straight down from a flat-windowed aircraft, no animals could be seen close to the transect line; therefore, close to the transect line, an increase in $g(x)$ was modeled by an increasing sine^2 function (Fig. 4). It was assumed that $g_{max} = 1$, i.e. that all surface-visible beluga whales situated at the best distance would be detected. Detection bias would occur if this assumption was incorrect.

The data were truncated at 6000 ft (1829 m) from the trackline; beyond this distance, sightings were few, and measured sighting angles and counts of numbers were imprecise. Within this range, the sighting curve was fitted by maximum likelihood to the distribution of distances from the trackline to individual beluga whales, not to the distribution of sighted groups (Hiby and Hammond, 1989). A single sighting curve was fitted, and a single estimate of k was calculated, and for the survey of James Bay and eastern Hudson Bay, all three strata were pooled. It was integrated numerically to calculate the effective strip width.

The transect counts were expanded to an estimate of detectable numbers:

$$\hat{N} = \sum_{s=1}^{S} \hat{N}_s = \sum_{s=1}^{S} kT_s B_s, \qquad [1]$$

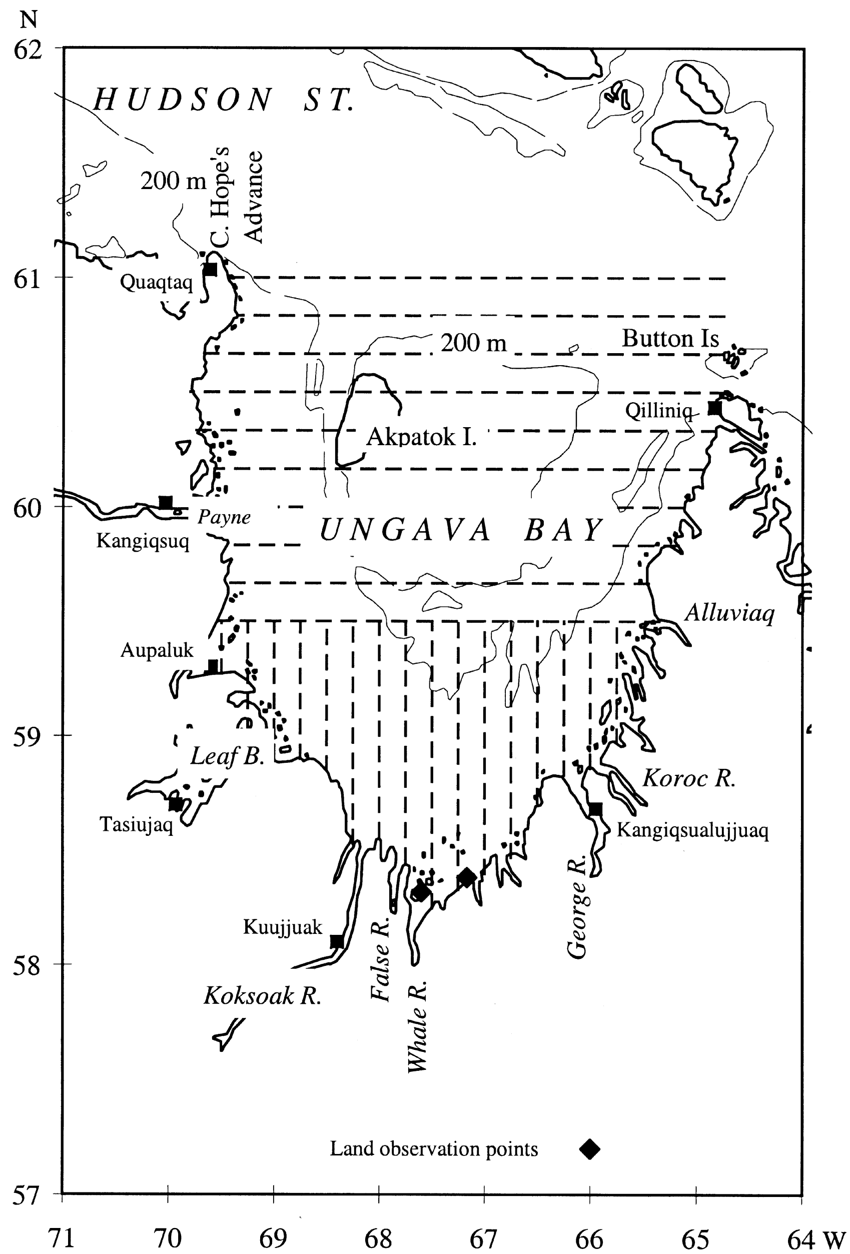

Figure 3

Map of Ungava Bay with the survey design for aerial surveys in July and August 1993.

where T_s = the transect spacing (km);
B_s = the total count of beluga whales in the s^{th} stratum; and
k = the survey expansion factor (/km) i.e. the reciprocal of the two-sided effective strip width.

