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Arrival and distribution of beluga whales (*Delphinapterus leucas*) along the Mackenzie Shelf: Report on the spring aerial surveys.

Arrivée et répartition des bélugas (*Delphinapterus leucas*) le long du plateau de Mackenzie : Rapport sur les relevés aériens effectués au printemps

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Arrival and distribution of beluga whales (*Delphinapterus leucas*) along the Mackenzie Shelf: Report on the spring aerial surveys

by

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ABSTRACT

To enhance knowledge of beluga spring habitat use in the Mackenzie Estuary, Beaufort Sea Shelf area, this ESRF project collected recent data on beluga location in relation to sea ice break-up and integrated historical beluga surveys into a digital format for comparisons. The objectives of this project were to: (1) provide an updated dataset on the spring arrival of beluga whales into the Mackenzie Estuary in relation to sea ice, (2) digitize historical surveys so they are available for comparisons with current aerial surveys so changes in beluga arrivals can be assessed as they relate to sea ice break-up and the start of beluga harvest in the region, and (3) involve local Inuvialuit students and community members in the data collection.

Prior to this project, the last beluga aerial survey was completed in 1992 (Harwood & Norton 1996). Spring aerial surveys were flown in 2012-2013 to provide updated information on the location and arrival timing of belugas. Historical surveys occurring in the 1970s and 1980s, were integrated into digital formats and made accessible for future use (https://polardata.ca; http://beaufortseapartnership.ca). This project has made decades of beluga aerial surveys available for continuing research. Community participation and feedback was an integral component to the data collection and presentation of results. While community members were active participants during all three years of data collection, during the last year methods were developed to provide the communities with near real-time data accessible via the internet. The new data collection methods combined with the positive response by the communities will allow future researchers to employ these methods to make data available to communities in a timely manner.

This report details the survey methodology and results of surfaced belugas and other marine mammals, as observed during eight days of aerial surveys in June of 2012 and 2013. In addition, it provides an overview on community involvement and methods for providing faster turnaround times on data back to the communities and HTCs (Hunters and Trappers Committees). Further analysis and interpretation of these results will enhance and update our understanding of beluga arrival patterns, and how spring distribution may be impacted by changing sea ice conditions and climate. Results will assist regulators, managers and Inuvialuit in protecting critical habitats, ensuring continued subsistence harvesting and advance our understanding of beluga habitat use.

Key words: Beluga whale; Mackenzie Estuary; aerial survey; sea ice; habitat use

RÉSUMÉ

Afin d'améliorer les connaissances sur l'utilisation par les bélugas de leur habitat printanier dans l'estuaire du Mackenzie et le plateau de la mer de Beaufort, des données récentes ont été recueillies dans le cadre de ce projet du Fonds pour l'étude de l'environnement (FEE) sur le lieu où se trouvent les bélugas par rapport à la dislocation de la glace de mer, et les relevés historiques des bélugas convertis en format numérique ont été intégrés aux fins de comparaisons. Les objectifs de ce projet étaient de : (1) fournir un ensemble de données actualisées sur l'arrivée au printemps des bélugas dans l'estuaire du Mackenzie par rapport à la glace de mer, (2) de numériser les relevés historiques pour les rendre disponibles afin d'effectuer des comparaisons avec les relevés aériens actuels, de sorte qu'il soit possible d'évaluer les changements dans l'arrivée des bélugas qui sont liés à la dislocation de la glace de mer et au début de la chasse aux bélugas dans la région, et (3) de faire participer les étudiants et les membres des communautés inuvaluit de la région à la collecte des données.

Avant la mise en œuvre de ce projet, le dernier relevé aérien des bélugas avait été exécuté en 1992 (Harwood et Norton 1996). Les relevés aériens du printemps ont été effectués en 2012 et 2013 afin de fournir des informations actualisées sur le lieu et la date d'arrivée des bélugas. Les relevés historiques menés dans les années 1970 et 1980 ont été intégrés en formats numérisés et rendus accessibles pour utilisation future (https://polardata.ca; http://beaufortseapartnership.ca). Ce projet a permis de rendre disponibles les relevés aériens des bélugas exécutés sur plusieurs décennies pour la poursuite de la recherche. La participation et la rétroaction des communautés constituaient une partie intégrante de la collecte des données et de la présentation des résultats. Alors que les membres des communautés ont participé activement aux trois années de la collecte des données, au cours de la dernière année, des méthodes ont été mises au point afin de fournir aux communautés des données en temps quasi réel accessibles sur Internet. Les nouvelles méthodes de collecte de données associées à la réaction positive des communautés permettront aux futurs chercheurs d'utiliser ces méthodes pour mettre leurs données rapidement à la disposition des communautés.

Ce rapport décrit en détail la méthode utilisée pour exécuter les relevés et les résultats obtenus pour les bélugas et d'autres mammifères marins remontant à la surface et observés durant les huit jours d'exécution des relevés aériens en juin 2012 et 2013. Il fournit également un aperçu de la participation des communautés et des méthodes utilisées pour offrir des délais de traitement plus rapides des données mises à la disposition des communautés et des comités de chasseurs et de trappeurs. D'autres analyses et interprétations de ces résultats amélioreront et actualiseront notre compréhension des schémas d'arrivée des bélugas et comment leur répartition au printemps peut être affectée par l'évolution des conditions de la glace de mer et du climat. Les résultats aideront les organismes de réglementation, les gestionnaires et les Inuvialuit à protéger les habitats essentiels, à assurer la poursuite de la chasse de subsistance et à faire progresser notre compréhension de l’utilisation que font les bélugas de leur habitat.

Mots clés : béluga; estuaire du Mackenzie; relevé aérien; glace de mer; utilisation de l’habitat

PART 1: Summary of Spring Beluga Surveys 2012-2013

Introduction

In the spring, beluga whales (*Delphinapterus leucas*) from the Beaufort Sea population arrive to the Canadian Beaufort Sea from their Bering Sea wintering areas (Fraker & Fraker, 1979; Hill & DeMaster, 1999). In mid to late June they concentrate at the seaward edge of a narrow bridge of land-fast ice that spans across the Mackenzie Estuary. As the sea ice break-up progresses, the ice bridge disintegrates allowing belugas to move quickly into the estuary. Throughout the month of July these whales form large aggregations in the four bays of the estuary (Shallow Bay, East Mackenzie Bay, West Mackenzie Bay, and Kugmallit Bay) (Harwood *et al*., 2014), and it is during this time that they are subject to an annual subsistence harvest (Fraker & Fraker, 1979, McGhee, 1988).

The beluga whale is an important cultural and nutritional resource for the Inuvialuit; the Inuit of the Western Canadian Arctic, within the Inuvialuit Settlement Region (ISR). Due to the cultural significance, in addition to past and renewed interest by the oil and gas industry in this area, the entry of beluga to the estuary and their distribution therein, have been relatively well studied since the 1970s (Fraker *et al*. 1979; Harwood & Norton 1996; Norton & Harwood 1986). Past surveys include systematic strip transect aerial surveys to examine their distribution in the estuary in July (the last in 1992, Harwood *et al*. 1996), and reconnaissance aerial surveys to document their arrival in June (the last was flown in 1985, Norton & Harwood 1986). Since these earlier surveys were flown, changes in climate, sea ice, river discharge, and depth of permafrost (Barber *et al*. 2008, 2012 Nghiem *et al*. 2014) have occurred, with unknown effects on beluga arrival and distribution within the Mackenzie Estuary.

Understanding of the timing and arrival of beluga into the estuary is of particular importance to the beluga harvesters of the ISR as it dictates when subsistence harvesters have first access to the whales. The distribution of whales amongst the four bays of the estuary is an important variable in the local harvest of whales (L. Harwood Pers. Comm.). Since harvesters access and harvest beluga from different bays within the estuary, how the whales assort themselves amongst the bays can have noticeable effects on harvest success. For example, in 1985, the sea ice bridge across Kugmallit Bay broke relatively late in the season. In that year the whales first entered and thereafter remained in the Shallow Bay (West Mackenzie Bay) for most of the season, and Kugmallit Bay was inaccessible early in the season. As a result, hunters relying on beluga whales being in Kugmallit Bay in early July did not have access to these whales until late in the season (Harwood *et al.* 2014). This was linked to lower harvest levels, resulting in a later harvest in Kugmallit Bay in 1985 compared with other years (Norton & Harwood, 1986).

