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Belugas in the Mackenzie River estuary, NT, Canada: Habitat use and hot spots in the Tarium Niryutait Marine Protected Area

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ABSTRACT

The Tarium Niryutait MPA (TNMPA) was created in 2010, through the collaborative efforts of Fisheries and Oceans Canada, the Inuvialuit, private industry and local stakeholders. The purpose of the TNMPA is to conserve and protect the biological resources within the Mackenzie Estuary, ensuring viability of a healthy population of beluga whales. TNMPA regulations allow for the conduct of certain industry activities (e.g., dredging, transportation, and hydrocarbon exploration and production activity), as long as disturbance, damage, destruction or removal of belugas do not occur or are not expected. Our goal is to summarize baseline knowledge of the times, areas and patterns of aggregation of belugas in the TNMPA, to inform future monitoring, research and environmental assessments of any developments proposed for the TNMPA. Sightings of surfaced belugas in the Mackenzie River estuary made during seven summers of aerial surveys between 1977 and 1992 were examined using contemporary geospatial analytical methods. A total of 77 aerial surveys met the minimum criteria for inclusion: flown in their entirety, without interruption, under calm sea conditions, and with full visibility. The distribution of surfaced belugas was significantly clustered in three time periods (June 26–July 9, July 10–20, July 21–31) and in all sub areas of the TNMPA (Ripley's *L*, $p < 0.0001$). Sighting rates varied by subarea and time period, with Niaqunnaq Bay having rates 3–4 times higher ($p < 0.0001$) in the corresponding period, compared with West Mackenzie (WM), East Mackenzie (EM) and Kugmallit (KB) bays, in all but WM in late July. During early and mid-July of 1977–1985, belugas were aggregated in seven localized, recurrent geographic areas within the TNMPA, termed here as 'hot spots'. Results will foster more confident and informed decisions about the acceptability of proposed industry activities in the TNMPA, ensuring assessments are evidence-based and not unnecessary restrictive.

1. Introduction

The Tarium Niryutait Marine Protected Areas (TNMPA), established in 2010, is Canada's first Arctic MPA and covers approximately 1 800 km^2 of the Mackenzie River estuary in the Beaufort Sea. It was created through a collaborative effort by Fisheries and Oceans Canada, the Inuvialuit, private industry and local stakeholders, made possible with enactment of Canada's Oceans Act in 1997 (Fast et al., 2001, 2005). The TNMPA consists of three MPAs within, Niaqunnaq in the west, Okeevik in East Mackenzie Bay and Kittigaryuit in Kugmallit Bay (Fig. 1).

The purpose of the TNMPA is to conserve and protect the biological resources within the Mackenzie Estuary, ensuring the viability of a healthy population of beluga whales (*Delphinapterus leucas*) and their habitats. While in the Mackenzie Estuary, these belugas have long been, and continue to be, the subject of an important traditional subsistence hunt conducted annually by the Inuvialuit of the western Canadian Arctic (Nuligak, 1966; McGhee, 1988; FJMC, 2013), a harvest which has been assessed by DFO as sustainable (DFO, 2000).

Collection of, and access to accurate scientific information about beluga behaviour and habitat use in the TNMPA is crucial to ensure

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the conservation objectives are met, and that management decisions are evidence-based (Fast et al., 2001). Specifically, a better understanding is needed of outcomes of harvesting; the sources, extent and impacts of pollution and loss of habitat; and the implications of climate change and loss of biodiversity (Fast et al., 2001). Consulting with the stakeholders throughout the planning process (Fast et al., 2005), Canada finalized the monitoring protocols, indicators and strategies for the TNMPA in 2010 (Loseto et al., 2010).

Belugas aggregate in the warm, shallow waters of the Mackenzie River estuary during summer (Fraker et al., 1979; Norton and Harwood, 1986) (Fig. 1). Use of the Estuary peaks in early to mid-July, and declines in late July (Fraker and Fraker, 1979; Norton and Harwood, 1986; Day, 2002; Richard et al., 2001), as the distribution shifts to largely offshore in August (Norton and Harwood, 1985; Harwood et al., 1996; Richard et al., 2001). The stock was last assessed as stable or increasing (DFO, 2000), numbering an estimated 39 258, with a coefficient of variation (CV) of 0.229 (Hill and DeMaster, 1999). The belugas moult while they are in the TNMPA (St. Aubin et al., 1990; Harwood et al., 2002), although the specific geographic locations within the TNMPA which promote moulting are not known.

Identification and protection of protected marine areas encompassing critical habitats such as estuaries is a practice that is well-established globally (Hoyt, 2011; WDC, 2014), with strategies that target 'hot spots' conferring the greatest conservation benefits (Ashe et al., 2009; DFO, 2009). This has been undertaken for other stocks of belugas, in both Alaska (e.g., Cook Inlet: Hobbs et al., 2005; Carter and Nielsen, 2011; NOAA, 2014; Goetz et al., 2012; Ashford et al., 2013; Ezer et al., 2013) and Canada (Gulf of St. Lawrence, Mosnier et al., 2010; Lefebvre et al., 2012), but not previously for the Mackenzie Estuary. Interest in formal, legal protection of belugas and their habitats in the Mackenzie River estuary date back to the Berger Enquiry in the 1970s (Berger, 1977).

MPAs encompass a range of protection levels, from fully protected no-take reserves, to MPA's where only certain types of activities are restricted (Lester and Halpern, 2008). The latter is the case in TNMPA, where there are exceptions which allow for the conduct of industry activities including dredging, transportation, and hydrocarbon exploration and production activity (Canada, 2013). These and other activities are permissible if they will not, or likely will not, result in the disturbance, damage, destruction or removal of a marine mammal. It is therefore essential that regulators, managers and the Inuvialuit are positioned to critically review development proposals, and make informed assessments, and set terms and conditions, to ensure compliance with TNMPA regulations (Canada, 2013).

