NRC Research Press

ARTICLE

Oceanographic, ecological, and socio-economic impacts of an unusual summer storm in the Mackenzie Estuary

Kevin C. Scharffenberg, Dustin Whalen, Shannon A. MacPhee, Marianne Marcoux, John Iacozza, Gail Davoren, and Lisa L. Loseto

Abstract: With increased warming and open water due to climate change, the frequency and intensity of storm surges is expected to increase. Although studies have shown that strong storms can negatively impact Arctic ecosystems, the impact of storms on Arctic marine mammals is relatively unknown. In July 2016, an unusually large storm occurred in the Mackenzie Delta while instrumented seabed moorings equipped with hydrophones and oceanographic sensors were in place to study environmental drivers of beluga habitat use during their summer aggregation. The storm lasted up to 88 h, with maximum wind speeds reaching 60 km/h; historical wind data from Tuktoyaktuk revealed a storm of similar duration has not occurred in July in at least the past 28 years. This provided a unique opportunity to study the impacts of large storms on oceanographic conditions, beluga habitat use, and the traditional subsistence hunt that occurs annually in the delta. The storm resulted in increased water levels and localized flooding as well as a significant drop in water temperature (~10 °C) and caused belugas to leave the area for 5 days. Although belugas returned after the storm ended, the subsistence hunt was halted resulting in the lowest beluga harvest between 1978 and 2017.

Key words: beluga, acoustic monitoring, climate change, habitat use, subsistence hunt.

Résumé : Avec l'accroissement du réchauffement et des eaux libres provoqué par les changements climatiques, la fréquence et l'intensité des ondes de tempête devraient s'accroître. Alors que des études ont montré que les tempêtes fortes peuvent affecter négativement les écosystèmes de l'Arctique, l'impact des tempêtes sur les mammifères marins de l'Arctique est relativement peu connu. Au cours du mois de juillet 2016, une tempête inhabituellement forte s'est abattue dans le delta du Mackenzie alors que des ancrages de fonds marins équipés d'hydrophones et de capteurs océanographiques étaient en place pour étudier les paramètres environnementaux de l'utilisation de l'habitat des bélugas durant leur estivage. Cette tempête a duré jusqu'à 88 h, avec des vents atteignant des pointes de 60 km/h; les données historiques sur les vents à Tuktoyaktuk ont révélé qu'une tempête d'une telle durée n'était pas arrivée en juillet au cours des 28 dernières années. Elle fournissait une occasion unique d'étudier les impacts de fortes tempêtes sur les conditions océanographiques, l'utilisation de l'habitat du béluga et la chasse

Received 2 November 2018. Accepted 1 August 2019.

K.C. Scharffenberg and G. Davoren. Department of Biological Sciences, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.
D. Whalen. Natural Resources Canada, Geological Survey of Canada, Dartmouth, NS B2Y 4A2, Canada.
S.A. MacPhee, M. Marcoux, and L.L. Loseto. Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, MB R3T 2N6, Canada.
J. Iacozza. Department of Environment & Geography, University of Manitoba, Winnipeg, MB R3T 2N2, Canada.
Corresponding author: Kevin C. Scharffenberg (e-mail: scharffk@myumanitoba.ca).

Lisa Loseto currently serves as an Editor and John Iaccozza currently serves as an Associate Editor; peer review and editorial decisions regarding this manuscript were handled by Greg Henry.

traditionnelle de subsistance qui se déroule annuellement dans le delta. La tempête a provoqué des augmentations du niveau des eaux et des inondations localisées de même qu'une chute significative de la température de l'eau (~ 10° C), ce qui a conduit les bélugas à quitter la région pendant cinq jours. Même si les bélugas sont retournés après la fin de la tempête, la chasse de subsistance a été interrompue, donnant lieu à la plus faible prise de bélugas entre 1978 et 2017. [Traduit par la Rédaction]

Mots-clés : béluga, surveillance acoustique, changements climatiques, utilisation de l'habitat, chasse de subsistance.