Three consecutive seasons (2011-2013) of reconnaissance aerial surveys were flown seaward of the ice bridge, offshore of the Mackenzie River Estuary and Tuktoyaktuk Peninsula. The specific objectives of these surveys were to; (1) provide updated data on the location of belugas during spring, (2) examine the arrival of beluga whales in relation to the timing and location of sea ice break-up offshore of the Mackenzie Estuary, (3) to foster community involvement in the surveys through data collection and analysis and (4) to the extent possible, provide the whale sighting information in near-real time to the communities and local HTCs (Hunters and Trappers Committees)[1]. Here we summarize details of the survey methods, and results from the surveys visible on maps, including surfaced marine mammals and satellite imagery of sea ice conditions for years 2012 and 2013. 2011 served as a pilot year for this project and the details can be found in Hornby *et al*. (2014).

While the number of beluga sightings are reported here, these surveys were not intended for population estimates and should not be interpreted as such. Methodology was developed based on historical surveys and to allow for future direct comparisons as per larger project objectives. Ultimately, the sighting data will be used to critically evaluate the patterns of beluga movement and habitat use (sea ice, turbidity, depth, distance to land) over the Mackenzie Shelf during late spring arrival, document the

[1] Providing data in a timely manner was added as an objective for the 2013 field season based on feedback from local HTCs in 2011 and 2012.

time(s) and locations(s) where they first enter the estuary, and compare these to historical records dating back to 1974. Preliminary analysis provides information on the location of belugas and some habitat associations.

By examining spring habitat features important to beluga, in addition to correlating the arrival to the estuary with sea ice break-up, we can better assess the impacts of a changing climate on the ecology of Beaufort Sea belugas. This information will assist regulators, managers and communities in decision making required for ensuring continued subsistence harvesting opportunities and protecting important habitats required by beluga.

Materials and Methods

Description of Study Area

Reconnaissance aerial surveys took place along the seaward of the edge of the landfast ice and offshore of the Mackenzie Estuary and the Tuktoyaktuk Peninsula, from Herschel Island (69° N and 140° W) westward to Baillie Islands (71° N and 128° W; Figure 1). For the purpose of this study, the nearshore waters (< 200 m) were identified by the southeastern portion of the Beaufort Continental Shelf (i.e., the Mackenzie Shelf).

Aerial Survey Methods

All surveys were flown from a de Havilland Twin Otter aircraft, equipped with bubble windows at primary search positions, on-board intercoms to ensure communication among observers and pilots, GPS for navigation, pilot, co-pilot, observers (2012: 4 observers, 2013: 2 observers), recorders (2013 only), and a survey coordinator. Charter flights were booked through Aklak (Kenn Borek[2]), Inuvik. All surveys were flown at 1000 ft (305 m), with a target groundspeed of 200 km/hr to maximize consistency with past surveys (e.g. Harwood *et al.,* 1996; Norton & Harwood, 1986). A line transect method was used on both the reconnaissance and zigzag surveys (Strindberg & Buckland, 2004), with sightings recorded within a 1 km swath, on either side of the airplane. In order to determine the lateral sighting distance of marine mammals from the aircraft

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[2] http://www.borekair.com/

track line, the 1 km strip was sub-divided into four “bins”, each 250 m wide (Figure 2A) and each sighting assigned to the appropriate bin. Due to the inability of observers to see directly below the airplane, the nearest bin started at a distance of 50 m from the flight path, while the outermost bin extended to 1050 m from the flight path (Figure 2A), to keep a 1 km strip.

As there were no distance markings on the wing of the airplane, bubble windows (left and right sides of the aircraft) were marked using a Sunnto PM-5 inclinometer to measure the angle of depression, to mark the inner and outer edges of the bin (Figure 2B). Observers then used these bubble window marks to assign all sightings to the appropriate bin. All other non-bubble windows were left unmarked and were used for observations noted by the recorders (in 2013) or survey coordinator (secondary observers), video cameras (2013) and GPS equipment.

Observers on the right and left sides of the airplane used a digital voice recorder to note whale sightings, lateral sighting distance (bin number), an estimate of ice cover (%), ceiling height, presence of glare, fog and/or precipitation. Sea state was recorded according to the Beaufort Scale of Wind Force[3] and surveys were terminated if sea state exceeded Beaufort Scale 4 (whitecaps) or when low cloud or fog blocked visibility. All observers wore polarized sunglasses to minimize glare, and did not take their eyes off the search area while surveying on transect and reconnaissance flights. The pilots notified observers and recorders of the beginning and endpoints for each transect.

The survey aircraft was reserved for use in each year for a period of seven days, timed to best coincide with the time when belugas would be migrating to and entering the estuary. Flights occurred every day in the reserved period that visibility, sea state and aircraft availability would allow. Interruptions due to these factors in some cases precluded our flying on the ideal day to observe beluga entry to the estuary.

On each survey, both a reconnaissance survey, approximately 1 km seaward of the ice edge (Figure 3), and also a zigzag survey design (Strindberg & Buckland, 2004), which followed 40 km transects positioned away from or toward ice edge (Figure 4) were

[3] http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html

attempted. Pre-determined waypoints were given to the pilots as a reference for the start of each transect. The zigzag survey was used to determine the presence of whales offshore of the ice edge, to capture more habitat features. Ice images presented in this report were all obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) website (http://modis.gsfc.nasa.gov/).

The survey plan for 2013 was to carry out both reconnaissance surveys and zigzag surveys within the same day on two separate occasions. This would allow for not only full survey area coverage in one day, but also to determine how belugas are using the different habitat areas (ice edge vs. open water; Figure 5). Field preparations included caching fuel at the Tuktoyaktuk airport to allow for refuelling closer to the survey area. The aircraft used in 2013 was equipped with wing tip tanks for extra fuel storage, which permitted longer trips between refuelling.

In 2012, a total of three GPS were running at all times to record the flight track. Most importantly, coordinates of the start and end time of transects were documented so that they could later be used to re-create flight track lines, with corresponding sightings data, onto satellite images with Geographic Information Systems (GIS). In 2013, through a partnership with Environment Canada, observations were entered directly onto data collection forms located on a Toughbook laptop computer equipped with a GPS signal. Thus, all observations were georeferenced and recorded by a spatial program on the laptop in real time (i.e., all data points have associated GPS coordinates; Figure 6).

In addition to point observations, video cameras were provided equipped with GPS to record a constant stream of video during all surveys in 2013. This video stream was also linked with the audio files so that the georeferenced videos will have the observer's voice and recordings embedded. Due to the modified data capture methods used in 2013, there was a greater need for survey participants to assist and manage technical gear (e.g., computers, GPS, video cameras), as such the number of observers was reduced from 4 to 2 with one observer on each side of the plane and an associated recorder sitting behind them to capture real time data, as well as one person manning both video cameras in the back windows.

This newer technology in 2013 allowed preliminary data to be processed upon completing the surveys each day. Given the interests of partners, communities and funders, one of our goals was to make data readily available to the communities of Aklavik, Inuvik, Paulatuk and Tuktoyaktuk. Data compiling from all observers took place shortly after flights and the maps were created indicating the locations and general numbers of belugas observed[4] (as shown in Figures 11-13). These maps were made widely available to the communities via their HTC online websites and Facebook sites.

Spring Habitat Analysis

In order to characterize the spring habitat and distribution of beluga in the study area prior to break-up of the landfast ice, four seasonal habitat features were examined: sea ice concentration, ice floe size, water depth and turbidity. Only observations from the 2012/2013 surveys were used, as the 2011 surveys yielded too few beluga sightings to be included in the habitat analysis. Ice conditions for June 2012 and 2013 were obtained using weekly regional ice charts from the Canadian Ice Service (CIS; available at http://www.ec.gc.ca/glaces-ice/). Bathymetry for the southeast Beaufort Sea was estimated using data supplied by The International Bathymetric Chart of the Arctic Ocean (IBCAO) version 3.0 (available at http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/downloads.html, from Jakobsson et al. 2012). Sea ice concentration, floe size and bathymetry features were organized into distinct habitat classes (Table 1).