Since the 1970s, long before the TNMPA was established, there were substantial research and monitoring efforts on belugas in the Mackenzie Estuary. Oil and gas exploration in the late 1970's and early 1980's led to regular, extensive aerial surveillance of the summer distribution of beluga whales in the Mackenzie Estuary. Surveys were reported annually in industry reports (Fraker, 1977; Fraker, 1978; Fraker and Fraker, 1979, 1981; Norton Fraker and Fraker, 1982; Norton Fraker, 1983; Norton and Harwood, 1986). Finally, there was a region-wide aerial survey, of both the Estuary and the offshore, in late July 1992 (Harwood et al., 1996), this being the most recent systematic survey of these belugas during the July aggregation period. To our knowledge there has not been a standardized, compilation of all these data using geospatial analyses that depict beluga distribution in the TNMPA.

The overarching goal of this paper was to rescue the available survey data from the 1970s and 1980s, provide a baseline about the ways that belugas used the habitats in the Mackenzie River estuary

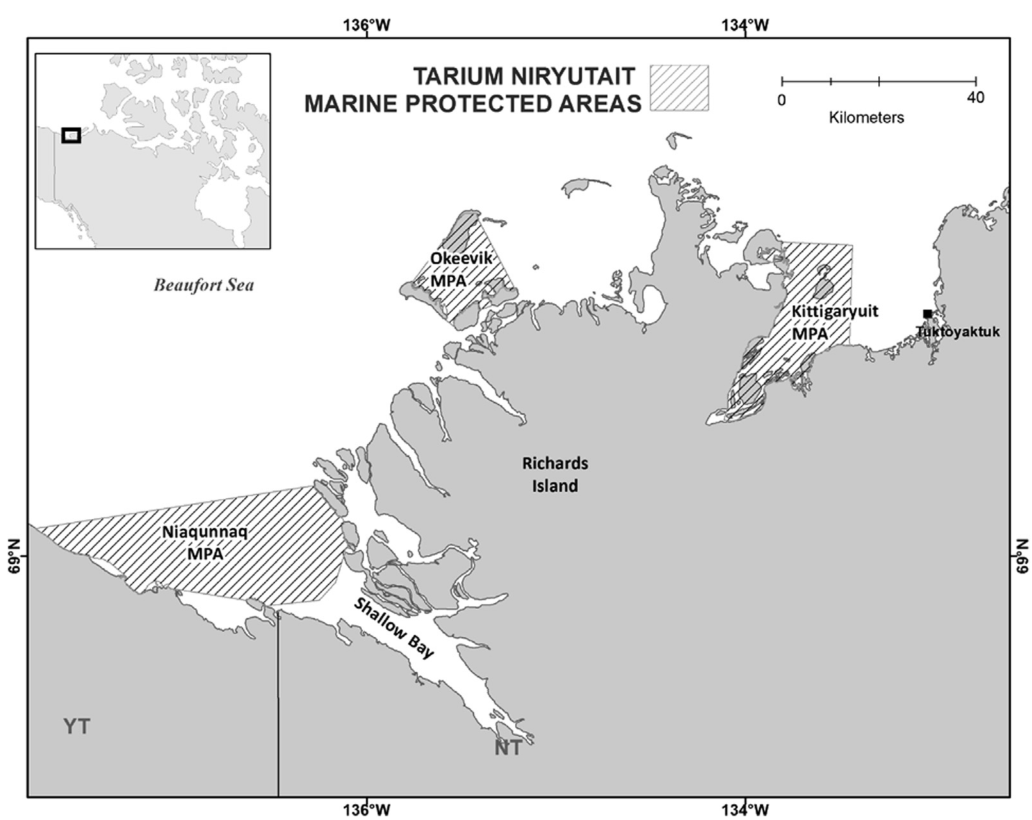

Fig. 1. Location of Tarium Niryutait Marine Protected Area and the Mackenzie River estuary, NT, Canada.

in the past, and provide results from a huge, existing historical database that can be accessed for future assessments, research and monitoring (Mathias et al., 2008). Our first objective is to describe the seasonal and annual extent of beluga spatial clustering in the Mackenzie River estuary during July, to provide a formalized, standardized and quantitative benchmark against which results from future surveys could be compared to evaluate if changes have occurred in the distribution of belugas in the TNMPAs behaviour.

Our second objective is to assess the relative use of the four subareas of the TNMPA, over three July time periods, also to provide a quantitative benchmark against which relative abundance of belugas among subareas could be compared in the future as means of detecting change in their numbers or the ways they apportion their time between the subareas of the TNMAP. Our final objective is to identify the specific geographic locations(s) in the TNMPA, if any, that were preferentially and recurrently used by belugas during the July aggregation period, and by doing so, provide a tool that could be used by regulators for assessing developments, setting terms and conditions for activities that are proposed by industry, and evaluating changes in the location of preferred areas.

The results we present are timely given recent renewed interest by the hydrocarbon industry in the Beaufort/Mackenzie region (AANDC, 2012) and Canada's legal requirement to design and undertake monitoring programs in the TNMPA (Loseto et al., 2010; Canada Gazette, 2010; Beaufort Sea Partnership, 2014). In addition, knowledge of beluga critical habitats and the ways in which they have used them in the past may also help us in the future to predict how belugas have or will respond to climate change or other factors that alter habitat (Laidre et al., 2008).

2. Methods

2.1. Study area and survey design

Systematic aerial surveys were conducted over six summers between late June and early August, 1977–1985, and in late July 1992, to monitor the distribution and relative abundance of belugas in all four bays (subareas) of the Mackenzie Estuary (Niaqunnaq Bay, East Mackenzie Bay, West Mackenzie Bay and Kugmallit Bay), including portions of the estuary that would eventually become the TNMPA in 2010. A total of 169 subarea surveys were attempted or completed during this period.

The same systematic transect lines were flown in all survey years in the 1970s and 1980s (Fig. 2), with transects spaced at intervals of 3.2 km, except in West Mackenzie Bay where they were spaced at 4.8 km. A strip-transect method was used (Caughley, 1977) in all surveys, with a strip width of 1.6 km (800 m per side), except in 1992 when the strip width was 400 m per side (Harwood et al., 1996). This provided survey coverage of 50% in the 1970s and 1980s (33% in West Mackenzie), and 29% and 15% in July 1992, respectively.

