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Trends in the Offshore Distribution and Relative Abundance of Beaufort Sea Belugas, 1982 – 85 vs 2007 – 09

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ABSTRACT. We used systematic strip-transect aerial surveys to examine the distribution and relative abundance of surfaced belugas in the offshore Beaufort Sea in late August of 1982, 1984 – 85, and 2007 – 09. Belugas were seen throughout the offshore area in both survey series, on 114 of 149 transects (76.5%). They were common over the continental shelf offshore of the Tuktoyaktuk Peninsula and within 30 km seaward of the Mackenzie River estuary, but they were also seen in most other offshore habitats surveyed. The distribution of belugas had a similar pattern in both series, but the number of surfaced belugas counted was higher in the 2000s than in the 1980s. In total, 305 belugas (145 sightings, mean group size 2.1) were observed on-transect in 20 858 km^2 of surveying in the 1980s, and more than three times that number (1061) were observed in a similar area (19 829 km^2) during the 2007 – 09 survey series (378 sightings; mean group size 2.6). Population growth alone, though probably not sufficient to explain the changes observed in relative abundance between decades, could be partly responsible for the apparent increase in belugas. The most plausible explanation is that the offshore became more attractive to belugas in the 2000s, because of either a decrease in the intensity or extent of industrial activity or changes to the marine ecosystem related to climate warming, or both.

Key words: belugas, aerial survey, distribution, abundance, Beaufort Sea, hydrocarbon industry, ecosystem changes, prey

RÉSUMÉ. Nous avons utilisé des levés aériens systématiques par transects en bandes pour examiner la répartition et l’abondance relative des bélugas faisant surface au large de la mer de Beaufort à la fin d’août 1982, d’août 1984 à 1985 et d’août 2007 à 2009. Des bélugas ont été aperçus au large dans les deux séries de levés et ce, dans 114 des 149 transects (76,5 %). Les bélugas étaient courants au large du plateau continental de la péninsule Tuktoyaktuk ainsi que dans un rayon de 30 km du côté mer de l’estuaire du fleuve Mackenzie, bien qu’ils aient également été aperçus dans la plupart des autres habitats étudiés au large. Dans les deux séries, la répartition de bélugas se ressemblait, mais le nombre de bélugas faisant surface était plus élevé dans les années 2000 que dans les années 1980. Au total, 305 bélugas (145 observations, taille moyenne du groupe de 2,1) ont été observés dans les transects des 20 858 km^2 étudiés dans les années 1980, et plus de trois fois ce nombre (1 061) ont été observés dans une aire semblable (19 829 km^2) dans les années 2007 à 2009 (378 observations, taille moyenne du groupe de 2,6). L’accroissement de la population seul pourrait être responsable en partie de l’augmentation apparente du nombre de bélugas, bien que ce facteur ne suffise probablement pas à expliquer les changements observés sur le plan de l’abondance relative d’une décennie à l’autre. L’explication la plus plausible serait que les bélugas ont été davantage attirés par le secteur extracôtier dans les années 2000 soit en raison de la diminution de l’intensité ou de l’ampleur de l’activité industrielle, soit en raison des changements à l’écosystème marin attribuables au réchauffement climatique, soit en raison d’un ensemble de ces deux causes.

Mots clés : bélugas, levé aérien, répartition, abondance, mer de Beaufort, industrie des hydrocarbures, changements à l’écosystème, proie

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INTRODUCTION

Beluga whales (*Delphinapterus leucas*) of the Beaufort Sea stock arrive in the southeast Beaufort Sea in late May and June (Fraker, 1979). During July, the belugas aggregate mainly in the warm, shallow waters of the Mackenzie River estuary (Norton and Harwood, 1986). From late July through August, their distribution shifts offshore (Norton and Harwood, 1985; Harwood et al., 1996), but the extent of their range beyond the estuary is less well known (Harwood and Smith, 2002). Recent satellite tracking studies have confirmed that belugas of this stock use the offshore Beaufort Sea extensively and also that they travel in August to even more distant summer ranges, including Amundsen Gulf and Viscount Melville Sound (Richard et al., 2001). Their return fall migration to wintering areas in the Bering Sea, which begins in August and continues into September, occurs far offshore, seaward of the continental shelf