As limited spatial data are available on measurements of freshwater flow from the Mackenzie River into the southeast Beaufort Sea during this time of year and seaward of the landfast ice, turbidity was estimated by classification of water colour using daily near-real time satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS) (available at https://earthdata.nasa.gov /labs/worldview/) and remote sensing software ENVI version 4.31. Turbidity class (high, medium and low), open water and non-landfast ice edges were all classified based on water colour

[4] The data is considered preliminary at this stage, and should not be interpreted as a population estimate, as some whales may have been counted more than once and this survey does not account for submerged animals.

(the latter two being combined as a ‘no turbidity’ group (Table 1). Sea ice cover and land were also classified and masked from analysis.

Each habitat feature was inputted into ArcGIS version 10.2 along with beluga observations from each flight day in 2012/2013. From each survey day, the observed sightings were joined spatially with the corresponding ice chart, depth range and classification image of turbidity. Further detail on analytical methods used can be found in Hornby *et al.* (in review).

Community Involvement and Training

As per the objectives for training and capacity building both DFO area office staff and community members were trained and participated in surveys during all three years. Each year, two community representatives were hired and trained to participate in the beluga aerial surveys. In the first year representatives were hired through the Inuvik HTC and in following years we worked closely with the Aurora College to identify youth in the Environmental and Natural Resources Training Program to participate in the program. All community participants were provided training and participated in a mock aerial survey to learn how to use the recording equipment and document beluga observations along with weather and ocean conditions. One community member from the Aurora College program participated in the program for two consecutive years during which she was also trained in the data integration and analysis portion of the work. She assisted with plotting of the recorded observations to ArcGIS as well as participated in the reporting and presentation of the data. In the final year HTC’s requested results be shared with members using their homepages on Facebook. As such, we were able to provide a short report and sighting maps within 24 hours of the survey for the communities to view.

Results

Summary of Survey Effort

The 2012 field season involved five survey flights between June 13th and June 22nd (Figures 6-10). Due to low numbers of observations in the 2011 surveys, the 2012 project allocated more flight time to allow for greater coverage of the survey area over more days (Table 2). Some flights originated as zigzag surveys, but were changed to follow the sea ice if the weather conditions were poor further from the ice edge (Figure 7).

On June 21st, 2012 the ice bridge began to fracture offshore of Shallow Bay. On June 22nd an ice edge survey was designed to begin at Baillie Island and head west toward the opening at Shallow Bay (Figure 10). The transects followed the ice edge starting near Baillie Island and heading west. At the end of the survey, transects were taken into the Mackenzie Estuary, slightly east of the Shallow Bay area, where the ice had broken up. Due to the impact of the broken landfast ice, turbid brown estuary water was observed along the survey area and visible as far as the eastern most point of the survey, near Baillie Island.

In 2013, the final year of aerial surveys, three survey days were scheduled (June 16th, 18th and 20th). Contingency dates of June 21st and 23rd were held in case flights were cancelled due to weather. Due to weather and mechanical issues with the plane, the surveys were rescheduled to June 18th, 22nd and 23rd (Figures 11-13; Table 2). Two longer surveys were planned (double the flight time) with refuelling at Tuktoyaktuk airport. Survey pilots had sighted six belugas and two bowheads on June 13th near Sachs Harbor, indicating there were belugas just outside of the study area.

In 2013, the ability to cache fuel at Tuktoyaktuk airport allowed for more flying time but only three survey days in total. The ice bridge north of Shallow Bay broke on June 21st. However, based on cloudy satellite images obtained the night before, it was unclear when the ice bridge had fractured. In order to capture beluga moving towards the Mackenzie Estuary, zigzag surveys were flown from Herschel Island to central Mackenzie Delta on June 22nd (Figure 12). Once surveys reached the Shallow Bay area, it was clear that the land-fast ice had broken. Some low fog was still in the area, but overall visibility was good. Here, the survey towards Shallow Bay was extended to include more transects in order to identify how many belugas were in this area.

Summary of Sightings

All sightings are listed in Table 3 and beluga observations and transect lines flown are presented in Figures 6-13. The 2011 observations and survey design can be found in Hornby *et al*. (2014).

The 2012 a total of 755 beluga sightings were made over the five days of surveys. It is important to note that this is not a population survey and the repetitive design enables us to evaluate habitat use at a critical time of entry into the Mackenzie Estuary rather than assess population (i.e., the cumulative number of whale sightings can have repeat counts over the survey days). Belugas were spotted both as individuals as well as in groups. In addition to beluga whales, seals and bowheads were observed (Table 3). Beluga sightings during the 2012 survey closely reflected the number of sightings in the 1970s and 1980s, as almost 300 whale sightings occurred along the ice edge on the day after the ice broke (June 22nd).

In 2013 the pack ice in the off-shore had moved in and was up against the landfast ice. This was a very different habitat ice regime than the open waters of 2011 and 2012 and as such impacted sightings. Although beluga sightings occurred during all three survey days, observations were generally lower than 2012, with just over 300 sightings on June 22nd (Table 3). Through investigation of satellite images after the surveys, it was determined that the ice bridge had indeed broke on June 21st, 2013. There were numerous whale sightings documented on the west side of the Shallow Bay area on the day of sea ice break-up (Figure 12), however, no whales were observed in Kugmallit Bay on June 23, 2013 (Figure 13).

Beluga Habitat Use

Despite the increased use of field studies and surveys, little is still known about the habitat use or ecology of beluga whales in the late spring and early summer in the

Beaufort Sea region. Historically, most beluga habitat studies occurred in summer or fall, due to ease in accessibility. Sea ice and bathymetry have often been considered as important habitat features for beluga whales (Loseto *et al*., 2006; Asselin *et al*., 2011), however, other potential environmental drivers such as primary production, freshwater inputs and sea surface temperature (Carmack and MacDonald, 2002) could also be significant.

Using observations from the 2012 and 2013 spring aerial surveys, we examined the distribution of beluga whales as it relates to the habitat features of the Beaufort Sea shelf. This spring habitat analysis investigated beluga habitat use of: sea ice, bathymetry and turbidity (i.e., freshwater flow from the Mackenzie River) (see Hornby *et al*. in review). Results showed increased numbers of beluga in locations of open water/ light ice concentrations and medium ice floes (Table 1), and show a significant association with turbid water in both years.

Largely ice-free conditions in 2012 led to a wide variation in habitat use in three designated subareas of the Mackenzie Shelf (i.e., Shallow Bay, Kugmallit Bay and the Tuktoyaktuk Peninsula). Results showed clusters of individuals using medium to heavy ice concentration, larger floes, and high turbid water ranging in depth from 50-100 m. In contrast, heavy ice, shallow depth range (<50 m), and low levels of turbidity were most significantly associated by whales found in Kugmallit Bay and Tuktoyaktuk Peninsula subareas in 2013.

Discussion

Changes in climate and sea ice extent have been detected in the Western Arctic and are linked to the location and arrival of belugas to the southeast Beaufort Sea and Mackenzie Estuary. Based on the 2012-2013 aerial surveys sea ice break-up dates occurred a few days earlier than observed during 1979-1984, which averaged June 24-25 in the Shallow/Mackenzie Bay region (Table 4, Norton & Harwood 1986). From 2002-2010, sea ice break-up dates have been observed to occur earlier in June; with an average break-up date of June 19th (S. Solomon Pers. Com., 2011). It is thought that due to local spring warming and snowfall decrease, we are observing an earlier ice break-up (averaging from 1974-2011) over the Mackenzie Delta (Lesack *et al*., 2014).

Arrival and timing of belugas into the estuary remains an important issue for the people of the ISR, who depend on beluga as a food and cultural resource. Recognizing the high costs of running aerial surveys, it may be viable to investigate other means of beluga sightings such as land or boat-based data collection methods that can be collected from local beluga hunt camps. This may increase knowledge related to changes in harvest activities as well as beluga distribution, abundance and use of the area over time. Land and boat-based approaches to distance sampling were attempted as part of a collaborative local knowledge program in 2014 (S. Ostertag and L. Loseto pers. com). This is a joint program with acoustic monitoring to evaluate temporal habitat use of the area (Simard *et al*., 2014) and future years will likely assess the use of unmanned vehicles as technology improves.