The uncertainty of N_s was estimated as the sum of V_{s1}, the component from sampling the spatial distribution of beluga whales in the stratum; and V_{s2}, that was due to uncertainty in the estimation of k. V_{s1} was estimated by a serial difference method appropriate to systematic sampling (Cochran, 1977):

$$V_{s1} = kT_s \cdot (kT_s - 1) \cdot \frac{J_s}{J_s - 1} \cdot \frac{\sum_{j=1}^{J_s - 1} (B_j - B_{j+1})^2}{2}, \qquad [2]$$

where B_j beluga whales were sighted on the j^{th} of J_s transects in stratum s.

V_{s2}, the component of sampling error due to uncertainty in the estimation of the effective strip width, was estimated by

$$V_{s2} = \mathrm{var}(k) \cdot (T_s \cdot B_s)^2. \qquad [3]$$

The sighting curve was fitted to nonindependent individuals instead of to independently sighted groups, so the standard error of k was estimated by resampling (Hiby and Hammond, 1989). The standard jack-knife method was used (Efron and Tibshirani, 1993), and sightings, presumed independent, were taken as observational units. Maximum-likelihood estimates are not necessarily unbiased in small samples but may be subject to sample-size bias. The effective number of sightings,[4] 57.7, was less than the recommended minimum (Buckland et al., 1993); therefore sample-size bias in the estimate of the survey expansion factor was reduced by using the standard jack-knife bias reduction (Efron and Tibshirani, 1993; Buckland et al., 1993; Kingsley and Reeves, 1998).

Sightings made on stratum-boundary transects where transect spacing changed were given half weight in each stratum.

Few sightings were made on the transect sample survey in Ungava Bay, and none within the designed survey strip. The sightings made outside the transect strip were converted to a population estimate by assuming an effective strip width based on statistics from other line-transect surveys that had used similar platforms. No standard error was calculated, but an upper confidence limit on the number of groups was calculated by assuming independent binomial sighting probabilities and by answering the question "Given that the sampling fraction was f, how many groups could there be for the chance of seeing none or one to be less than p%?"

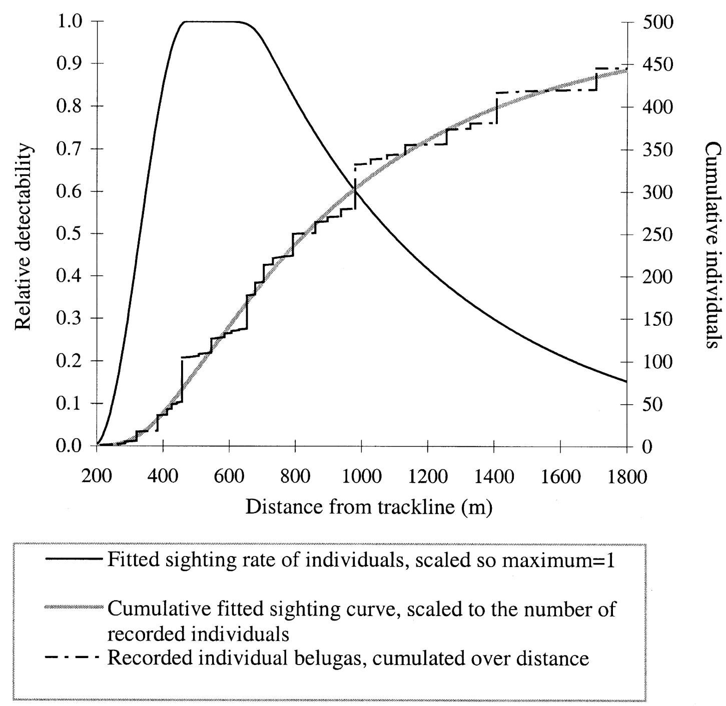

Figure 4

Distribution of sighting distances to individual beluga whales in the line-transect aerial survey of James and Hudson bays in August 1993, with fitted sighting curve.

Results

The survey in James Bay was flown quickly in good conditions from 12 August through 14 August. Winds were light and, apart from occasional fog patches, survey conditions were good. The southern part of eastern Hudson Bay was flown on 15–17 August with light winds and good visibility. Aircraft problems imposed a delay from 18 through 20 August, and on 21 and 24 August there were strong winds. Richmond Gulf was surveyed on 16 August (Fig. 2).