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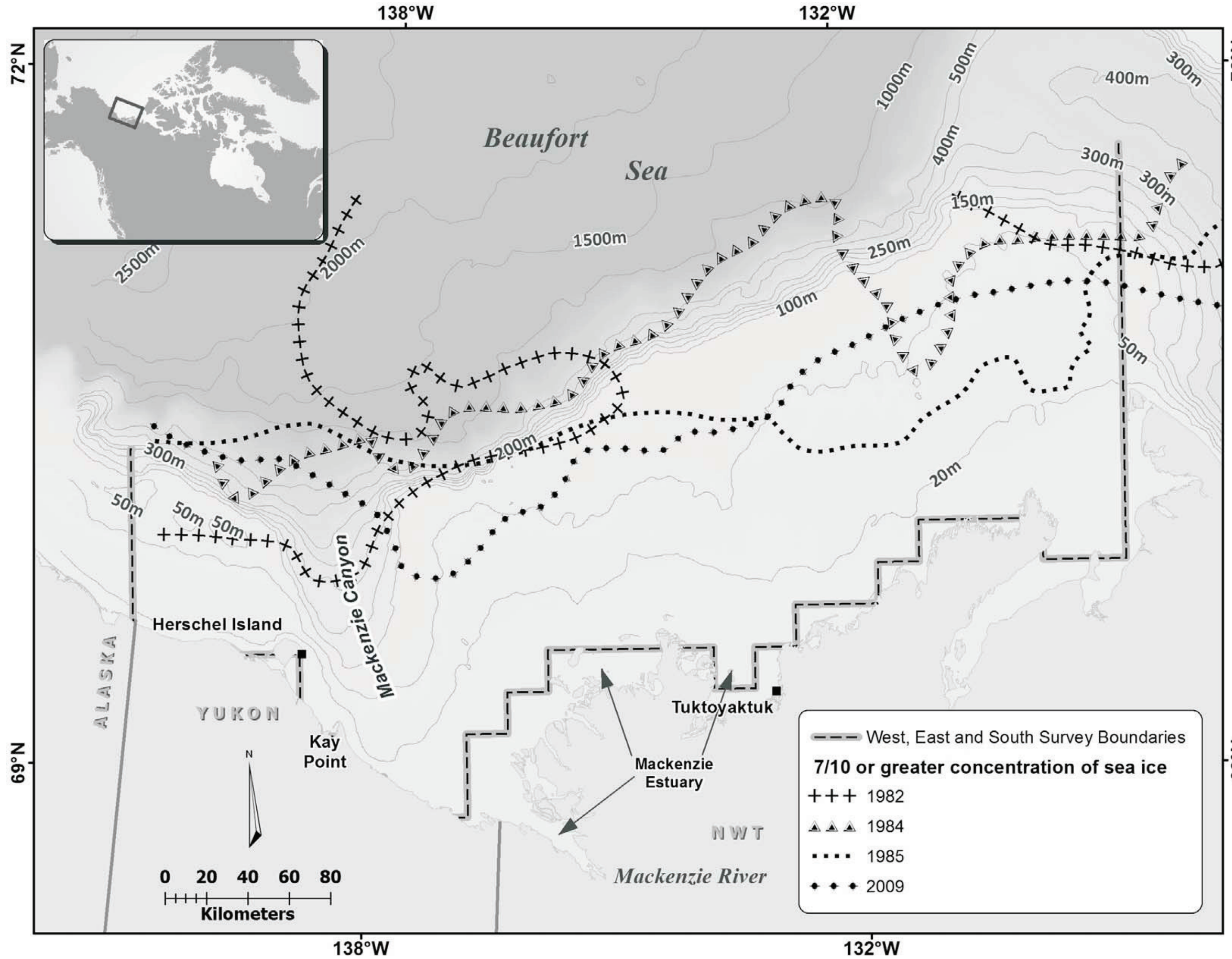

FIG. 1. Survey area and location of 7/10 or greater concentrations of sea ice in 1982, 1984–85, and 2009. The survey area was ice-free in 2007 and 2008.

(Clarke et al., 1993; Moore and DeMaster, 1998; Richard et al., 2001).

Hill and DeMaster (1999) calculated the population size for Beaufort Sea belugas to be 39 258, with a coefficient of variation (CV) of 0.229. This estimate was derived from an aerial survey conducted in late July 1992 (Harwood et al., 1996), to which an availability bias correction factor of two, which was not based on data, was applied (Duval, 1993). This stock of belugas is the second largest in Canada and has been assessed as stable or increasing (DFO, 2000).

While in the Mackenzie River estuary, the Beaufort Sea belugas have long been the subject of an important traditional subsistence hunt of the Inuvialuit, the people of the western Canadian Arctic (Nuligak, 1966; McGhee, 1988). The annual landed harvest averaged 111 in 1990–99 (Harwood et al., 2002) and 97 in 2000–09 (FJMC, unpubl. data). Harvest levels are regulated by the hunters themselves, in that they take only what they need for subsistence (FJMC, 2001).

We examined the distribution and relative abundance of belugas in the offshore Beaufort Sea in late August, using systematic strip-transect aerial surveys in 1982, 1984–85 (the 1980s) and in 2007–09 (the 2000s). Our first objective was to describe present patterns of beluga distribution in the offshore Canadian Beaufort Sea (Fig. 1). Such information is important to complement the larger, existing body of knowledge regarding the distribution of belugas in the Mackenzie River estuary (Norton and Harwood, 1986). We expect that these data will be useful to resource managers and harvesters in assessing potential environmental impacts of offshore hydrocarbon exploration, development, and production in the Beaufort Sea, and they are timely, given renewed industry interest in the offshore since 2006 (AANDC, 2012).

Our second objective was to examine the relative numbers of belugas in the offshore Beaufort Sea in late August, both within and between the two periods for which data are available, the 1980s and the 2000s. Together these data sets, separated by over two decades, provide a unique opportunity to examine broad trends in relative numbers of surfaced belugas. Given the importance of belugas to the culture and nutrition of the Inuvialuit, maintaining a