With extreme sea-ice annual variability in the Beaufort Sea (Galley *et al*. 2008), it remains difficult to predict the behaviour of beluga in response to changing ice conditions. Nevertheless, this continued research provides some understanding of the mechanisms and timing of beluga spring habitat use and requirements in the southeast Beaufort Sea. The results of this work provide new knowledge on spring habitat selection and provide insights into the adaptability of beluga under expected changes associated with climate change. In combination with historical studies, this increased understanding of beluga spring habitat use will provide a baseline from which to evaluate the impacts of human activity and environmental changes on the ecology of Beaufort Sea belugas.

PART 2: HISTORICAL SURVEYS

Introduction

For consideration of potential changes of beluga habitat use in the area, historical aerial surveys data were digitized. Historical aerial surveys (run from 1972 to 1992) were digitized and transferred into ArcGIS (see Figures 14-15) and are now available for analysis, specifically so that they can be compared to recent beluga survey data (2011-2013) or other future research needs. Given recent observations of beluga hunts occurring both earlier and later in Kugmallit Bay (Harwood et al. 2014), we can use sea ice break-up dates and beluga entry as an indicator of hunter accessibility to belugas for consideration of food security concerns around harvest success and efficiency.

Materials and Methods

Geo-referencing Historical Beluga Surveys From Images

After reviewing all the historical surveys, the highest quality maps depicting historical survey extent and beluga location were chosen and scanned at a high resolution (at least 300dpi). If the map was larger than the scanner could accommodate, it was scanned into overlapping pieces and then the files were stitched together into one image using Image Composite Editor (ICE) from Microsoft. ArcMap was used to create a reference map, using a 'best guess' on the projection and scale of data that provided a similar level of complexity to the scanned image.

The original scanned image was then used to identify a few areas, preferably in opposite corners, where distinctive features allow a match between the image and the new map. Once the image was added to the map, Control Points were created and used to match the identified areas. This allows the image to be approximately the same perspective and scale as the new map. If the map projection did not match the image, more sets of control points were created. After the best match was achieved, a mathematical transformation was chosen. These are listed by increasing order of complexity, with more complex transformations requiring more matched pairs. A Spline transformation was used in many images, as it requires at least 10 pairs of points, offering higher precision in the end resulting image.

Digitizing the Data

To digitize data from the beluga maps, new layers (polygon, line or point) were added to the map in ArcCatalog and the appropriate symbology assigned to the layer based on the type of data being added (i.e., whale locations or transect lines). Using the Editor tool, points, lines or polygons were created. If there was more than one type of data being digitized at the same time (e.g., how many whales a point represents), attributes, categories and/or values were assigned to the data point. If the chosen feature was too large, it was digitized in pieces and then merged together.

To add the flight track data, spreadsheets with fields for latitude and longitude expressed as decimal degrees were verified in Excel. From ArcMap, the XY data was added as points and a coordinate system was selected. The data was then exported as a shapefile or feature class in a geodatabase and re-added to the map. This data was then used to generate a flight line using the Point to Line tool. Depth information for the Mackenzie Estuary, was added from a subset of data provided by the International Bathymetric Chart of the Arctic Ocean (IBCAO; version 3).

Integration with Historical Sea Ice Images

Historical surveys were integrated with corresponding sea ice images available from EOSDIS: NASA's Earth Observing System Data Information System (https://earthdata.nasa.gov/data/near-real-time-data/rapid-response/modis-subsets). Files of remote sensed sea ice imagery are available by either weekly (3 or 8 day composite) or daily images in jpeg or geotiff formats. These files are georeferenced, so they can easily be integrated into ArcGIS for comparisons with beluga locations. Images were used to determine beluga proximity in relation to sea ice features.

Analytical Tools

Euclidean distance to an object (ex. coastline or ice) was calculated by using the Near Tool in ArcMap. This method calculates the distance from the created points in the new map, to the nearest point in one or more selected files. This tool was especially useful if the coastlines data was located in several files. Since this tool calculates the distance to the nearest object, when more than one type of object was present (e.g., a coastline was in a file that has sandbars and mudflats, or an ice file had landfast and floe ice data), a Definition Query was used on the layer to restrict the types of objects that are available for the calculation.

Summary of historical surveys included in the digitization are provided in Table 5 below. Here the dates of each survey are compared with the number of belugas sighted and any indication of sea ice break-up dates. A comprehensive image of all flight tracks flown from all surveys is demonstrated in Figure 14, with all observed belugas shown in Figure 15.

Summary

Historical surveys have been combined with the recent (2011-2013) surveys and have been uploaded to the BSOP (Beaufort Sea Online Platform) and PDC (Polar Data Catalog), and are available upon request to the scientific community, local communities, and the general public. Summer sea ice data for the Inuvialuit Settlement Region can be used to assess changes in other species in order to tease out the effects of climate change. The data presented here is the most extensive dataset, spanning 5 decades of spatial data for belugas and sea ice. By providing the data via online data websites, it is intended this data will be used for many purposes such as historical analysis to assess changes in beluga arrivals into the Mackenzie Estuary and how migrations are linked to sea ice changes. The long-term digital dataset generated under this project will not only provide key insights into recent changes, but also serve as the historical baseline for future changes and assessments that may be of interest to management planning in the TN MPA (Tarium Niryutait Marine Protected Area).

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Table 1: Classification of Beaufort Sea habitat features used in spring beluga habitat analysis of total ice concentration, floe size, depth and water turbidity (Hornby *et al*. in review).

Total ice concentration	**Ice floe size**	**Depth (m)**	**Water colour/ turbidity measure**
Open water/ light (0-1/10) Light/medium (2/10-4/10) Medium/heavy (5/10-7/10) Heavy (8/10-10/10)	No floes/open water (0) Medium (4-6) Large (8)	0-50 50-100 100-200	Brown (High) Green/brown mixing (Med.) Light Green (Low) Black/Dark green* (None) Sea ice and Land (No value)

*Water colour not available for classification of images in 2013

Table 2. Extent of aerial surveys, type of survey flown and flight plans by date, June 2012-2013.

Year	Survey Date	Area covered	Type of transect	#	Detailed flight notes
2012	June 13	W. of Baillie to mid-Delta (380 km)	ZZ	12	A ZZ approach was used to identify whales further from the ice edge. Started just off of Baillie Island and headed westward (13:30-16:00). Due to white caps observed north of the Tuk Peninsula area, a portion of the survey was unable to be completed. Ice bridge was still persistent, with the narrowest section at SB (just over 50 km wide).
	June 14	W. of Baillie to NE of Kugmallit (415 km)	R/ZZ	11	Heavy white caps prevented initial transects from Baillie Island to be terminated. Remainder of transects followed west toward ME (14:14-16:43). The ice bridge at Shallow Bay was still intact, with the narrowest section ~25-30 km wide
	June 16	W of SB to Tuk Peninsula (470 km)	R/ ZZ	14	Start at west side of Shallow Bay with a ZZ survey, then heading east to cover Shallow Bay and mouth of ME (13:00-16:00), Weather was mostly ideal, with low clouds and fog at times. To avoid glare, a few ice edge transects were conducted. Ice bridge at SB was ~20 km wide.
	June 21	SB to east of Kugmallit Bay (470 km)	R/ZZ	12	Ice bridge started to break on this day in SB. Transects started in SB moving north of the bay to see how far belugas were from ice edge and estuary area (9:20-11:40). The survey was again challenged by high glare and fog that resulted in many short transects and combining ice edge with zigzag.
	June 22	Baillie Island to SB (530 km)	R	13	Ice edge survey from Baillie to SB opening, transects were also taken in the ME, slightly east of SB.
2013	June 18	Baillie Island to Herschel Island (900 km)	R/ZZ	30	Weather was sunny, with clear skies and high cloud. Due to unclear ice images and high southerly winds, survey efforts were focused towards the western area, which contained more open water between Herschel Island and the central ME, 22 ZZ transects completed (11:00-16:00). The ice bridge at SB was still intact (~30-40 km wide).Thick ice in the eastern portion prevented ZZ survey from Baillie Island to central ME, eight ice edge transects completed (~18:30-19:30).
	June 22	Herschel Isl. To Baillie Isl. (940 km)	R/ZZ	23	Survey covered larger openings in the ice from Herschel Island to the central Mackenzie Delta area (11:00-15:30). Some low cloud and fog required transects to be altered early on. Ice bridge at SB had broken since last survey (June 21st), surveyed SB area in order to identify how many belugas were present. Ice edge from Tuk. Peninsula to Baillie

				Island (17:45-18:45). Due to fog and thick ice coverage near the end of the survey, the remainder of survey was canceled.
June 23	Baillie Island to mid-Delta (280 km)	R	9	Thick fog delayed the departure out of Inuvik, but cleared during ZZ transects across Kugmallit Bay. Three zigzag transects were completed in the inner Delta and no whales were spotted. Due to more thick fog in the western portion of the survey area surveys redirected east toward Baillie Island (11:00-13:00). Thick ice and fog prevented transects from reaching all the way to Baillie Island. Ice edge surveys from Tuk. to Hershel Island were canceled due to limited visibility.