The field of view was limited by the flat windows of the aircraft. No observations were recorded closer than a viewing angle of 65° from the horizontal (at a flying height of 1500 feet, 213 m from the line), and few closer than 55° (320 m) (Fig. 4). Sighting distances were grouped, because the observers tended to round sighting angles. The last-digit frequencies of the recorded angles were analyzed, and it was found that rounding to the nearest 5° was mostly at the expense of the adjacent marks, i.e. those with a remainder of 1° or 4°. Against an expectation of equal frequency of last digits, rounding caused a mean absolute error of 0.42° and was not expected to bias results or to increase uncertainties. Recorded mean group size increased slightly with sighting distance.

The sighting frequency reached its maximum at 467 m (44.2°) and dropped off sharply beyond about 670 m (35°) (Fig. 4). There were few sightings of beluga whales in Hudson Bay; therefore one sighting curve was fitted to the data for all strata. The bias-reduced survey expansion factor was 0.575/km (SE=0.074).

Beluga whales were widely distributed in James Bay (Fig. 5A). There were 123 sightings in 4520 km of transect (27/1000 km), comprising 295 individuals (65/1000 km) (Table 1). Line-transect analysis gave an estimate of 3141 detectable beluga whales for James Bay (Table 2). This number is about three times the estimate obtained by Smith and Hammill (1986). However, their survey was earlier, when a lot of ice still remained in northwest James Bay and may have affected the distribution of these whales. The highest densities in the present survey were in this area. In eastern Hudson Bay (Fig. 5B) there were 63 sightings on 7100 km of transect (9/1000 km) comprising 150 beluga whales (21/1000 km) (Table 2).

[4] Effective number of sightings is defined here as the number of animals seen divided by the contraharmonic mean of group size.

Table 1

Sizes of beluga whale groups sighted on transect survey flights in James Bay, eastern Hudson Bay, and Ungava Bay, during the summer of 1993. CHM = contraharmonic mean, i.e. the size of the group containing the average beluga.

	Sightings	No. of beluga whales	Group size Mean	CHM	SD	Effective no. of sightings
James Bay	123	295	2.40	6.29	3.05	46.9
Hudson Bay	63	150	2.34	10.52	4.40	14.2
Ungava Bay (July survey)	1[1]	4	5.6[2]	13.5[2]	6.93[2]	
Ungava Bay (August survey)	1[1]	19				

[1] These transect-survey sightings were outside the designed survey strip. No sightings were made within the strip.
[2] These statistics are for all 12 sightings in Ungava Bay, including coastal reconnaissance flights, and for both surveys.

Error coefficients of variation (ECV) ranged from 25% for James Bay to 86% for the northern stratum of widely spaced transects in eastern Hudson Bay, where the estimate was based on 10.5 sightings made on 2.5 transects (Table 3). The ECV of the overall estimate was 23%. The use of a common sighting curve reduced the estimated standard errors for individual strata. Uncertainty in k composed only 2% and 20% of the error variances for the two Hudson Bay strata, but 32% of the overall error variance.

On the coastal survey of eastern Hudson Bay, 13 groups of beluga whales were seen, distributed from the northern end of the offshore chain of islands to south of the Great Whale River (Fig. 6). The total number of individuals was 115–148. One large group—70 to 100 individuals—was seen, close to the Manitounuk Islands.[5] A few beluga whales were seen in the Great Whale and Little Whale rivers.

Observers on land at the Little Whale River saw beluga whales on 14 of the 22 observation days. The mean daily maximum count for days on which the whales were seen was 40.4 individuals (range 5–130). At the Nastapoca River, beluga whales were present on 7 of 13 observation days, and the mean daily maximum was 23.3 (1–53). Even on days when they were seen, beluga whales were not continuously present: at the Little Whale River; none were seen on 45% of scans made on days when they were seen at least once, and at the Nastapoca, River, 54% of scans on such days showed no sightings.

The first aerial survey in Ungava Bay was flown on 15–19 July, 1993. It was limited by dense pack ice that remained in the central and northern part of the bay, heavy enough