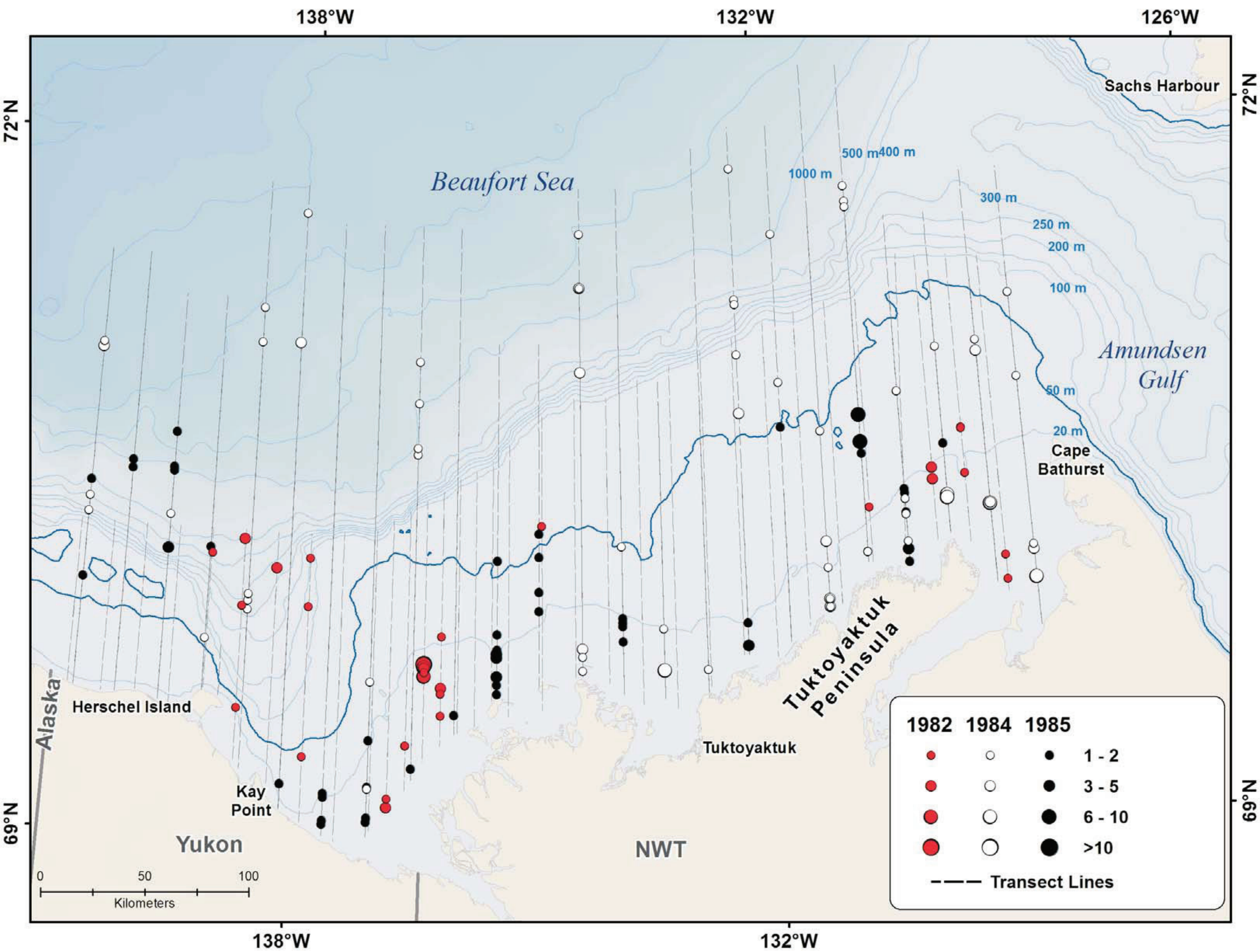

FIG. 2 Location of transects (numbered from west to east) and numbers of surfaced belugas sighted in the offshore Beaufort Sea during aerial surveys in late August 1982, 1984, and 1985.

healthy, stable population of belugas is important to meet management objectives, to demonstrate that the hunt is sustainable, and to ensure that the harvest can continue to satisfy the nutritional and cultural needs of the Inuvialuit (FJMC, 2001).

METHODS

Study Area and Survey Design

Systematic aerial surveys were conducted in late August in 1982, 1984–85, and 2007–09 to monitor the distribution and relative abundance of bowhead whales (*Balaena mysticetus*) and other marine mammals, including belugas, offshore in the Beaufort Sea (Harwood and Ford, 1983; Norton and Harwood, 1985; Duval, 1986; Harwood et al., 2010). The survey area extended from the Alaska-Yukon border (141˚ W) eastward to Cape Bathurst (128˚ W), and from the 2 m isobath seaward to the shelf break or beyond (Fig. 1). The eastern, western, and southern boundaries of the study area were established in the 1980s, and the positions of the north-south transects, systematically spaced about 20 km apart, were the same in 2007–09 as in 1984 and 1985. Transects in 1982 were also flown within the same study area boundaries, but were more closely spaced (about 16 km apart). Survey coverage was 10% in all years.

In 1982, four extra transects were interpolated ad hoc midway between each pair of transects (numbered 10 through 14 in the original design) lying north of the Mackenzie Delta (Fig. 2), creating a survey stratum with a halved transect spacing. The data from this survey were therefore analyzed as arising from three distinct strata.

A strip-transect method (Caughley, 1977) was used in all surveys, with a strip width of 2.0 km (1.0 km per side) in all years except 1982, when the strip width was 1.6 km (800 m per side). Strips were defined by marks or tape placed on the bubble windows, offset from the flight path by 50 m to account for reduced visibility directly under the aircraft (Davis and Evans, 1982; Norton and Harwood, 1986).