Introduction

Climate change has caused warming in the Arctic at a faster rate than anywhere else in the world, resulting in rapidly shrinking sea ice and a longer open water season (Stroeve et al. 2012; Larsen et al. 2014). With warmer temperatures and more open water, the frequency and intensity of storm surges is expected to increase (Manson and Solomon 2007; Sepp and Jaagus 2011; Vermaire et al. 2013); changes in weather patterns, including increases in strong winds, have already been noted by Inuit in Ulukhaktok, Sachs Harbour, Tuktoyaktuk and other communities (Berkes and Jolly 2001; Pearce et al. 2010; Waugh et al. 2018). Large storms have been known to negatively impact Arctic ecosystems (Pisaric et al. 2011; Kokelj et al. 2012); however, their effects on marine mammals, especially cetaceans, remain relatively understudied. Even in southern regions, few studies have examined the effects of storms or wave exposure on cetaceans, owing to the unpredictability of storms and reduced visibility during periods of increased wave height. Research conducted by Dittmann et al. (2016) is a notable exception, where acoustic monitoring (use of underwater microphones) was used to verify visual findings that Hector's dolphins, *Cephalorhynchus hectori* (P.-J. van Bénéden, 1881), leave near-shore habitats during large swell. Pertinently, passive acoustic monitoring (PAM) is emerging as a popular marine mammal monitoring technique (Ford et al. 2010; Risch et al. 2014; Wang et al. 2015) and long-term device deployments may improve the detectability of marine mammals during rough conditions associated with storms.

Beluga whales (*Delphinapterus leucas* (Pallas, 1776)) are a notoriously vocal Arctic cetacean, producing a variety of calls, generally categorized into whistles, pulsed tones, echolocation clicks, and combined calls (Sjare and Smith 1986), thus making them a popular species for PAM studies (Roy et al. 2010; Castellote et al. 2013; Lammers et al. 2013). Eastern Beaufort Sea (EBS) belugas migrate from their overwintering location in the Bering Sea to the Beaufort Sea in the spring (Hauser et al. 2014; Muto et al. 2016) and form large summering aggregations in the Mackenzie Estuary (Harwood et al. 1996). The reasons for this estuarine occupation are unclear, though it may be to use the warm/fresh water to initiate moulting, or to provide a thermal advantage for calves (Fraker et al. 1979; Scharffenberg et al. 2019) as suggested for belugas in other estuaries (Sergeant 1973; St. Aubin et al. 1990; Watts et al. 1991; Smith et al. 1992). The summering aggregation in the Mackenzie Estuary is important for the annual subsistence beluga harvest by the Inuvialuit, who have been hunting belugas in the estuary for centuries (Fraker et al. 1979). The hunt has declined by 28% since the 1970s (Harwood et al. 2015); however, it still has cultural significance and remains important for its contribution to food security (Usher 2002; Hoover et al. 2016). This important relationship with belugas has resulted in a long-term conservation effort with the creation of Canada's first Arctic Marine Protected Area, the Tarium Niryutait Marine Protected Area (TN MPA) in 2010 (Fisheries Joint Management Committee 2013). Research objectives in the TN MPA are driven towards gaining a better understanding of climate driven changes in the region, and the conservation and protection of belugas while maintaining harvesting traditions and ensuring sustainable management of the species.

In 2016, we deployed instrumented seabed moorings equipped with acoustic recorders to understand the environmental drivers of beluga habitat use during their summer aggregation in the Mackenzie Estuary; however, an unusually large storm occurred in mid-July, making it difficult to assess beluga habitat use drivers under normal conditions. Given that storm frequency and intensity are expected to increase as the Arctic climate warms (Manson and Solomon 2007; Vermaire et al. 2013), the 2016 storm provided a unique opportunity to examine the effects of a major summer storm on beluga habitat use. Thus, the objectives here are to (1) determine if the 2016 storm was unique by identifying and measuring other storms in July from 1990 to 2017; (2) determine the impact of the storm on beluga habitat use, by comparing vocalizations detections before, during, and after the storm; and (3) assess the impact the storm had on the traditional subsistence harvest that occurs each summer in Kugmallit Bay by comparing harvest numbers and timing with previous years.