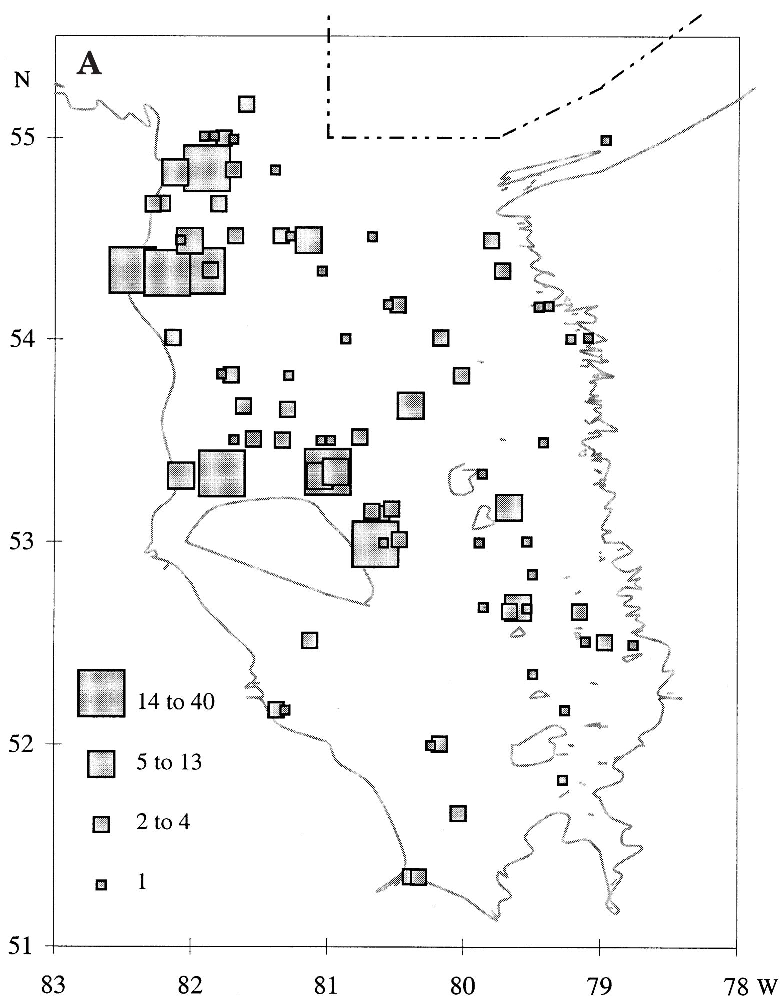

Figure 5

Beluga whale sightings on line-transect aerial survey of (**A**) James Bay and (**B**) eastern Hudson Bay, in August 1993

[5] Doidge, D. W. 1993. Coastal reconnaissance survey for belugas in eastern Hudson Bay, August 21, 1993. Report prepared for the Department of Fisheries and Oceans, 104, rue Dalhousie, Quebec P.Q. G1K 4B8, Canada by Makivik Corp., C.P. 179, Kuujjuaq, P.Q. J0M 1C0 Canada, 8 p.