SB= Shallow Bay, ME= Mackenzie Estuary, Tuk= Tuktoyaktuk
R= Reconnaissance survey, ZZ= Zigzag survey

Table 3: Marine mammal observations from spring aerial surveys in Mackenzie Estuary, Beaufort Sea (2012-2013).

Year	Survey Date	Belugas	Beluga /km^2	Bowhead	Seals	Other
2012	June 13	32	0.084	3	4	2
	June 14	156	0.376	12	-	-
	June 16	185	0.394	3	1	-
	June 21	112	0.238	2	-	-
	June 21	Observed date of break up*				
	June 22	270	0.509	13	1	-
2013	June 18	54	0.060	3	-	-
	June 21	Observed date of break up*				
	June 22	305	0.324		-	-
	June 23	54	0.193		2	Polar bear

* Break-up may have occurred sooner than documented dates, but could not be confirmed based on cloud cover on sea ice images.

Table 4. Break-up dates (approximate) of the landfast ice bridge across Shallow/ Mackenzie Bay and Kugmallit Bay during years of historical and most recent spring aerial surveys (Norton and Harwood, 1986; Hornby *et al*., 2014).

Year	Mackenzie Bay	Kugmallit Bay
1972	NA[a]	NA
1973	June 22-23	June 27
1974	July 10-11	July 10-11
1975	Late June	Late June
1976	NA	NA
1977	June 17	NA
1978	July 5	July 5-6
1979	June 19	July 1
1980	June 27	June 30
1981	June 15	June 27
1982	June 22	July 10
1983	June 23	June 29
1984	NA	NA
1985	June 26	July 6
Mean 1972-1984	**June 24-25**	**July 2-3**
2011	June 22	June 25
2012	June 21-22	June 24-25
2013	June 21	June 28

[a] NA = no data available

Table 5: Summary of digitized historical (1972-1992) beluga surveys.

Year	Dates of field study	Area covered by survey	Date first whales arrived to estuary	# of belugas sighted before ice break up (total)	Population estimate for estuary	Refs	Data Digitized
1972-1983	End of June to mid-July	KB, SB, MB, TP, OFS	June 26	NA	5,300 (average) 2,000 (1972)-11,000 (1982)	Robertson & Millar 1984	N
1973	May 26-Aug 11	SB, MB, KB, TP, OFS	June 26	602	3,500-4,000	F.F. Slanley & Company Limited 1974	Y
1974	June 19-Sep 8	KB, MB, SB, OFS	July 11	NA	NA	F.F. Slanley & Company Limited 1975	Y
1975	June 23-Aug. 7	KB, MB, SB	June 26	NA	4,000	F.F. Slanley & Company Limited 1976	Y
1976	June 27-Aug. 17	KB, MB, SB, TP	July 1	NA	5,500-6,000	F.F. Slanley & Company Limited 1977	Y
1977	July 4-Aug. 10	SB, MB, KB	June 30	(2,646)	5,500	Fraker 1977	Y
1978	June 25-Aug 12	SB, MB, KB	July 6	0 (7,024)	6,600	Fraker 1978	Y
1979	June 20-Aug.11	SB, MB, KB, TP, OFS	June 19	245 (9,997)	7,000	Fraker & Fraker 1979	Y
1980	June 19-Aug. 13	KB, TP, SB, MB	June 27	765 (4,717)	4,500	Fraker & Fraker 1981	Y
1981	June 15-Aug. 7	KB, TP, SB	June 17	472 (2,582)	3,500	Fraker & Fraker 1982	Y
1982	June 21-July 20	SB, MB, KB, TP	June 24	765 (3,552)	11,000	Fraker 1983	Y
1983	June 20-July 10	OFS, SB, MB, KB	June 24	789	9,000	Robertson &Millar 1983	Y
1985	June 23-July 25	OFS, SB, MB, KB	July 3	502	6,400	Norton & Harwood 1986	Y[1]
1992	July 23-25	OFS, MB	NA*	504	19,630	Harwood & Norton	Y[1]

						1996	
SB=Shallow Bay, MB=Mackenzie Bay, KB=Kugmallit Bay, TP= Tuktoyaktuk Peninsula, OFS=Offshore, generally covered ice edge offshore of the Mackenzie Estuary NA=insufficient data collected to determine approximate date [1] Data is available in a digital format, but not integrated with the historical surveys. Authors should be contacted directly for data use.							

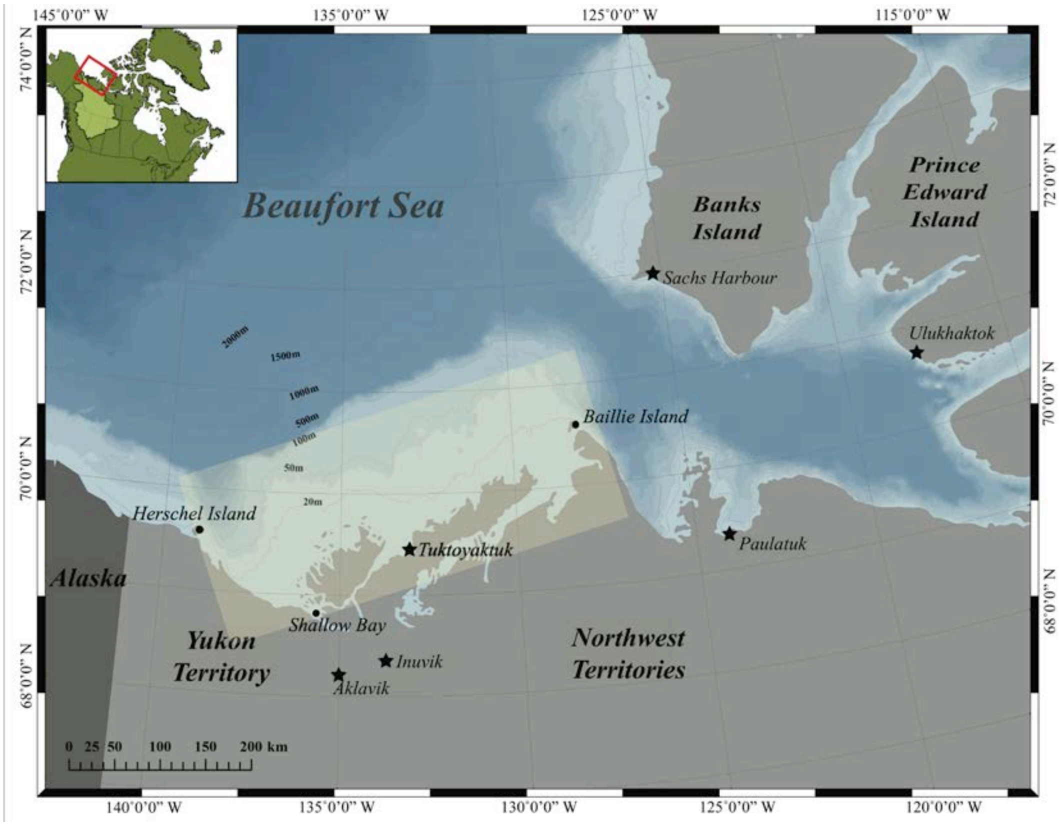
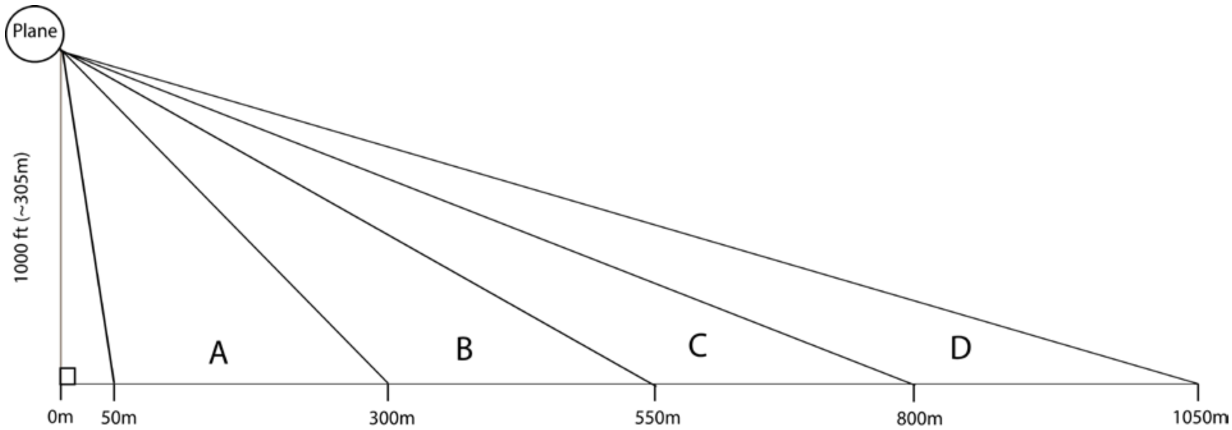