Survey altitude was 305 m during all surveys, which was measured with the aircraft's altimeter, and adjusted by the pilots during the surveys as necessary. Target ground speed was 200 km/

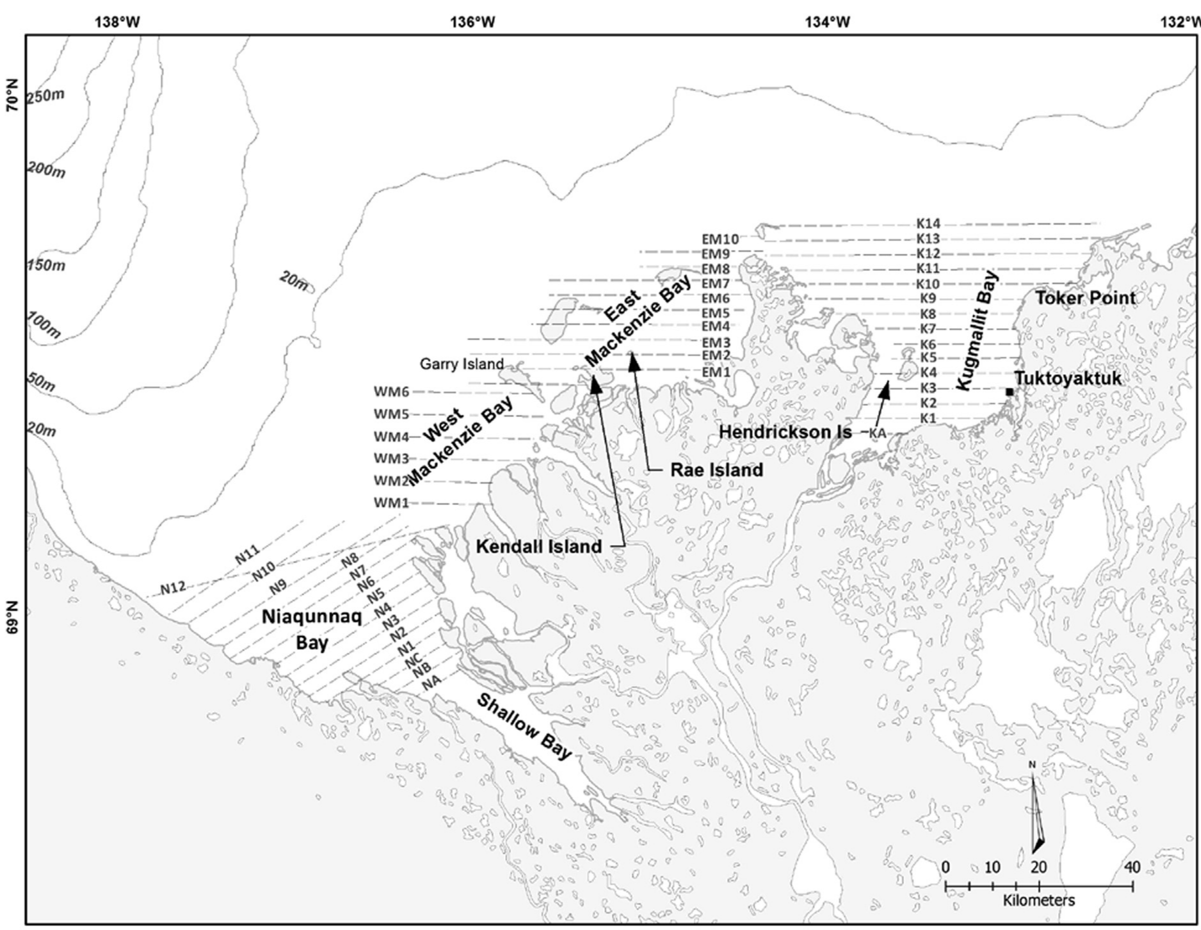

Fig. 2. Location of transect lines flown during systematic aerial surveys of the Mackenzie Estuary, July 1977–1985 and July 1992, and places mentioned in text.

h. Sighting coordinates were calculated using ArcGIS, using start and end-coordinates for each transect, and elapsed time. Mean ground speed for all surveys pooled was 188 km/h (SD 54.2). Primary search positions were equipped with bubble windows in 1984, 1985 and 1992, for enhanced visibility under the aircraft, close to the flight path. Surveys were flown in Cessna 185 on wheels (1970s) and in de Havilland Twin Otters (1980s and 1992).

Survey conditions were assessed and recorded by observers at the beginning and end of each transect, and were summarized in the database for each subarea survey, by transect line. The usual flying time was 6–8 h per day. Observers rested during ferrying flights, refuelling stops, and when flying between transects. Data reported here were collected by the same six observers, all with extensive and recent aerial survey experience.

Observers recorded species, time of sighting, and number in group. 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). For each sighting, observers independently recorded information on number in group, time of sighting, relative size and colour of whale (e.g. white [adult], large gray [subadult], small gray ["calf", either young-of-the-year or one year old], behaviour (e.g., tail splashing; calf lying on mother's back). A sighting consisted of either an individual whale or a group of whales. To ensure a consistent and uninterrupted search, there were no departures from the transect lines to circle groups of beluga that were sighted.

Sighting locations were determined on the basis of elapsed time and aircraft speed, and in later years (1985, 1992) using the aircraft's Global Navigation System (GNS) to record geographic location 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) and sea state according to the Beaufort Scale of Wind Force. Audio tapes were transcribed to data sheets after each survey.

2.2. Data analysis

We reviewed sighting conditions and transect coverage from 169 subarea surveys, selecting 77 of these for inclusion in our basic dataset (Table 1, Fig. 3). These met our criteria of having been completed without interruption in survey coverage or progression, and were rated by observers as having been flown under 'good' or 'excellent' survey conditions (Fraker et al., 1979; Norton and Harwood, 1986) (seas were calm or near-calm with no whitecaps, sea states of 0–2 on the Beaufort Scale of Wind Force) (DeMaster et al., 2001) and full visibility (e.g., no fog or low cloud that obstructed visibility in any way on either side of the aircraft).

Table 1
Summary of systematic surveys[a] and beluga sightings for Mackenzie Estuary, 1977–1985 and 1992.