Methods

Study area

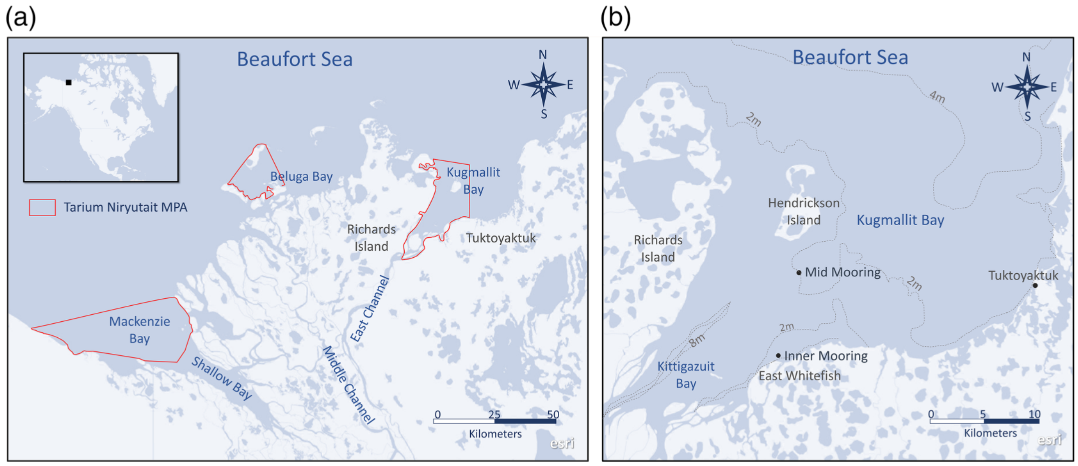
The Mackenzie River flows into the Beaufort Sea at the Mackenzie Estuary, which is 80 km across, and is composed of low-lying alluvial islands with three main channels: the East Channel, Peel Channel, and Middle Channel (Fig. 1*a*). The East Channel of the Mackenzie River flows out into Kugmallit Bay, located between Richards Island and the Tuktoyaktuk Peninsula (Fig. 1*a*). Kugmallit Bay is very shallow with depth rarely exceeding 2 m, although a narrow channel approximately 5–9 m deep exists along the western shore. Of the belugas landed in the Mackenzie Delta, the majority are landed in Kugmallit Bay (Harwood et al. 2015); landed whales are brought to Hendrickson Island, East Whitefish, or Tuktoyaktuk, where the meat is harvested (Fig. 1*b*).

Study design

To address the research objectives, data were collected in Kugmallit Bay under NWT science license number 15915 in 2016. Beluga vocalizations and oceanographic conditions were recorded at two instrumented seabed moorings (Mid and Inner Moorings) deployed in Kugmallit Bay from 13 June to 23 August 2016 (Fig. 1*b*). Moorings were equipped with Song Meter SM2M Submersible Marine Recorders (Wildlife Acoustics, Maynard, MA, USA), conductivity, temperature, and depth recorders (CTDs) (RBR Ltd., Kanata, ON, Canada) and wave loggers (RBR Ltd.). Audio was recorded at a sample rate of 96 kHz (Mid) or 384 kHz (Inner) with a sample size of 16 bits and a 25% duty cycle (15 min/h). The 96 kHz sample rate provided a recording bandwidth of 2 Hz to 48 kHz, sufficient to capture beluga social calls, broadband calls, and low frequency echolocation clicks (Belikov and Bel'kovich 2006), whereas the 384 kHz sample rate provided a recording bandwidth of 2 Hz to 192 kHz, covering the entire beluga vocal range, including ultrasonic echolocation clicks (Sjare and Smith 1986). The Mid hydrophone stopped recording 12 August, the Inner hydrophone recorded until retrieval on 23 August. CTDs were programmed with a 5 s sampling period, and wave loggers recorded wave bursts of 512 samples every 5 min at a 6 Hz sampling rate.