Figure 1. Map of the southeast Beaufort Sea and study area (shaded yellow).

A: Bin distances for whale observations

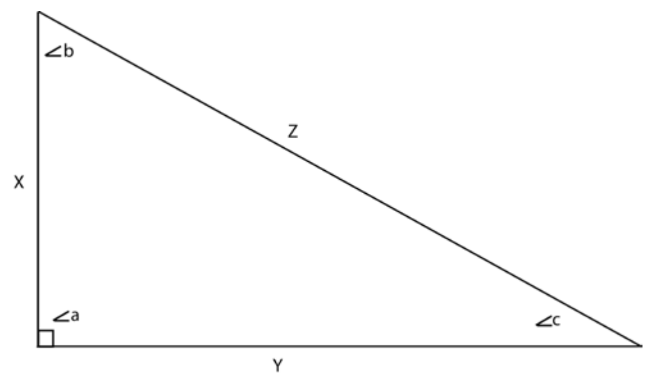


B: Bins were marked on the window of each observer, calculated using equations 1 and 2:

(1) $X^2+Y^2=Z^2$

(2) $\sin(c)=X/Z$

Where X was set to the altitude of the airplane (305m), and Y was set to the distance from the plane for each bin (see A). Values for angles B and C and bin distances are shown in table bellow.



Bin	Distance from aircraft (Y) in meters	Z (m)	<c (degrees)
Start Bin A	50	309.1	80.7
Start Bin B	300	427.8	45.5
Start Bin C	550	628.9	29.0
Start Bin D	800	856.2	20.9
End of Transect	1050	1093.4	16.2

Figure 2. Methods used for calculating bin angles and animal distances from plane: A) bin distances for whale observations starting at 50m from the plane (each bin of 250m was shifted 50m further away from the plane to keep consistent), and B) angle calculations and values for bin distances.

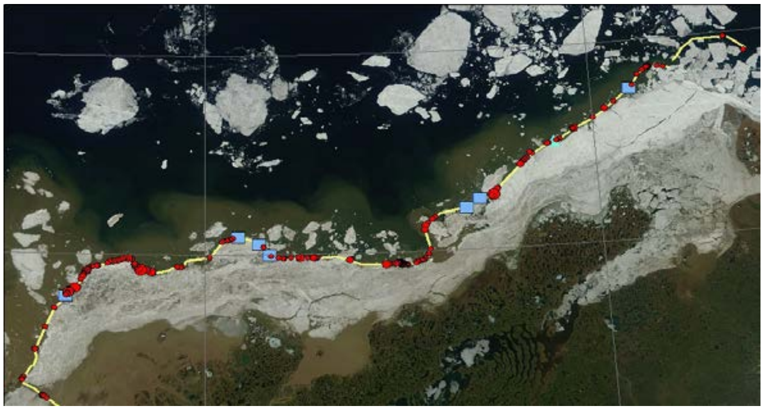


Figure 3. Example of ice edge survey design (map from June 22, 2012 survey).

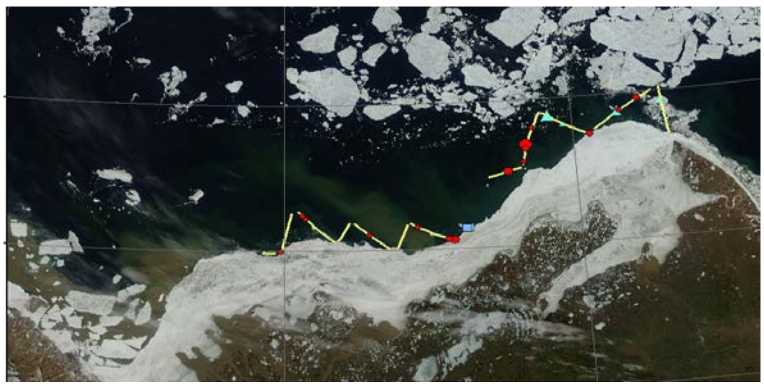


Figure 4. Example of transect (zigzag) survey design (map from June 13, 2012).

Figure 5. Aerial view of belugas in the offshore area during the 2012 field season.

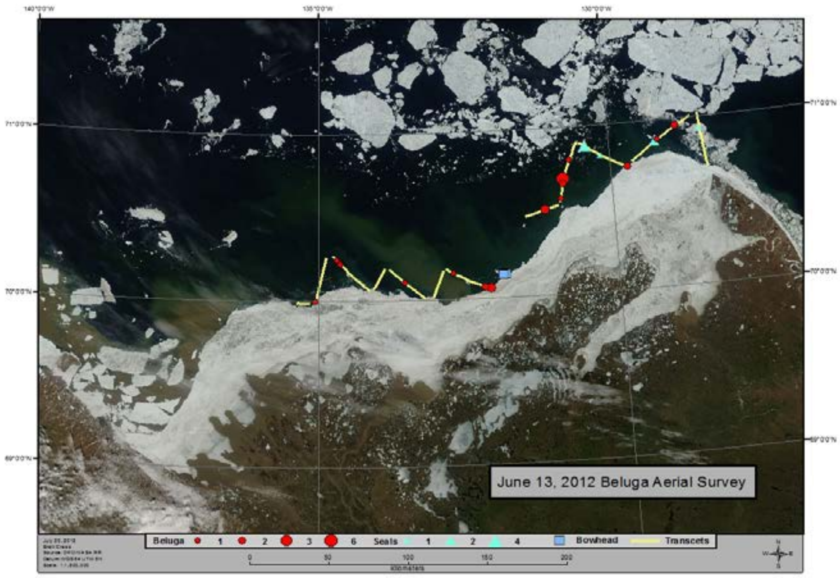


Figure 6. June 13th, 2012 zigzag flight transects from Baillie Island to mid-Delta with beluga sightings (red dots), bowhead (blue square) and seals (triangle). The majority of the area surveyed off the sea ice in the east was blue water, which began to turn turbid toward the west, north of the Kugmallit Bay region.

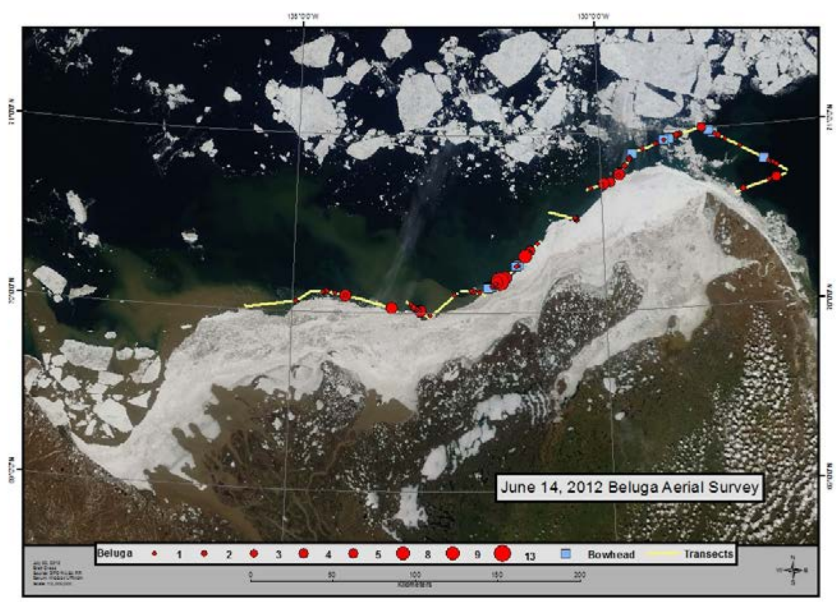


Figure 7. June 14th, 2012 ice edge survey with all marine mammal sightings: beluga (red dots), bowhead (blue square) and seals (triangle). Ice bridge remained intact, with large number of sightings recorded offshore of the Tuktoyaktuk Peninsula.