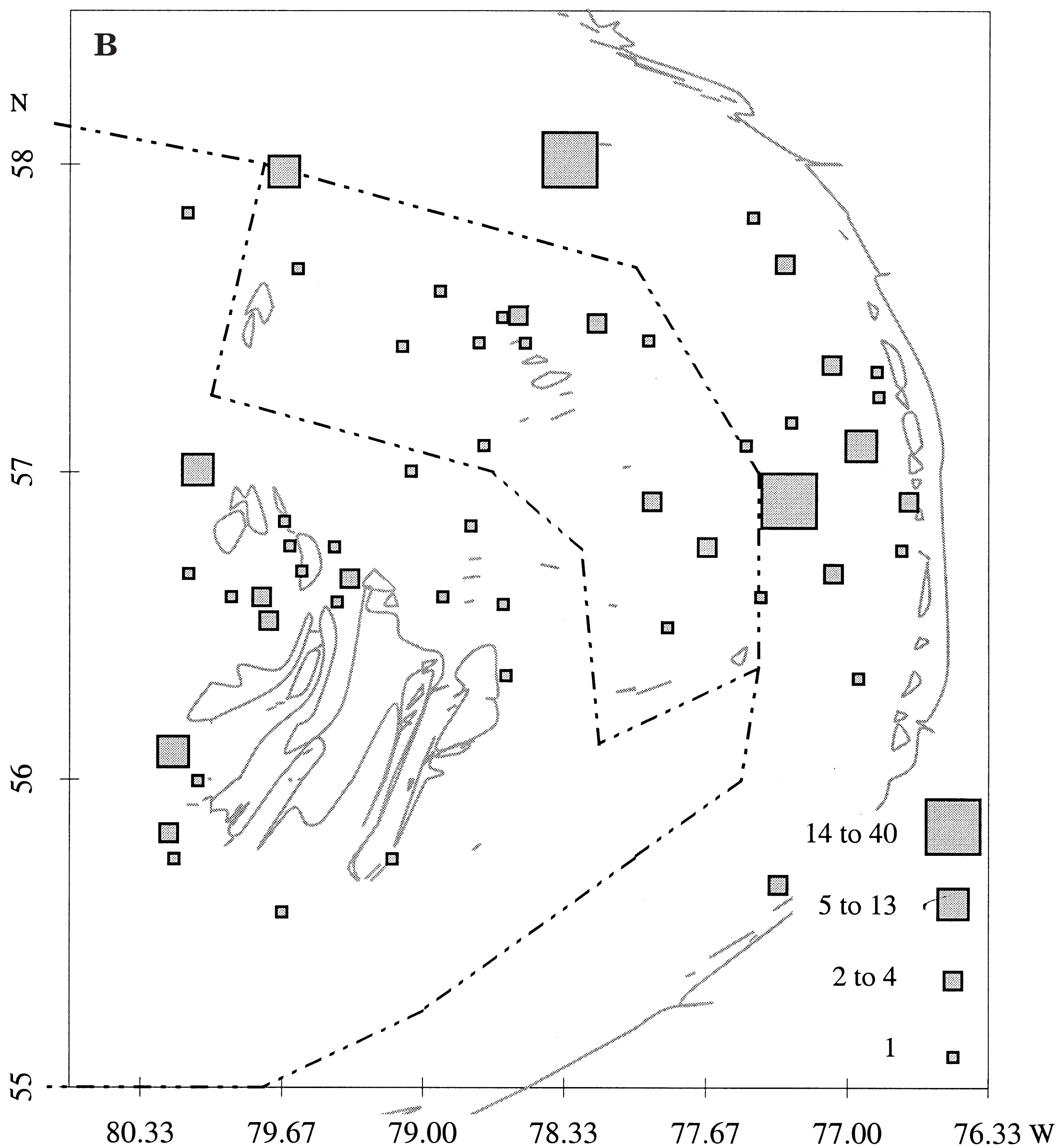

Figure 5 (continued)

to restrict the distribution of beluga whales and to make it difficult to count them. The survey was not extended into this area of heavy ice. North–south transects were flown in southern Ungava Bay, south of the ice. The second survey, 24–29 August, was flown over open water throughout Ungava Bay. However, some planned flight patterns were limited by fog in northeastern Ungava Bay.

In Ungava Bay, beluga whales were seen on four of five flying days in July, with a maximum daily count of 20 individuals in one sighting, and on three of six flying days in August, with 20 individuals in two sightings on the best day (Table 3). In the two surveys together, beluga whales were sighted in the Whale River estuary on six of seven overflights. There were also two sightings in southern Ungava Bay close to the Whale River, and two sightings of small groups in western Ungava Bay. The mean sighting size was 5.6 groups (SE=2.0).

However, no beluga whales were seen within the designed survey strip. From independent binomial sighting probabilities, corresponding upper 90% CLs would be 25.5 groups for the first survey and 34.3 groups for the second (assuming the mean group size of 5.6, equal to 143 and 192 animals). One off-strip sighting was made on a sample survey flight during each survey, but no distance measurements were made. Off-strip effort is considered to have an outer visibility limit similar to that estimated by line transect analysis of the data for James Bay and eastern Hudson Bay, but an inner limiting angle similar to the 72° estimated for a similar platform by Harwood et al. (1996). This would result in a strip width of about

Table 2

Estimates of numbers of beluga whales by stratum and overall, in James Bay, eastern Hudson Bay, and Ungava Bay, during August 1993.

Stratum	Count of beluga	No. of transects	Transect spacing (km)	N_{est}[1]	V_1[2] (10^3)	V_2[3] (10^3)	SE
James Bay (including southern Hudson Bay arc)	295	26.5	18.52	3141	454	165	787
Central Hudson Bay arc: closely spaced transects	109.5	26	9.26	583	25	6	174
Northern Hudson Bay arc: widely spaced transects	40.5	7.5	18.52	431	135	3	372
Central and northern Hudson Bay total	150	33.5	—	1014	160	17	421
Ungava Bay (July survey)	4[4]	15	13.9	38[5]	—	—	—
Ungava Bay (August survey)	19[4]	16	18.52	50[5]	—	—	—

[1] The survey expansion factor k for the line-transect survey in James Bay and eastern Hudson Bay, including the jack-knife bias correction, was 0.575/km with a jack-knife-estimated SE of 0.0742/km. The one-side effective strip width was 870 m.

[2] V_1 is the component of error variance due to the variability in the encounter rate and consequent uncertainty in estimating its mean.

[3] V_2 is the component of error variance due to the uncertainty in estimating the effective strip width.

[4] These sightings were made outside the designed transect strip of the strip-transect survey, and estimates are based on an assumed effective strip width of 1020 m each side; k = 0.49/km (see text).

[5] Population estimates are based on the mean size (5.6) of all groups sighted on reconnaissance and transect flights.

Table 3

Sightings of beluga whales in aerial surveys of Ungava Bay during July and August 1993.