Year	No. of bays surveyed	Km flown	No. beluga sighted at surface	No. beluga groups sighted	No. calves[b] sighted at surface
1977	28	13 313	9 313	2 247	113
1978	10	3 849	2 452	523	21
1980	15	5 212	3 205	781	49
1981	11	5 723	1982	570	44
1982	4	2 619	1 489	269	45
1985	5	3 251	1783	1 387	8
1992	4	1 184	946	580	18
Total	77	35 151	21 170	6 357	298

[a] Includes complete surveys flown under good or excellent conditions.
[b] Calves = neonates and yearlings.

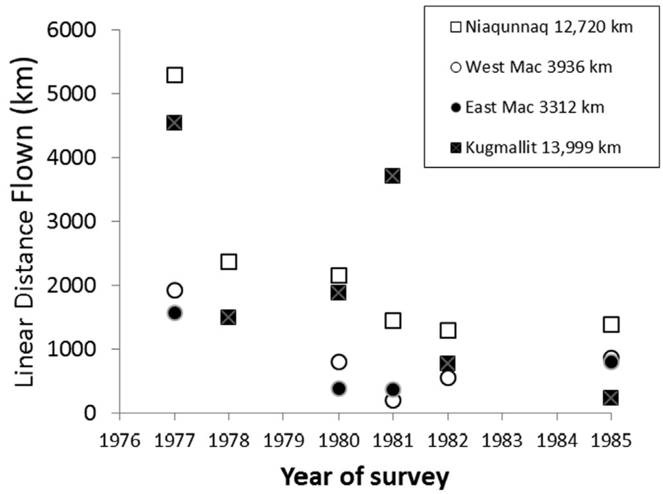

Fig. 3. Linear transect distance (km), by subarea, of systematic aerial surveys flown in the Mackenzie River estuary, late June to early August, 1977–1985.

Sightings from the subareas were then pooled into four time periods; early (June 26–July 9), mid (July 10–20), late (July 21–31) and early August (Aug. 1–9). Whale counts, calf counts, and group sizes, were tabulated by time period, subarea (bay) and year using SAS V.8 (1990). Subarea surveys flown in each time period and subarea were pooled, to achieve adequate sample sizes.

Two spatial methods were used to statically assess beluga distribution, both independent of survey effort. The extent and degree of clustering was examined using the Ripley's L function, and the identification of 'hot spots' was done using kernel density estimates (KDE), and the calculation of Percent Volume Contours (PVCs) by time period (Silverman, 1986; Worton, 1989; Wand and Jones, 1995). Sighting rates of surfaced belugas among subareas and time periods was assessed for the 1977–1985 surveys, using a two-way unbalanced ANOVA in XLStat (V. 2013.6). Subarea and July time period, and their interaction, were considered as possible effects. One outlier was removed.

Ripley's L function is a second-order measure of spatial homogeneity, and summarizes the spatial dependence of sightings over a range of distances (Besag, 1977; Nekola and Kraft, 2002; Lancaster and Downes, 2004). This statistic can be used to examine whether the observed spatial pattern of sightings is clumped, evenly, or randomly distributed. Using the Ripley's L function, if a set of locations lack homogeneity, then the spatial distribution is considered clustered. The Ripley's L function is stabilized in terms of the variance between dates (compared to the Ripley's K function), and thus allows for comparisons between years.

The Ripley's L function (L_s) is defined by:

$$L_s = \left[\frac{\lambda^{-1} n^{-1} \sum I(d_{ij} < s)}{\pi}\right]^{1/2}$$

where λ is the average density of locations, n is the number of locations, d_{ij} is the Euclidean distance between the ith and jth locations in the data set, and I is the indicator function. Here we calculated the Ripley's L function from 0 km to 21 km, and graphed the function of the number of lags, along with the L functions determined for a random distribution using Monte Carlo permutations (defined as L_{min} and L_{max}). If the Ripley's L function is greater than that for a random distribution (i.e. greater than L_{max}), the distribution of beluga whales is considered clumped. Values between L_{min} and L_{max} indicate a distribution that is random.

Mean centre and standard distance were calculated, being the spatial equivalents to mean and standard deviation in classical statistics. The mean centre is the mean of the latitude and longitude of all the beluga sighting locations in a given bay (subarea), thus providing the average geographic position for all sightings in the time period in the whole subarea.

Standard distance provides a measure of the degree to which the locations of beluga sightings were clustered or dispersed around the mean center. This measure is the standard deviation of the distance of each point from the mean centre. A large standard distance thus indicates a larger cluster of locations, and a small standard distance, vice-versa. The mean centers and standard distances for each subarea and survey were plotted and tabulated, to facilitate visual comparison of the extent of overlap among years.

The KDE procedure takes a series of locations and then fits a probability density (usually a normal distribution) to each. Percent Volume Contours (PVCs) were created using ArcGIS (ESRI, 2004) Spatial Analyst Extension 9.3.1, and earlier using Hawth's Analysis Tools v. 3.27. (The latter have since been incorporated into Geospatial Modelling Environment, http://www.spatialecology.com). KDEs were processed using a bivariate normal kernel estimator, and polygons derived from the KDE raster datasets (Sain et al., 1994; Seaman and Powell, 1996; Seaman et al., 1999; Gitzen and Millspaugh, 2003). The PVC represents the boundary of the area that contains a given percentage of the volume of a probability density distribution, in our case shown for 10, 25, 50, 90 and 95% of the observations. The 10% contour contains only the areas with a high probability of use, while the 90% contour contains areas encompassing most observations, and both high and low probability of use (Quakenbush et al., 2010). Geographic coordinates for the center points of the PVC contour for each time period, all years pooled, were obtained using ArcGIS (ESRI, 2004), and we have termed these here as 'hot spots'.

3. Results

3.1. Overview of surveys, sightings and group sizes

A total of 21 170 surfaced beluga whales (6 357 groups) were included in the basic dataset, collected over seven survey seasons between 1977 and 1992. The overall survey transect distance was 35 151 km (Table 1).