One or two de Havilland Twin Otter Series 200 or 300 aircraft were used for all surveys, each with one primary observer on the left and one on the right side of the aircraft. The target survey altitude was 305 m, and this altitude was achieved in all surveys in 2007–09 and for 92.8% of the surveying in the 1982 and 1984–85 series. Altitude was measured with the aircraft's altimeter and monitored or adjusted by the pilots during the surveys. The target ground speed for all surveys was 200 km per hour. All primary search positions were equipped with bubble windows to enhance downward visibility close to the flight path.

Surveying was attempted and continued only when sea states on the Beaufort wind force scale were 0 (calm, sea like a mirror), 1 (light air, ripples but without crests), 2 (light breeze, small wavelets with crests that do not break), or 3 (gentle breeze, large wavelets with crests that are beginning to break). We do not have a reliable estimate of the percentage of the transect distance corresponding to each sea state (0, 1, 2 or 3). Sea state was recorded at the beginning and end of each transect, as well as during surveying as time allowed and when observers noticed and recorded changes. Essentially, the approach was to terminate the survey (or designate as off-effort) if winds were over 10 knots and frequent whitecaps were seen (= Beaufort 4 or greater). These conditions were established as our standard cutoff, which was consistently applied among observers and surveys and years.

The usual flying time was 6–8 h per day. Observers rested during ferrying flights, refueling stops, and transits between transects. Left side data were collected in all years by the same primary observer, partnered with other primary observers on the right, all of whom had recent and extensive aerial survey experience.

For all marine mammals sighted, the observers recorded species, time or location of sighting, number in group, colour, direction and relative rate of movement, and any associations with seabirds. A group of belugas was defined as two or more individuals moving in the same direction and at the same rate, or within approximately five body lengths of each other (Norton and Harwood, 1985).

In the 1980s, the aircraft's Global Navigation System (GNS) was used to determine the geographic position of sightings, which were recorded on audio tapes and later transcribed to data sheets. In 2007–09, observers used individual hand-held Garmin GPS Map 76 units, each with an external antenna, to log the geographic locations of sightings.

At the beginning and end of each transect, observers recorded the time (min, s) using synchronized digital watches, transect number, direction of flight (compass points), seat position, glare levels (nil, moderate, strong, forward, or back), sea state, and concentration of sea ice according to the Canadian Ice Service categories (< 1/10, 1–3/10, > 3–5/10, > 5–7/10, > 7–9/10, 9+/10). Observers recorded changes in sea state, ice concentration, and survey conditions when conditions changed. Waypoints were downloaded from the GNS and GPS units after each survey, and on-transect sightings of belugas were tabulated and plotted.

Data Analysis

Data from the original field sheets for the 1982, 1984, and 1985 surveys were entered into Excel and re-analyzed for consistency with the 2007–09 surveys. Only survey effort in the offshore Beaufort Sea (e.g., not the Mackenzie Estuary or Amundsen Gulf) was included to ensure standard eastern, western, and southern boundaries for the study area in all years.

Sightings of belugas for each survey series were plotted using ArcGIS (ESRI, 2004), along with the ice-edge position recorded by observers at the time of the survey. The mean and range of group sizes, by survey year, were calculated in SAS (1990).

If animals are randomly and independently distributed, the expected standard error of the CV (relative uncertainty) of estimates of density or numbers is roughly $1/\sqrt{n}$, where n is the number of animals seen. A "clump factor" was therefore defined and calculated as $n \times (error\ CV)^2$. If groups of animals are randomly and independently distributed, the clump factor is expected to equal the contraharmonic mean (CHM) of group size. In these surveys, the sampling was systematic and the error CV was based on serial differences between transects, not on deviations from the mean; this choice affects the relationship between distribution and the calculated clump factor.

North-south transects converge at their poleward ends, especially at high latitudes. Therefore, on-transect sightings of belugas were expanded by the transect spacing at their latitude:

$$E_{ti} = \frac{n_{ti} s_{ti}}{w}$$

where E_{ti} is the expanded number for the i^{th} sighting on the t^{th} transect, n_{ti} is the number of belugas in the sighting, s_{ti} is the transect spacing at its latitude and in its stratum, and w is the survey strip width. The total expanded number for the transect is then given by

$$T_t = \sum_i E_{ti}$$

and the estimated number in the stock by summing the T_t.

To estimate the uncertainty of this estimate, a stratum mean square for error, s^2, was calculated from the serial differences between the T_t:

$$s^2 = \frac{\sum_{t=2}^{M} (T_1 - T_{t-1})^2}{2(M-1)}$$

where M is the number of transects in a stratum (Cochran, 1977; Kingsley and Smith, 1981). The error variance of the stratum total was calculated as Ms^2. The calculations of stratum totals and their error variances were adjusted as appropriate where adjacent strata with different transect spacings in the 1982 survey had a transect in common, sightings on the common transect being applied equally to

TABLE 1. Aerial survey effort, sightings and estimates for 1982,[1] 1984–85,[1] and 2007–09 offshore aerial surveys in the southeastern Beaufort Sea.[2]