Date	Area covered by flight	No. seen	Where seen	When seen
15 Jul	Transects in southeast Ungava Bay; and the southeast coast from the Kosoak River to the Koroc River			
16 Jul	Transects in southwest Ungava Bay; and the southwest coast from the Whale River to the Leaf River	3 adult	Whale River estuary	between transects
17 Jul	The southern and eastern coasts from the Koksoak River to the Button Islands	20 mixed	Whale River estuary	on coastal flight
18 Jul	The western coast from the Koksoak River to Quaqtaq	2 adult + possibly 1 calf 1 adult	NW Ungava Bay near Leaf Bay	
19 Jul	Transects in southern Ungava Bay between the Leaf River and the George River; also the south coast from the George River to False River	2 adult + cow-calf pair 1 adult; 1 adult + 1 juv. + 1 neonate; 1 adult	SE Ungava Bay Whale River estuary Whale River estuary Whale River estuary	on transect[1] on coastal flight on coastal flight on coastal flight
24 Aug	The western coast, from the Koksoak River to Quaqtaq	10	Whale River mouth	on coastal flight
25 Aug	The southern coast, from the Whale River to the George River	2	Whale River mouth	on coastal flight
26 Aug	Transects in southwest Ungava Bay, and the coasts of Leaf Bay and the Leaf River			
27 Aug	Transects in southeast Ungava Bay, and the southeast coast from Whale River to Alluviaq	19 1	15 km E of Whale River 10 km E of Whale River	on transect[1] on coastal flight
28 Aug	Transects in northwest Ungava Bay, and the coast of Akpatok Island			
29 Aug	Transects in northeast Ungava Bay, and the northeast coast from Alluviaq to the Button Islands			

[1] Sightings made "on transect" were outside the designed transect strip of 600 m each side of the aircraft.

1020 m on each side and survey expansion factors of 6.8 for the first survey and 9 for the second. Resulting estimates would be 6.8 and 9 groups (38 and 50 whales), with approximate 90% upper CLs of 25.0 and 33.8 (119 and 157 whales, if mean group size was 5.6). These estimates and confidence limits were imprecise and did not account for the uncertainty of mean group size or for the known lower bound on numbers.

The large tidal range in southern Ungava Bay creates extensive foreshore flats, and few beluga whales were sighted from the observation points on land. In 1992, 160 scans made over 35 days between 5 Aug. and 30 Sept. showed a total of 24 individuals. In 1993, 145 scans over 29 days in June and July resulted in four sightings totaling 8 individuals; 68 scans over 15 days in August and September resulted in three observations totaling 30 individuals. The largest count in any sighting was 17.

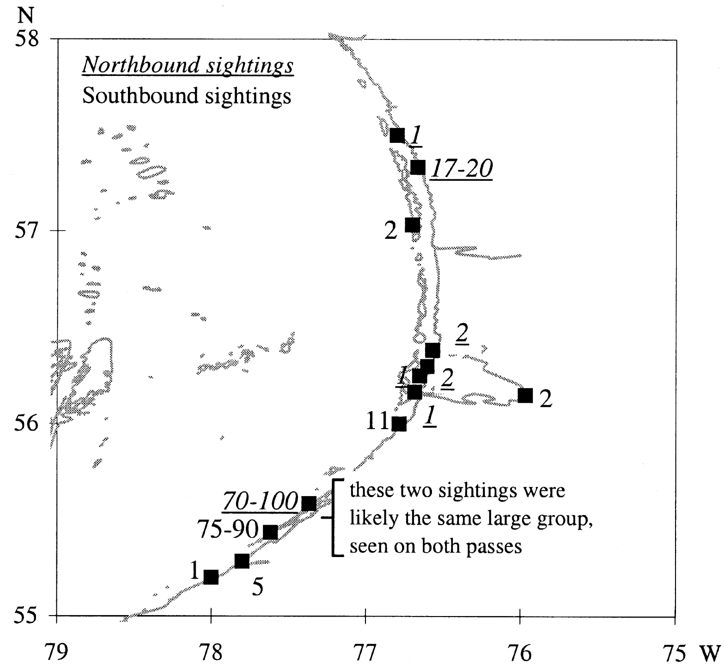

Figure 6

Sightings of beluga whales on coastal aerial survey of eastern Hudson Bay, 21 August 1993.

Discussion

The 1993 estimate of surface-visible beluga whales in James Bay, about 3140, was 2.6 times that of the previous survey (Smith and Hammill, 1986). In that survey, flown in early August, ice cover was still present in northwestern James Bay; most groups were composed of fewer than 5 animals and they were distributed in the southern part of James Bay (Smith and Hammill, 1986, Fig. 1). In the present survey, there was no ice and there were many observations of larger groups. The highest densities were north of Akimiski Island and up the western side of James Bay, where many groups were found in shallow turbid water close to shore (Fig. 5A). The beluga whales may have been distributed differently in the two surveys because of the ice that still remained at survey time in 1985.