Surveys were flown from late June (earliest, June 26) through to early August, although sample size was only sufficient to analyze surveys for the July period. Of 77 accepted surveys, most were flown in July: 36.6% were flown June 26–July 9), 35.2% during mid-July (10–20), 28.2% during late July (21–31) (Table 1). A total of 298 calves (young-of-the-year or one year olds), distinguished on the basis of size and colour, were seen by observers in the four subareas (Table 1), 53% of these in Niaqunnaq Bay, and the rest in Kugmallit Bay, East Mackenzie Bay and West Mackenzie Bay (28.9%, 4.7%, and 13.4%, respectively). Calves were observed mainly in mid-July (33.6%) and late July (43.3%).

The distribution of surfaced belugas sighted in the Mackenzie Estuary was clustered, in each of the three July time periods in 1977–1985, and in late July 1992. Lag distances peaked in the 7–10 km range in 1977–1985, in all three July time periods, indicating a significant ($p < 0.05$, Fig. 4) and similar degree of clustering throughout the month of July. The lag distance during the late July 1992 survey peaked at the lowest distance, 3.7 km, suggesting a tighter degree of clustering in late July of that year, compared with the corresponding period in 1977 through 1985.

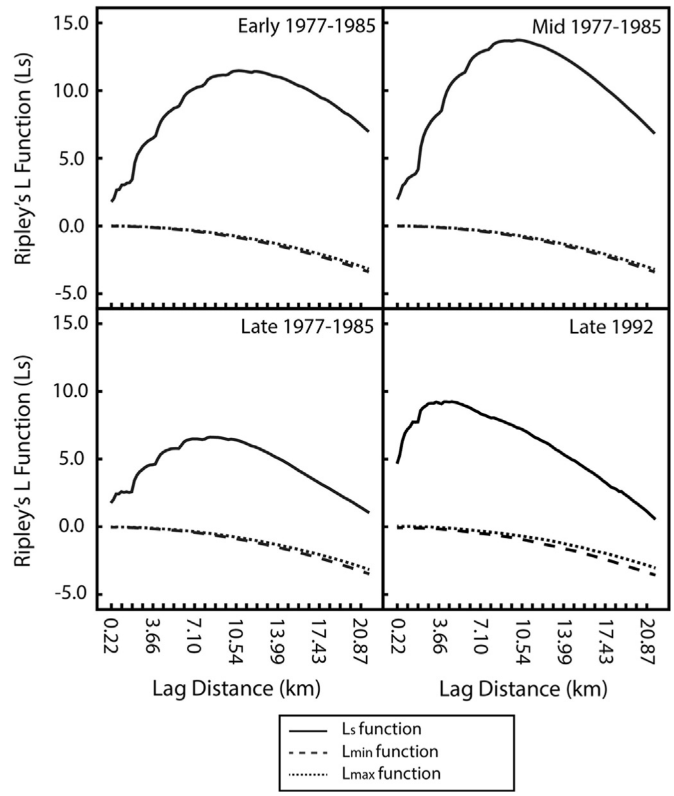

Fig. 4. Ripley's L functions for different time periods. The solid line is the graphic representation of the function for different lag distances. When the L_s function is greater than the L_{max}, the distribution of locations is clustered.

The size of clusters can be compared visually among years using the mean centers (points) and standard distances (circles) (Fig. 5). The mean centers for each year were in close proximity to each other in a given subarea, and standard distances overlapped among years, in each time period and subarea. This indicated the belugas were clustered to a similar extent in each subarea of the TNMPA, for the years examined. The degree of overlap of the standard distances was the most closely matched in Niaqunnaq Bay, with values averaging 10, 9 and 9 km in the early, mid and late time periods, respectively (Table 2, Fig. 5). Mean standard distances for belugas showed a similar tendency to overlap in Kugmallit Bay, with average standard distances of 10, 12 and 16 km during the early, mid and late July time periods. The magnitude and range of the standard distances for West Mackenzie Bay were greatest in early July (i.e., 21–28 km), indicative of a wider dispersion of sightings at that time and location (Table 2).

Overall, 48% of the variability in sighting rates was explained by the model ($R^2 = 0.48$, df = 55). Subarea had the greatest impact on the model ($F = 11.986$, df 3, 6, $p > F < 0.0001$). Sighting rates varied among subareas and time periods (Fig. 6), being statistically higher in Niaqunnaq Bay in early and mid-July ($F = 13.71$, df = 3, 6, $p > F < 0.0001$). Niaqunnaq Bay sighting rates were 3–4 times higher in all time periods than the other subareas, except for West Mackenzie Bay in late July (Fig. 6). Within subareas, sighting rates were not statistically different between the three July time periods ($F = 0.024$, df = 2,6, $p > F = 0.976$), and there were no significant interactions ($F = 1.671$, df = 1, 6, $p = 0.146$).

The PVC analysis revealed multiple and specific geographic locations within each subarea of the TNMPA where the beluga sightings were the most concentrated, by July time period. These focal areas of concentration (Fig. 7) were used to define seven 'hot