	1982	1984	1985	2007	2008	2009
Survey coverage:						
Survey dates in August	18–24	18–27	18–24	22–23	2–20	15–20
Area surveyed (km²)	6350	9316	5192	7167	4703	7959
Number of transects flown	31	22	24	24	24	24
Approximate transect spacing (km)	16	20	20	20	20	20
Size of study area (km²)	59950	102047	52920	79600	58400	81000
Observations:						
Number of belugas on-transect	78	145	82	337	401	323
Number of beluga groups on-transect	30	67	48	98	186	94
Transects with belugas	13	19	17	22	19	24
% transects with belugas	42	86	71	92	79	100
Mean group size	2.6	2.2	1.7	3.4	2.2	3.4
SD group size	3.3	1.9	1.4	3.0	4.6	3.2
Range group size	1–15	1–10	1–6	1–13	1–60	1–18
Relative abundance:						
Estimated surfaced, visible belugas	524	1405	814	3374	4023	3380
SE	192	220	207	587	777	602
Error CV (%)	36.7	15.7	25.5	17.4	19.3	17.8

[1] Data originally reported in Harwood and Ford (1982), Norton and Harwood (1985), and Duval (1986).
[2] Does not include any flying or observations from Amundsen Gulf or from the Mackenzie Estuary.

the two strata. (In every other year, transect spacing was uniform and the survey comprised a single stratum.)

RESULTS

Overview of Survey and Sightings

The eastern, western, and southern boundaries of the study area remained the same in all surveys, but the northern boundary varied from year to year with the position of the ice edge (if any). The size of the area surveyed within the study area varied from 4703 km^2 to 9316 km^2 (Table 1), averaging 6953 km^2 per year in the 1980s and 6610 km^2 in the 2000s. Some transects were truncated at the north end owing to a more southerly position of the ice edge (Fig. 1, e.g., 1985, 2009) or were shortened or omitted altogether (westernmost two transects in 1982; two transects north of the Mackenzie Delta in 1984, 2008) because of local fog or low cloud. The 2007 survey was completed in the shortest time (48 h) and without any missed transects or portions of transects. In 1984, transect lines were extended farther north (in some cases to 72˚ N), and well into the pack ice to meet program objectives specific to that year.

The most obvious feature of the distribution of belugas in the offshore was that (1) they were observed on most transects in all surveys (Figs. 2 and 3), and (2) the patterns were similar in the 1980s and the 2000s.

Belugas were observed on 114 of the 149 transects (76.5%) surveyed, with sightings particularly prevalent over the shelf offshore of the Tuktoyaktuk Peninsula, seaward of the shelf break, in the Mackenzie Canyon approximately 25–75 km north of Kay Point, and within 30 km seaward of the Mackenzie Estuary (Figs. 2 and 3). We did not detect other high-use offshore areas. Water depths where belugas were sighted were mainly, but not exclusively, less than 50 m. However, the whales did not appear often in waters offshore of the Yukon coast that were shallower than 50 m in either series, and they were also absent from one large 50–200 m deep area of the continental shelf located 100 km offshore of the Mackenzie Estuary.

In the 1980s series, 305 belugas (145 sightings) were observed on-transect during 20 858 km^2 of surveying (Table 1). In the 2000s series, with an essentially equal survey area (19 829 km^2), more than three times the number of belugas were sighted on-transect in the same area at the same time of year (1061 belugas; 378 sightings). In both series, belugas were observed mainly in groups of 1 to 3 (49% in 1980s, 43% in 2000s) and groups of 4 to 10 (30% in 1980s; 39% in 2000s) (Fig. 4). Mean group size was 2.1 (SD 2.1, range 1–15) in the 1980s and 2.6 (SD 3.9, range 1–60) in the 2000s (Table 1; Fig. 4). Except for 1984, our clump factors ranged between 150% and 200% of the group-size CHM (Table 2). Both group-size CHM and clump factors were larger in the 2000s surveys. This pattern is consistent with the higher densities of animals, which would tend to be associated with more clumpiness in distribution.

Relative Numbers

Extrapolation of visible surfaced whale counts to unsurveyed areas provides an index of relative numbers. We emphasize that these estimates do not reflect actual stock size, since they are not corrected for surfaced whales missed