It is difficult to ascertain the origin of this population. Significant numbers of beluga whales were once reported wintering in James Bay (Jonkel, 1969) prompting the suggestion that a large part of that population might be resident (Sergeant, 1986). However, a resident population could not increase fast enough to account for the difference between the 1985 estimate and the present one (Eberhardt and Siniff, 1977; Sergeant, 1981; Kingsley, 1989; Doidge, 1990). In 1985 there was significant ice cover in northwest James Bay, and beluga whales moving into James Bay from southwestern Hudson Bay may have been delayed by the ice in 1985, and not in 1993. However, Richard (1993) suggested that the principal southward spring migration route for James Bay beluga whales may be down the east coast of Hudson Bay, in which case ice in northwest James Bay would not have been a barrier. Alternatively, the populations in western and southwestern Hudson Bay (Richard et al., 1990; Richard, 1993) may have been colonizing James Bay. A small fraction of the estimated 23,000 beluga whales of the western Hudson Bay stock would have had a large effect on survey counts if they had been present in James Bay.

The estimated density of beluga whales in eastern Hudson Bay was slightly greater than the 1985 transect-survey estimate (Smith and Hammill, 1986 Table 1). However, for the latter survey, strip transects (with a total width of 2000 m) were used. This distance probably exceeds the range at which beluga whales can be effectively counted in a survey in the Beaufort Sea. With the same platform, target species, and type of aircraft window, Harwood et al. (1996) estimated an effective strip width of about 1300 m. The 1985 strip-transect estimate may have been biased downward in relation to the present survey. In 1985, 200 beluga whales were counted; in 1993, 150 whales were counted on the same transects.

Few beluga whales were seen on the coastal survey of eastern Hudson Bay in 1993. There were no large concentrations in the mouths of rivers, but scattered small groups and probably only one large group. The total was less than 150 individuals. The land-based observations in 1993 also did not record large groups in the estuaries. Therefore, the transect sample survey estimate probably did not have large errors due to inefficient sampling of large estuarine concentrations. In 1985, a total of 481 whales were counted on the eastern Hudson Bay coastal survey, including concentrations in Richmond Gulf and in the estuaries of both the Little Whale and Nastapoca rivers (Smith and Hammill 1986), and land-based observations in 1984 counted as many as 200 individuals in the Nastapoca estuary (on 24 August: Caron and Smith, 1990) compared with the 1993 maximum of 53.

Transect sample survey and nearshore total-count indices apparently corroborate the finding that numbers in

Table 4

Distribution of beluga whale observations and estimated numbers of beluga whales in eastern Hudson Bay between the Nunavik area, the Nunavut Settlement Area, and the Equal Use and Occupancy Area.

	Observations (%)	Mean number per observation	Estimated numbers (%)
Nunavik area	23 (36)	4.2	774 (71)
Nunavut Settlement Area	25 (39)	1.4	211 (19)
Equal Use and Occupancy Area	16 (25)	1.2	111 (10)

eastern Hudson Bay were not larger in 1993 than they had been in 1984–5, but instead were very likely lower.

Sightings of beluga whales in eastern Hudson Bay showed that they were widely distributed in the shallow water between the mainland coast and the Belcher Islands (Fig. 4). Thirty-six percent of sightings were outside the areas defined by the Nunavut Agreement (Table 4), but these were on average the larger groups, and represented 71% of the total numbers. Beluga whales were distributed also around the Belcher Islands, particularly to the north, and as far west as the survey extended. There was no evidence of a discontinuity in the east–west distribution. The survey results were consistent with the hypothesis of a single continuous population distributed from the coast out to the survey limit. However, it is not known for sure whether all the beluga whales in the study area were among those that frequent the estuaries on the eastern Hudson Bay mainland coast, nor whether they would be available to hunters there. It remains possible that the beluga whales using those estuaries are only a fraction of the total numbers counted in the survey area. The question of single or multiple summering stocks in eastern Hudson Bay is important in designing strategies for managing exploitation by residents of the communities on the Belcher Islands and on the eastern Hudson Bay coast; aerial survey results alone can not provide conclusive answers.

The north–south extent of the sightings in eastern Hudson Bay was limited, as in 1985; no beluga whales were seen on the northernmost transects, and there was no continuous distribution extending into areas farther north. There are no large estuaries to attract summering beluga whales to the eastern Hudson Bay coast north of the Nastapoca River, and there are no reports, even anecdotal, of beluga whales spending the summer in those areas. Thus it is unlikely that significant additional numbers would have been detected if this survey had extended farther north.

The estimate of numbers in Ungava Bay was uncertain. In James Bay, beluga whale groups were widely distributed. In Hudson Bay, densities were lower, but sightings were frequent and widely distributed. In Ungava Bay very few beluga whales were seen, indicating a very low density. Population estimates from the transect surveys, based on 0 or 1 sighting per survey, are imprecise, but small, of the same order as the highest daily total counts on survey and reconnaissance flights combined, and consistent with the maximum of about 25 beluga whales in the Mucalic River estuary in summer estimated by Finley et al. (1982). The present survey could have resighted the same small group of about that size, or subgroups of it, on different flights. The largest sighting from land was 17 individuals, on 24 August 1993. Smith and Hammill (1986) surveyed Ungava Bay in 1985, and saw few beluga whales; they were unable to make a population estimate.