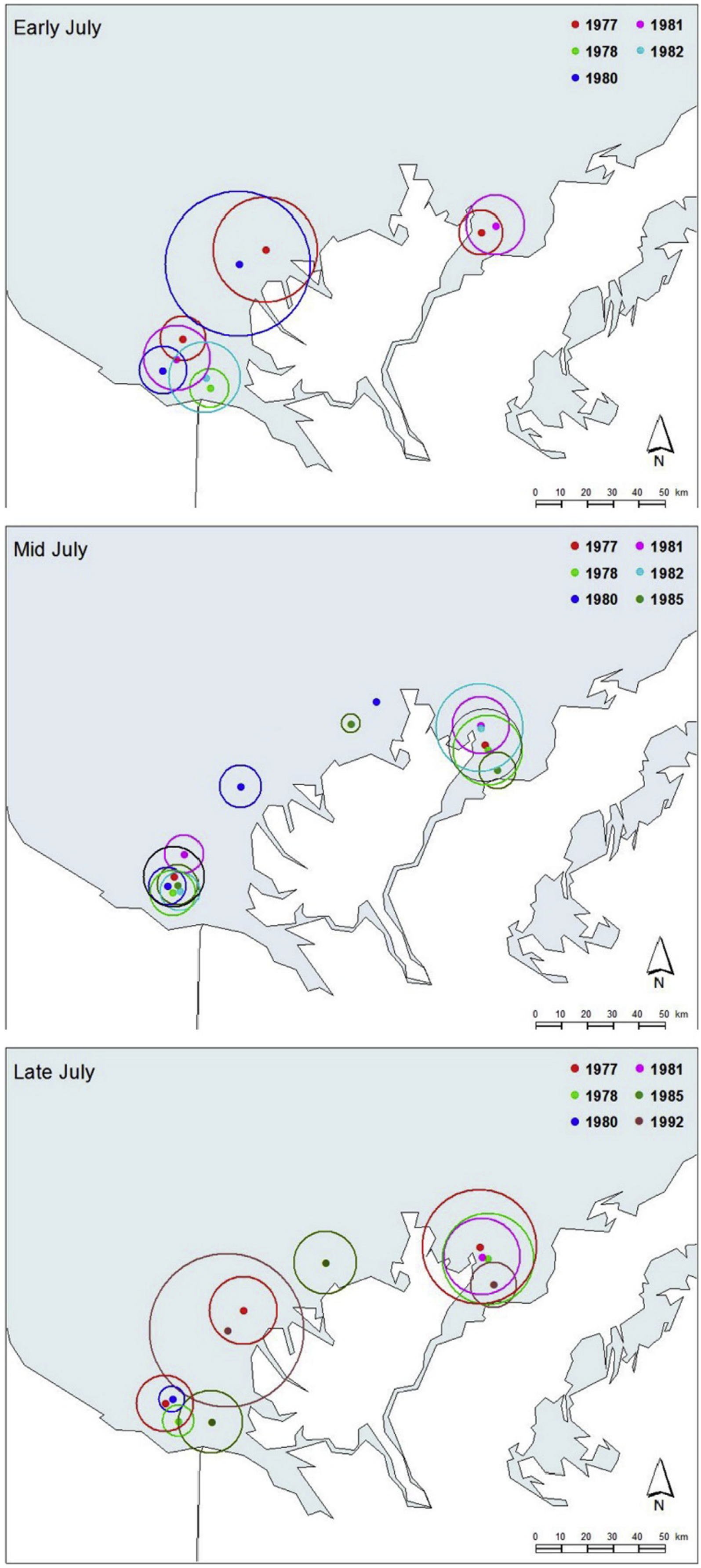

Fig. 5. Mean centres (small closed circles) and standard distances (large open circles) for the beluga whale locations in the Mackenzie River estuary subareas, 1977–1985 & 1992 for early (a, top), middle (b) and late (c, lower) July.

Table 2
Mean and range of standard distances between mean centers, by bay and July time period.

Time period	Shallow Bay			West Mackenzie Bay			East Mackenzie Bay			Kugmallit Bay		
	Survey years with one or more surveys in subarea	Mean standard distance (km)	Range	Survey years with one or more surveys in subarea	Mean standard distance (km)	Range	Survey years with one or more surveys in subarea	Mean standard distance (km)	Range	Survey years with one or more surveys in subarea	Mean standard distance (km)	Range
June 26–July 9	5	10	8–14	2	24	21–28				2	10	9–12
July 10–20	6	9	7–12	2	5	2–8	2	2	1–4	5	12	7–17
July 21–31	4	9	5–12							4	16	9–22

spots' used by belugas in the 1970s and 1980s, within the subareas for each of the July time periods (Table 3). The 'hot spots' were located in each subarea: 2 in Niaqunnaq Bay, 3 in Kittigaryuit (Kugmallit Bay), 2 in Okeevik (East Mackenzie Bay), and 1 in West Mackenzie Bay (Table 3; Figs. 1 and 7).

In Niaqunnaq Bay, the distribution of belugas was similar in the early July and mid-July time periods, with the 'hot spots' in two locations: in the central portion of the subarea (and extending 10–15 km in all directions), and also where the west channel of the Mackenzie River enters Niaqunnaq Bay. This subarea was the most attractive to belugas, including belugas with calves. The distribution of belugas in Niaqunnaq Bay was more dispersed in late July, than in early or mid-July.

With lower sighting rates than Niaqunnaq Bay, but similar patterns of clustering, Kugmallit Bay had three 'hot spot' areas (Table 3; Fig. 7). The most prominent was located approximately 6 km directly south of Hendrickson Island, in both early and mid-July (Fig. 7a and b). In mid-July (only), there was also a 'hot spot' used by belugas approximately 2 km offshore of Toker Point (Fig. 7b). By late July, the belugas were more widely distributed in Kugmallit Bay (Fig. 7c), and the location of the early July 'hot spot' had shifted 8 km to the northeast of its early and mid-July location.

In East Mackenzie Bay, there were two 'hot spots' revealed by these analyses, one near Rae Island, and a second between Garry and Pelly islands (Fig. 7). In West Mackenzie Bay, there was a single 'hot spot' indicated, this being southwest of Garry Island, most apparent during late July (Fig. 7c), but a generally widespread distribution in this subarea in late July.

4. Discussion

4.1. Overview

Here we present results of our analyses of beluga distribution in an Arctic estuary during the 1970s, 1980s and 1992, using spatial methods which have not been published previously for belugas in this, or other estuaries. Survey biases associated with poor visibility and detectability were minimized, enabling our analyses to be based on the most consistent data set available and possible, including seven survey seasons, >35 000 km of transect coverage and >20 000 sightings of surfaced beluga. The effect of reduced detectability of belugas at increasing distances from the aircraft negatively biases the counts downward (Davis and Evans, 1982; Norton and Harwood, 1985), but this would be consistent among the surveys reported here given standardized method and minimum survey condition criteria applied in all cases.

The relative abundance of belugas was highly variable among the three subareas of the TNMPA, with Niaqunnaq being used by 3–4 times more belugas, including by females with calves. The Ripley's *L* analyses revealed clustering of beluga within the TNMPA in all July time periods, in both the 1970s–1980s and especially in late July 1992, and similarly among the three subareas. Our observation of distribution being less clumped in West Mackenzie Bay aligns well with previous suggestions that belugas use this area as a travel corridor between the other three subareas and the offshore (Fraker et al., 1979; Norton and Harwood, 1986).