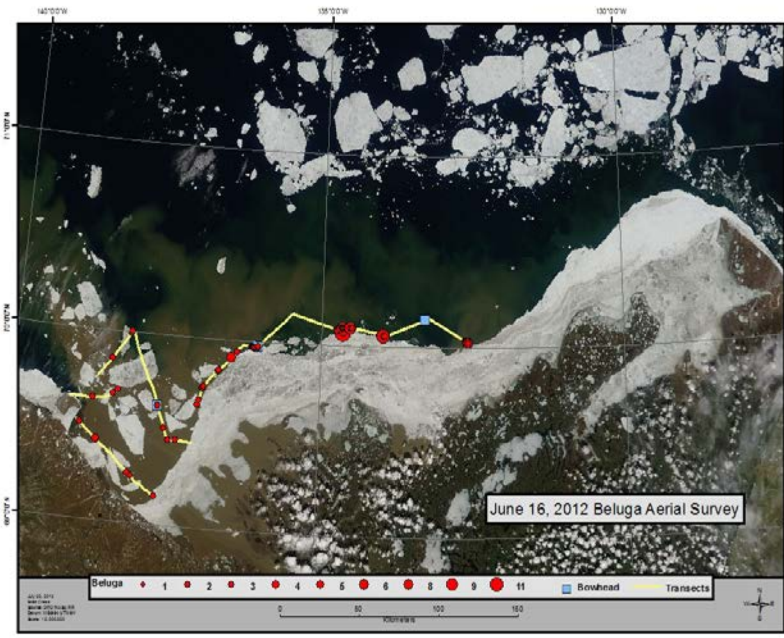


Figure 8. June 16th, 2012 transects from mid-Tuktoyaktuk Peninsula to Shallow Bay. Map includes all sightings of beluga (red dots), and bowhead (blue square) whales.

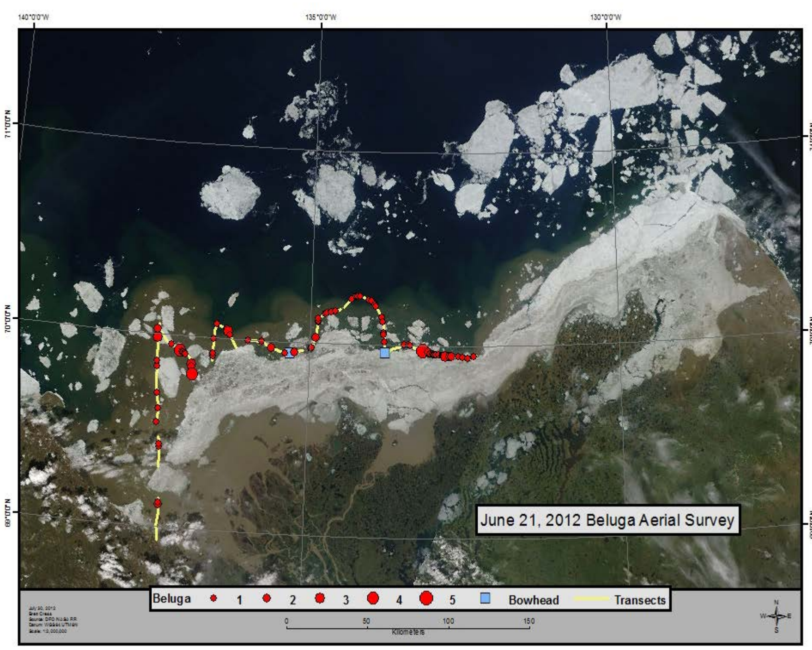


Figure 9. June 21st, 2012 zigzag and ice edge survey. Due to poor weather conditions and large floes of ice, flight lines had to be adjusted resulting in slightly more rounded transects. June 21st was the day the ice bridge began to fracture. Beluga (red dots) were observed both off the ice edge and entering the estuary. Bowhead (blue square) sightings were recorded off the ice edge.

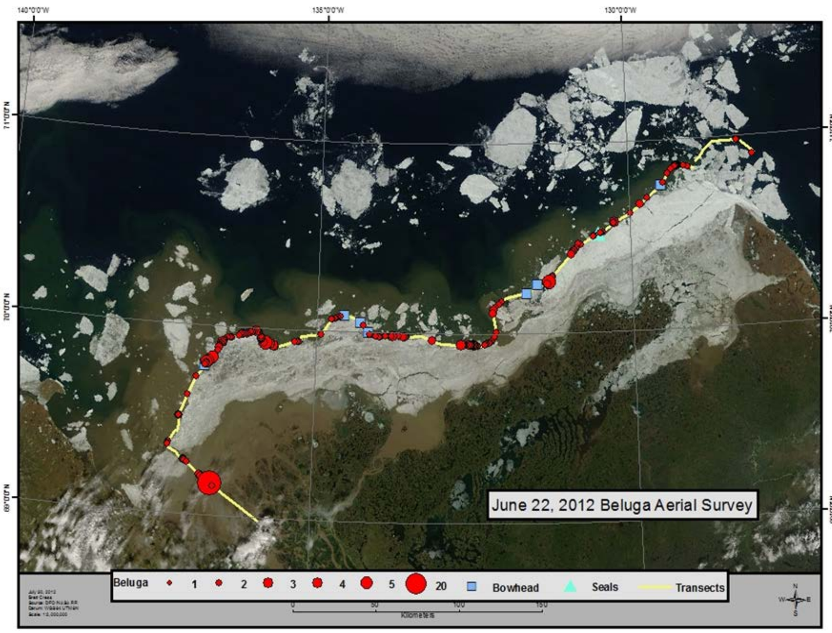


Figure 10. June 22nd, 2012 ice edge survey extending from Baillie Island to Shallow Bay, showing beluga (red dots) and bowhead (blue square) sightings. A large number of beluga were observed in the Shallow Bay estuary.

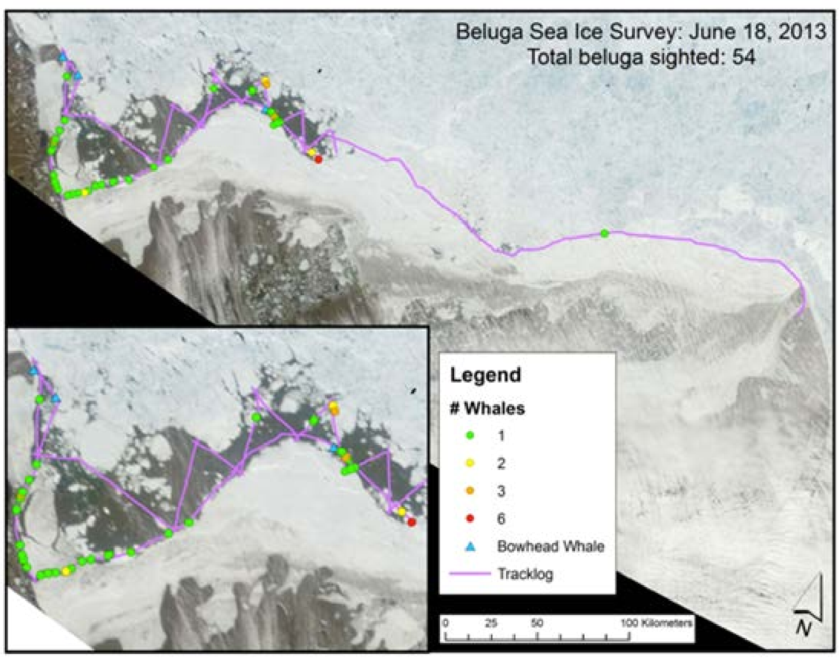


Figure 11. June 18th, 2013 aerial survey transects with data indicating location and number of beluga (circles) and bowhead whales (triangles).