Most sightings were made in and near the Whale River estuary, but a few, small, scattered groups were also sighted elsewhere in Ungava Bay (Table 3). Residents of the area see beluga whales in summer, but not in large numbers and not all the time (Brooke[6]; Brooke[7]; Portnoff[8]). Ungava Bay communities capture beluga whales in most years, but often outside the bay and outside the season when they inhabit their summer grounds. Neither survey results nor harvest statistics provided a basis for considering a trend in summering stock size.

Estimates from line-transect survey analysis were conditional on the use of the Richards curve as a sighting curve. Both the hazard-rate curve and the normal curve fitted the data worse. Maximum detection was not obtained until 470 m from the aircraft, owing to its having flat windows. Similar visibility restrictions have been estimated in other surveys. In a line-transect aerial survey of narwhals in Scoresby Sund, in which the survey plane had flat windows, there were poor sighting rates out to a sighting angle of about 40° from the vertical (Larsen et al., 1994) and in an aerial survey of cetaceans in the Gulf of St Lawrence, in which the survey aircraft had shallow bubble windows, maximum detection was not achieved until 35° from the vertical (Kingsley and Reeves 1998). The loss of visibility close to the aircraft militates in favour of lower flying heights if surveys must be carried out in flat-windowed aircraft and raises concerns about detection, if the

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[6] Brooke, L. F. No date. A report on the 1994 Nunavik beluga and walrus subsistence harvest study. Unpublished report prepared for the Department of Fisheries and Oceans, 104, rue Dalhousie, Quebec P.Q. G1K 4B8, Canada, 29 p.

[7] Brooke, L. F. No date. A report on the 1995 Nunavik beluga and walrus subsistence harvest study. Unpublished report prepared for the Department of Fisheries and Oceans, 104, rue Dalhousie, Quebec P.Q. G1K 4B8, Canada, 29 p.

[8] Portnoff, M. 1994. The 1993 Nunavik beluga whale and walrus subsistence harvest study. Report prepared for the Department of Fisheries and Oceans, 104, rue Dalhousie, Quebec P.Q. G1K 4B8, Canada by Nunavik Graphics, Montreal, 61 p.

maximum visibility is not reached until so far away from the aircraft. The present results have not been corrected for detection bias, but Harwood et al. (1996) estimated, from paired-observer data, that it would be appropriate to add about 40% to correct for detection bias at the peak of the sighting curve even when using bubble windows.

The sightings curve fitted to the present data set has a shoulder at 670 m, and the width of the maximum-visibility strip, a critical determinant of the precision of the survey, was small. Larsen at al. (1994, Fig. 2) noted a marked drop in visibility of narwhal from the air beyond 823 m. In other studies, visibility of beluga whales dropped off beyond about 600 m from the aircraft (Norton and Harwood 1985), and by 600 m visibility of small cetaceans was less than 40% of maximum (Kingsley and Reeves 1998); both these surveys were flown lower than the 457 m of the present survey.

Estimates were not been corrected for diving beluga whales, but instead were conservative estimates of surface-visible beluga whales. Corrections to counts of beluga whales for diving have been estimated from visual records of their appearance and disappearance (Brodie, 1971; Sergeant, 1973; Fraker, 1980; Gauthier, 1999), by recording surface signals from attached VHF radio transmitters (Frost et al., 1985), and by studying diving behavior with attached pressure recorders (Martin and Smith, 1992; Richard et al., 1997; Heide-Jørgensen et al., 1998; Kingsley, unpubl. data). Early studies (Brodie, 1971; Sergeant, 1973) were restricted to nearshore areas. Correction estimates have ranged from adding 40% (Brodie, 1971) to adding 200% (Sergeant, 1973). A correction for eastern Hudson Bay, deduced from satellite-tag data on five beluga whales tagged in 1993, was about 80%, but there was a wide margin of uncertainty. This value was similar to values estimated for beluga whales summering in other waters of the Canadian Arctic (Martin and Smith, 1992; Richard et al., 1997; Heide-Jørgensen et al., 1998).

Large sampling variability is common in beluga whale surveys, the species being gregarious. Most of the error variance for individual strata in the line-transect survey was due to uncertainty in encounter rate, especially in the northern Hudson Bay stratum, where a few large groups were seen on a few transects. Overall, the error coefficient of variation was 23%, of which about 2/3 was due to uncertainty in encounter rate. The jack-knife bias reduction (Efron, 1982) reduced the estimate of the survey expansion factor by only 1%, from 0.583 /nmi to 0.575 /nmi.

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