The clumped pattern of distribution in the three zones of the TNMPA is in marked contrast to patterns that are observed in the offshore Beaufort Sea (Harwood and Kingsley, 2013), where sightings are widespread and consist almost exclusively of small, widely distributed singles or groups of 2 or 3 whales (Norton and Harwood, 1985). This underscores how Beaufort Sea belugas use habitats in the TNMPA differently than the offshore, and likely for different reasons (Norton and Harwood, 1985, 1986).

The PVC distribution analysis revealed seven specific geographic areas within the TNMPA subareas ('hot spots') where belugas were regularly and recurrently concentrated during 1977–1985. There was overlap in the specific 'hot spot' locations among years (Fig. 6), consistent with local knowledge held by beluga harvesters, who have for centuries known of the beluga's tendency to concentrate in certain areas (Nuligak, 1966; McGhee, 1988; Day, 2002). This tendency for recurrence in the same geographic locations within an estuary has also been reported for the Cook Inlet beluga (Carter and Nielsen, 2011), and St. Lawrence beluga (Mosnier et al., 2010), where local knowledge and experience have been used to identify important habitats and examine linkages to potential environmental change.

4.2. Monitoring

Predicted and contemporary oceanographic and sea ice changes, both with potential to influence beluga moulting and other activities in the Estuary, and the availability of their prey (Tynan and DeMaster, 1997; Serreze et al., 2007; Comiso et al., 2008; Bluhm and Gradinger, 2008; Walsh, 2008; Laidre et al., 2008) are basis

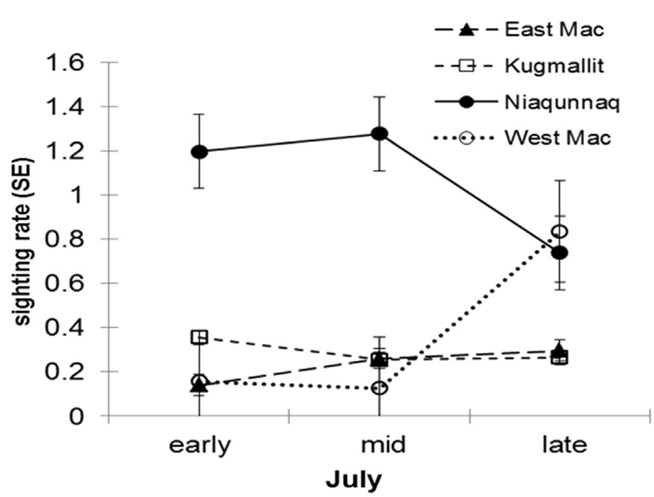

Fig. 6. Beluga sighting rate (belugas per km of transect) (+SE) in the Mackenzie River estuary, by subarea (no. of surveys, Niaqunnaq, 24; Kugmallit, 23; West Mac, 16; East Mac, 8) and July time period (no. of surveys, early, 26; mid, 25; late, 20), 1977–1985.

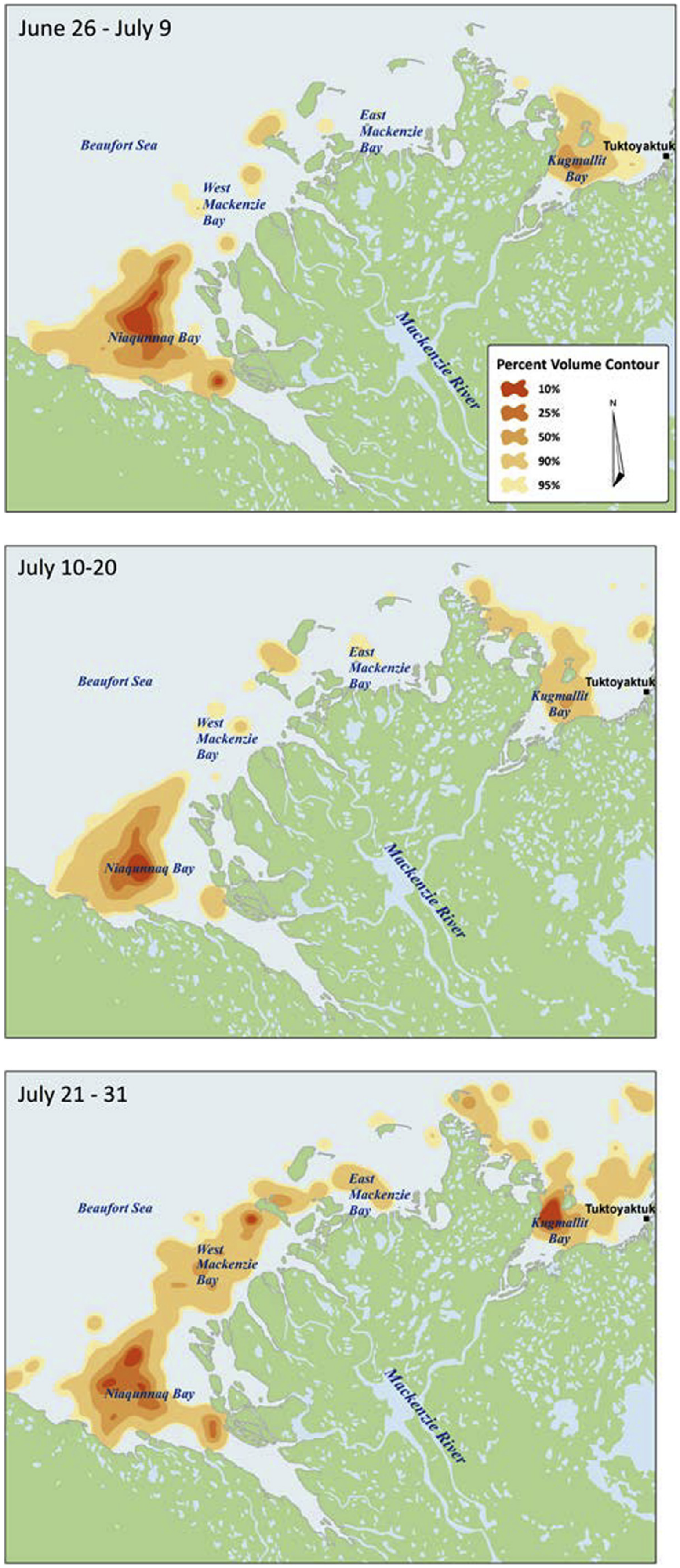

Fig. 7. Percent Volume Contours (PVCs) of beluga sightings made during systematic aerial surveys in the Mackenzie Estuary during early (top), mid (middle) and late July (lower) time periods, 1977–1985 and 1992.