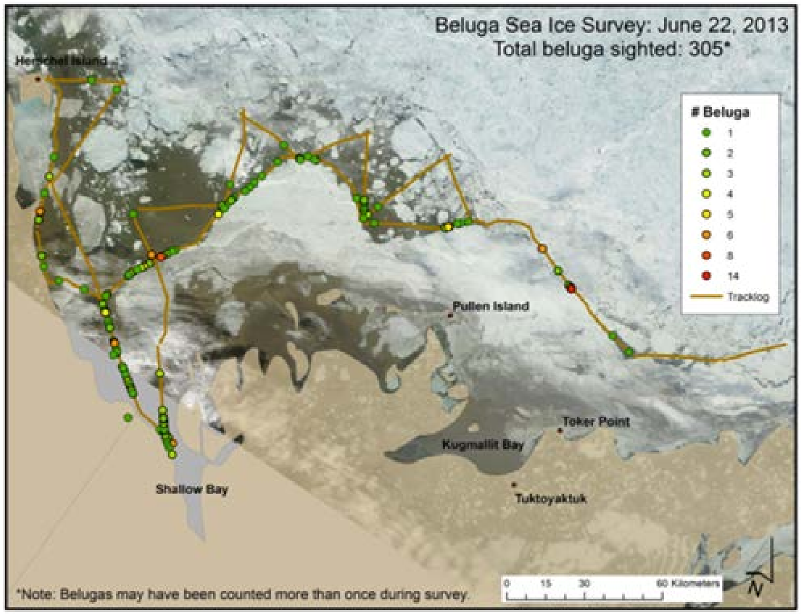


Figure 12: June 22nd, 2013 survey transects (brown line) and beluga observations. Ice bridge had broken on June 21st and many whales were observed entering Shallow Bay.

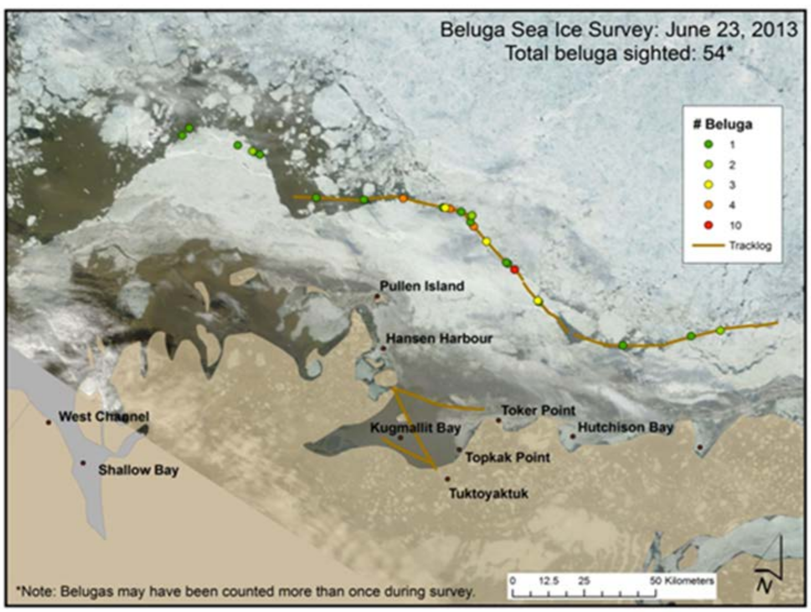


Figure 13. June 23rd, 2013 survey transects and observations. Total flight distance was hampered by poor weather in Shallow Bay. Zigzag transects were completed across Kugmallit Bay, including three transects in the inner Delta, however, no whales were spotted.

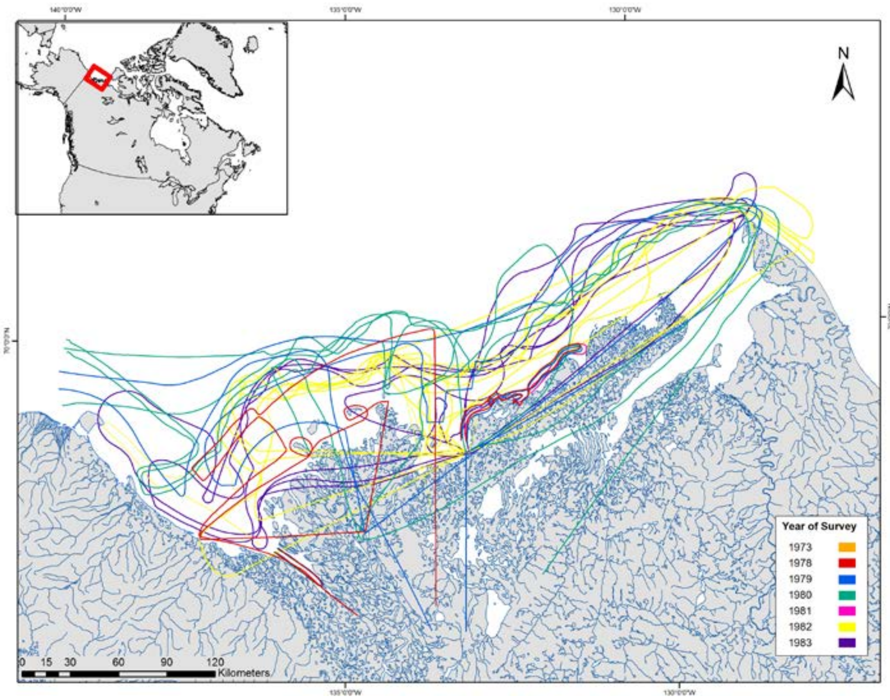


Figure 14. Flight track lines from all historical beluga surveys (1973-1983) listed in Table 5.

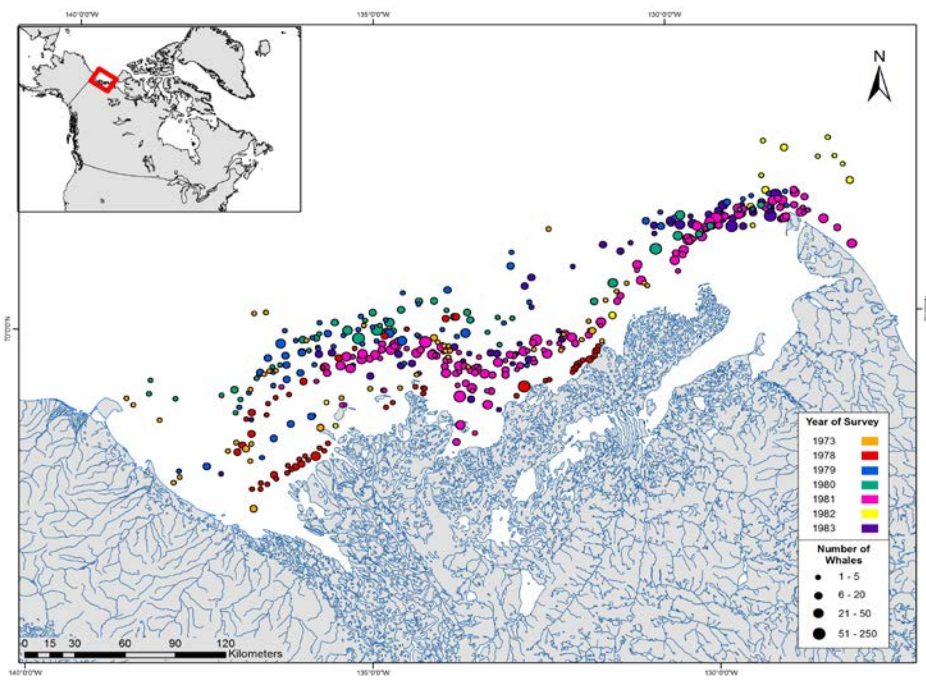


Figure 15. All beluga sightings (1973-1983) documented from the digitization of historical reports for surveys identified in Table 5.