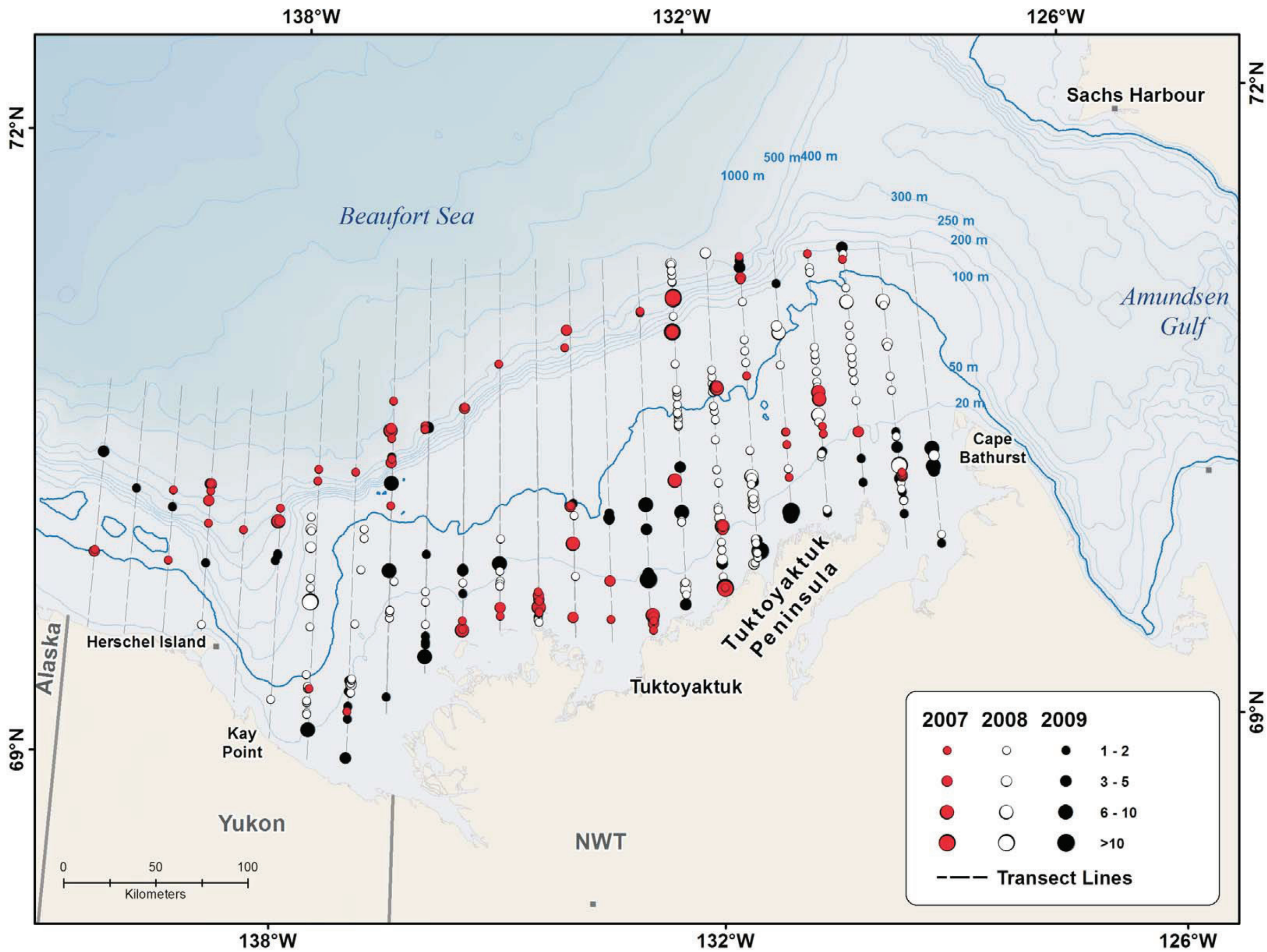

FIG. 3. Location of transects (numbered from west to east) and numbers of surfaced belugas sighted in the offshore Beaufort Sea during aerial surveys in late August in 2007–09.

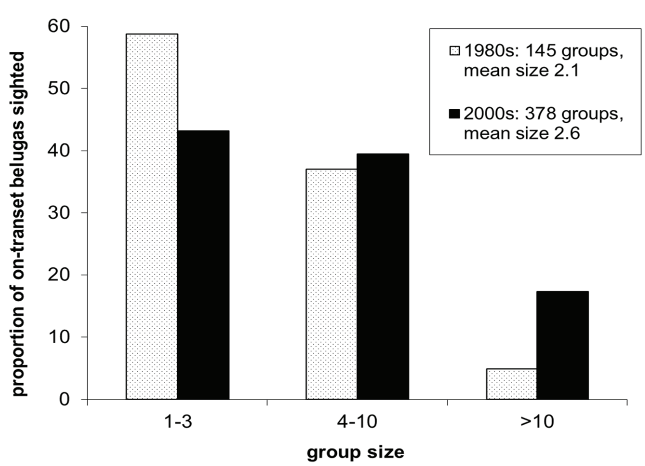

FIG. 4. Group sizes of belugas sighted on-transect in late August in the 1980s and the 2000s.

by observers, whales below the surface at the time of the survey, or whales outside the offshore study area. However, they provide a relative means by which to examine trends in the number of belugas using the offshore Beaufort Sea in late August, since they were based on standardized surveys of the same study area at the same time of year, using the same method and many of the same observers.

TABLE 2. Contraharmonic mean (CHM) of group size and clump factors for beluga aerial surveys in the southeastern Beaufort Sea, 1982, 1984–85, and 2007–09.

Year	CHM group size	Clump factor	Ratio
1982	6.64	10.53	1.585843
1984	3.63	3.57	0.983471
1985	2.76	5.32	1.927536
2007	6.1	10.47	1.716393
2008	11.75	17.06	1.451915
2009	6.64	10.82	1.629518

The annual indices ranged from 524 to 1405 (mean 914) during the 1980s and from 3374 to 4023 (mean 3592) in the 2000s (Table 1; Fig. 5). For both the 1980s and 2000s, the indices for individual years in the same survey series are within each other's confidence ranges. However, the means of these indices showed a fourfold increase from the 1980s to the 2000s in the relative number of surfaced belugas using the offshore Beaufort Sea in late August.

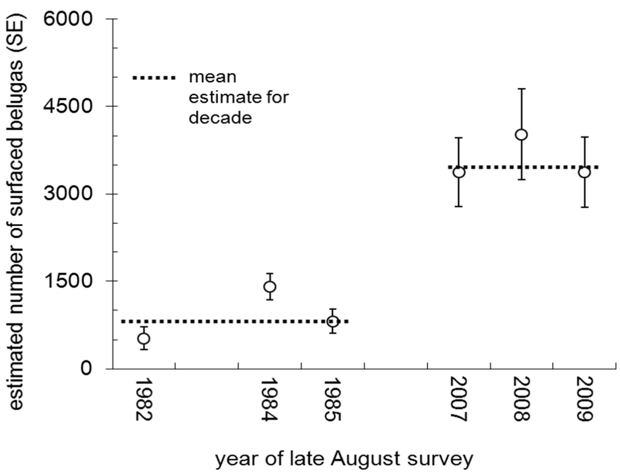

FIG. 5. Estimated number of surfaced, visible belugas (and SE) in the southeastern Beaufort Sea, extrapolated for unsurveyed areas but not corrected for subsurface belugas or belugas outside the study area at the time of the survey, 1980s vs 2000s.