Table 3
Location of beluga hot spots in the Mackenzie Estuary, early and mid-July.

	Geographic coordinates	Location
Niaquunaq Bay	136.414, 69.223	Central part of bay
	136.647, 69.0052	NE of West Channel inflow
Kugmallit Bay	133.713121, 69.424839	6 km S Hendrickson
	133.75000, 69,4833	5 km SW Hendrickson
	133.118957, 69.625385	2 km offshore Toker Point
East Mackenzie Bay	135.0005, 69.5783	1-2 km NE Rae Island
	135.72149, 69.543523	North of Garry Island
West Mackenzie Bay	135.920002, 69.38973	Central Bay

of the requirement for ongoing monitoring of beluga habitat use in the TNMPA (Loseto et al., 2010). Monitoring is especially important in the TNMPA, where the clumped distribution of belugas makes them particularly vulnerable to future disturbances associated with industrial activities and development (AANDC, 2012). When selecting indicators for monitoring, it is best to select indicators with existing baseline data, to allow for comparison to that baseline to detect change (Rice and Rochet, 2005). In the case of the TNMPA, beluga distribution and abundance, determined using replicated aerial surveys and the same transects, survey platform, timing and analytical methods as the surveys presented here, would be an indicator of choice. Such surveys in the future would provide opportunities to compare, by subarea and July time period, (1) sighting rates (e.g., whales per km flown), (2) patterns of clustering (e.g., standard distances), and the geographic location of 'hot spots' that are used by belugas (e.g., contemporary locations of 'hot spots' vs those listed in Table 3). This would also complement concurrent, long-term and on-going harvest monitoring efforts in the TNMPA, which have involved sampling harvested belugas since 1980 and revealed an emerging trend of declining growth rates since 2000 (Harwood et al., 2014).

4.3. Future research

Our identification of 'hot spots' using the PVC approach provides at least three new and unique opportunity to conduct research on beluga habitat use in the TNMPA. First, it would be possible to further explore the propensity of belugas to aggregate in certain geographic locations of the TNMPA, by obtaining and standardizing data collected by hunters during hunting. The location of areas revealed in this manner could be compared to results from aerial surveys, past and contemporary, to see if patterns are similar or have changed. Changing patterns of beluga habitat use in the TNMPA could be an indication of changes in the quality or characteristics of TNMPA habitat. This could be achieved using shore- or boat-based surveys, and would have the added benefit of engaging beluga hunters as participants in the research. Hunters would use hand-held GPS units to record spatial-temporal patterns of beluga distribution, and this would reveal changes over the course of the July hunting season, and between years. This would fine-tune our understanding of where and when belugas aggregate in certain areas of the TNMPA.

Another means to further study beluga use of 'hot spots' in the TNMPA, and compare to past and contemporary locations of the specific areas that the belugas prefer, is through the conduct of acoustic monitoring of the whales and background noise levels in their habitat. This would involve installation of passive acoustic recorders and hydrophones at 'hot spot' and 'cold spot' areas, to document vocalizations or lack thereof, as a measure of whale occurrence and relative abundance over time (Simard et al., 2010; Lammers et al., 2013). Preliminary work of this type was initiated in 2011 and 2012 (Simard et al., 2014), with a preliminary indication of the presence/absence of belugas in the TNMPA being linked to the tidal cycle.

A third opportunity for research that could build on the results reported here would be the in-situ investigation of 'hot spot' areas, past and contemporary, to characterize the substrate, water depth, slope, acoustic environment and oceanographic features in such areas, building on preliminary work done in 1977 (Fraker, 1977). Sampling of the bottom substrate in one of the Kugmallit Bay 'hot spots' was initiated in July 2013 and July 2014 (Hansen-Craik et al., 2013; D. Whalen, NRCan, unpubl. data), and results will be forthcoming.

4.4. Environmental assessments

One requirement of the TNMPA management framework is to prohibit specific activities, or classes of activities, that could potentially negatively impact beluga or any part of the ecosystem in the areas upon which they depend (Canada, 2013; Beaufort Sea Partnership, 2014). Given renewed and considerable interest by the petroleum industry in the Mackenzie Estuary (AANDC, 2012), the types of activities that may arise for screening include proposed flight corridors, ship traffic, seismic surveying, exploratory drilling, and various activities associated with the production of hydrocarbons. Other activities which might be proposed for the TNMPA include whale watching, gravel removal or dredging, by government or local operators. Determining if any such activity would cause impacts on beluga, as required under the TNMPA regulations, would be impossible without detailed knowledge of the ways that belugas use their TNMPA habitats, both in time and space.

The mapped results presented here would be useful to decision makers and to proponents, at three stages: in initial screening of such projects, the detailed assessments which follow, and in the case of projects which are allowed, the setting of terms and conditions to mitigate potential impacts. This could take the form of ensuring key habitats (e.g., 'hot spots') and/or times of year are avoided, and that conservation efforts are targeted towards the most important areas and times (Williams et al., 2014).

Hypothetically speaking, dredging of a new harbour or removal of gravel could have direct but localized effects on beluga habitats, compromising habits which concentrate prey or facilitate rubbing to slough skin (Smith et al., 1992), regardless of time of year. However, the spatial extent of disturbed habitat from such activities would be relatively localized, compared with, for example, anthropogenic activities which introduce underwater noise and the potential to disturb marine mammals (Erbe and Farmer, 2000; Lesage et al., 1999; Tyack, 2008; Gervais et al., 2012. In those cases, there is potential for ensonification of an entire subarea, although only temporarily.

In summary, results presented here could enhance the capabilities of regulators and managers to make confident and informed assessments and decisions regarding the acceptability of a proposed industry development or activity in the TNMPA, on a case-by-case basis. This would contribute to compliance with TNMPA regulations, and at the same time, ensure assessments and decisions are evidence-based and not unnecessary restrictive.

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