DISCUSSION

Belugas are smaller in size and thus not as readily detectable as the other target species, the bowhead whale, on the more distant parts of a transect. The detectability of belugas across the transect width has been measured in three studies in the offshore Beaufort Sea and appears to be consistent up to 600 m from the flight path, declining beyond that distance (Davis and Evans, 1982; Norton and Harwood, 1985; Harwood et al., 1996). The effect of reduced detectability of belugas in parts of the transects more than 600 m from the flight path would negatively bias the counts and indices downward. However, this bias would be consistent among the surveys reported here because the same method, same platform, many of the same observers, and same minimum survey condition criteria were used in all surveys. Surveys in 1982 have a slight upward bias because the strip was narrower; still, the 1982 estimate was among the lowest in the six surveys examined here.

In contrast to their highly clumped distribution in the Mackenzie River estuary during July (Norton and Harwood, 1986), belugas were widely, and it seemed haphazardly, distributed in the offshore Beaufort Sea study area in late August of all survey years. They were observed mainly as individuals and in small groups of 2–3 whales (Fig. 4). The pattern of distribution of belugas observed in late August in the 2000s was similar to that observed in late August in the 1980s.

Compared with results of some other recent aerial surveys of belugas in James Bay and eastern Hudson Bay (Hammill et al., 2004; Gosselin, 2005; Gosselin et al., 2009), the ratio of the annual group size CHM to the annual clump factor, our measure of aggregation, was small (Table 2). For James Bay and eastern Hudson Bay, for example, we calculated approximate values based on reported survey results. The group size CHM was about 86 and the clump factor was 350, and sighting maps show the population to have been highly aggregated (adapted from Gosselin et al., 2009). The groups of belugas were much more uniformly distributed in the Beaufort Sea than has often been the case in some other habitats (e.g., Gosselin et al., 2009). As a result, uncertainties associated with the estimates of surface-visible numbers were not large for this study, given the number of sightings we made and patterns of aggregation and distribution that we observed.

We know that belugas are well adapted to ice, and we suspect that they use ice as a refuge more readily in windy weather and possibly when threatened by predators (e.g., killer whales, *Orcinus orca*). We have observed that they use open-water habitats readily, especially in calm weather (Norton and Harwood, 1985; Harwood et al., 1996). Our aerial survey experience has revealed belugas in all habitats throughout the Beaufort, with or without ice (Norton and Harwood, 1985), and satellite-tracking results have shown a similar pattern (Richard et al., 2001).

Belugas were particularly common in all surveys offshore of the Tuktoyaktuk Peninsula shelf and within 30 km seaward of the Mackenzie River estuary. Aside from these areas, we were unable to detect any high-use offshore areas that were consistently favoured from survey to survey, but we recognize that six surveys might not be a sufficient basis for firm conclusions. Belugas were rarely observed in waters offshore of the Yukon coast that were shallower than 50 m, and they were not observed in a 50–200 m deep area of the Tuktoyaktuk Shelf offshore of the Mackenzie Estuary in any year.

The number of surfaced belugas was similar in all of the 2007–09 surveys, with no obvious trend toward increasing or decreasing relative abundance within each series (Fig. 5). This was also the case in the 1980s, all indices being within each other's confidence intervals.

The indices of beluga numbers in the 1980s series and the 2000s series were markedly different (Fig. 5). In the 2000s, both the mean number of surfaced belugas counted and the number of surfaced belugas estimated for the study area were four times those in the 1980s. Three other systematic aerial surveys were flown in the southeastern Beaufort Sea in the 1980s, and all produced indices of belugas that were even lower than our 1982, 1984, and 1985 surveys (i.e., August 1981 surveys, estimated 138 surfaced belugas, Davis and Evans, 1982; August 1983 surveys, estimated 322 surfaced belugas, McLaren and Davis, 1985; August 1986, 160 surfaced belugas, Ford et al., 1987). The results of all surveys conducted in the 1980s provide compelling evidence that belugas had become more common in the offshore Beaufort Sea in the 2000s.

Survey methods and timing were generally the same in the 1980s and 2000s, yet the two series yielded very different numbers of surfaced belugas. Methods used here are the standard ways of assessing stocks of belugas throughout the Arctic, although their limitations and inaccuracies are well known (Hammill et al., 2004; Gosselin et al., 2007). The limitations of these methods underscore the importance of obtaining defensible knowledge of distribution and habitat

TABLE 3. Summary of industry activities[1] in the southeastern Beaufort Sea during 1982,[2] 1984–85[2] and 2007–09.

	1982	1984	1985	2007	2008	2009
No. active seismic vessels	3	4	4	1	2	1
Active offshore sites	15	18	19	0	0	0
Operating dredges	6	7	8	0	0	0
Operating drill ships	4	5	5	0	0	0
Wells spudded	8	6	19	0	0	0

[1] Does not include support vessels or helicopters.

[2] Data for 1982, 1984, and 1985 adapted from Brouwer et al. (1988).

use, as well as movements and behaviour, and the need to use complementary methods (satellite telemetry, acoustics, etc.) to inform and improve survey estimates, as was possible with the 1993–97 satellite tagging in the offshore Beaufort (Richard et al., 2001).

The reasons for the change in beluga numbers are not understood, and we do not know where the majority of belugas might have summered in the 1980s. It is well known, however, that the offshore animals represent only part of the larger stock (Norton and Harwood, 1985; Richard et al., 2001), a proportion of which regularly occurs outside the survey area at this time of year—in Amundsen Gulf, Viscount Melville Sound, and Alaska (Richard et al., 2001; Clarke et al., 2012). Interannual variation in the amount of use of these areas by belugas has also been seen in survey results from other areas. For example, surveys concurrent with ours flown in the northeastern Chukchi Sea also reported very few belugas in the summers of 1982 to 1991 (Moore et al., 2000; Clarke et al., 2012), and again in 2008 to 2010 (Clarke et al., 2012).

Population growth is one possible explanation of why there were more belugas in the offshore Beaufort Sea in late August in the 2000s than in the 1980s. Certainly late August is a time when belugas sighted offshore exhibit feeding behaviours, such as darting and aggregating at points of land (Norton and Harwood, 1985). Enhanced resources could translate into increases in growth, reproductive rates, and ultimately stock size, and could thus be a contributing factor to the greater index of abundance in the 2000s compared with the 1980s. We fitted exponential growth to our 1980s and 2000s survey results, which indicated that an instantaneous growth rate approaching 7% per year would be necessary to explain this increase. Unexploited beluga populations that are below carrying capacity appear to increase at a rate of 2.5% to 3.5% (and possibly as high as 4%) per year (COSEWIC, 2004). Further, there is no clear evidence that extensive growth such as this occurred in this stock, judging by the size and age of landed whales in the Delta in July (DFO, 2000; Harwood et al., 2002). The present rate of harvest removal is small in relation to the expected maximum net productivity rate (DFO, 2000). The continued harvesting opportunities, the continued availability of large and old individuals after centuries of harvesting, and the apparent lack of change in the size and age structure of the catch in recent years up until at least 2009 (Harwood et al., 2002; DFO, unpubl. data) suggest that the stock is not decreasing in size. Thus, population growth alone is probably not sufficient to explain the changes observed in relative abundance between the 1980s and 2000s, but could account for some unknown proportion of the increase.

The final, and we believe most plausible, explanation is that in recent years the offshore habitats in the Canadian Beaufort have become more attractive to belugas in late August than they were in the 1980s. This increased attractiveness could have resulted either from a change in the intensity or extent of industrial activity related to hydrocarbon activity in the 1980s (Brouwer et al., 1988) or from shifts in the ecosystem related to climate change (Tynan and DeMaster, 1997; Laidre et al., 2008).

In regard to the first mechanism, changes in the relevant environmental factors cannot be studied directly, at least not at a scale that is consistent with the extensive foraging range used by these belugas (Richard et al., 2001). Still, enhanced pelagic marine productivity is predicted by most climate change models (Barber et al., 2008; Sallon et al., 2011). As appears to be the case with bowhead whales (Harwood et al., 2010), the belugas in the 2000s could be accessing resources in the offshore Beaufort Sea to a greater extent or for longer periods than in the 1980s, or both. Changes in the timing of fall migration also cannot be discounted as a possible explanation, at least in part, for the differences between decades that we observed in the abundance of belugas.

Another way in which the attractiveness of the offshore Beaufort Sea to belugas could have changed might be linked to displacement or deterrence of belugas from the offshore Beaufort in the 1980s in the presence of industry activity in this area, as has been reported for 2001–02 (Miller et al., 2005). The level of industry activity and potential for disturbance of marine mammals in the Canadian Beaufort Sea was considerably higher at the time of the 1980s surveys than in the 2000s (Table 3; Brouwer et al., 1988). Open-water industry activity in the 2000s has to date comprised at most two offshore air-gun seismic surveys per season, no offshore dredging, and no exploratory drilling from ships, islands, or caissons during the open-water period. This level of activity is in sharp contrast to that of the 1980s, when 4–5 seismic vessels, 4–5 drill ships, 6–8 dredges, 2 drilling caissons, and numerous artificial islands were operating concurrently in any open-water season from 1980 through 1986 (Brouwer et al., 1988). In addition, standard mitigation procedures and practices are now in place in the southeastern Beaufort Sea to minimize or eliminate impacts of seismic and other industrial activity on cetaceans. These procedures include spatial and temporal preseason planning measures to avoid important habitats and times (Harwood et al., 2009), ramp-up procedures to deter marine mammals during start-up, and full shutdown of the seismic array if a cetacean is observed within the 180 dB safety zone surrounding the seismic source (DFO, 2012).

We cannot discount the possibility that the hydrocarbon industry was active enough in the offshore Beaufort Sea in the 1980s to displace a part of the stock from the shelf waters, leaving fewer belugas to be seen in the aerial surveys flown in those years. As interest by the hydrocarbon industry in the offshore Beaufort grows in the coming decade(s), and given continuing ecosystem effects of a changing climate, it is prudent to monitor the use of offshore habitats by belugas. Such monitoring will facilitate valid comparisons with existing 1980s and 2000s data sets, and we encourage the use of survey methods and timing comparable to those reported here.

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