Meteorological data (i.e., air temperature, wind speed and direction) from 1990 to 2017 were obtained from the weather station in Tuktoyaktuk, which is maintained and monitored by the Department of Environment and Climate Change Canada (ECCC; downloaded from http://climate.weather.gc.ca/). Hourly data were available for 1995–2017 but were only available every 6 h for 1990–1992, and hourly from 0600 to 2200 for 1993–1994. Mackenzie River mean daily discharge data were obtained from the hydrometric station in Inuvik, maintained and monitored by ECCC (downloaded from http://wateroffice.ec.gc.ca/).

Fig. 1. (*a*) Map of the Mackenzie Delta, showing the Tarium Niryutait Marine Protected Area (TN MPA). (*b*) Map of Kugmallit Bay, showing the location of mooring deployments from June to August 2016. This map was created using ArcGIS® software by Esri, used under license, and contains data from Esri, HERE, Garmin, OpenStreetMap contributors, and the GIS user community.



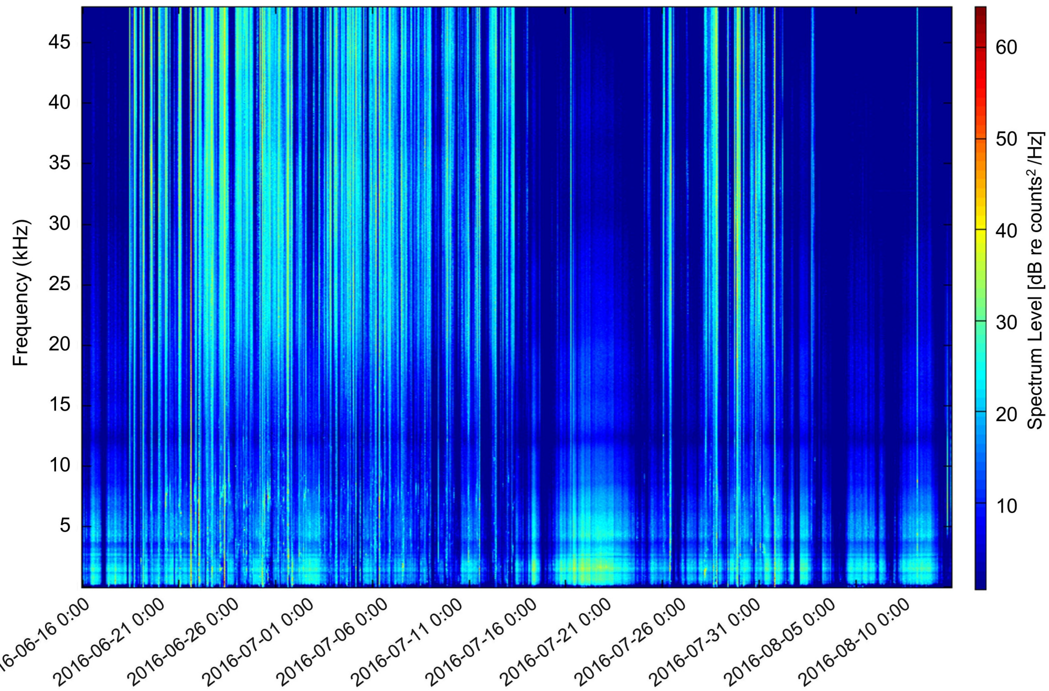
The timing and number of belugas landed in Kugmallit Bay each year from 1990 to 2017 was determined from a database maintained and monitored by Fisheries and Oceans Canada and the Fisheries Joint Management Committee (FJMC; see Harwood et al. 2002 for details).

Defining storms

To put the July 2016 weather conditions into context, meteorological data were compared with observations from 1990 to 2015 and 2017. First, July storms from 1990 to 2017 were identified and measured, following Atkinson (2005). Wind speed data from 1990 to 1994 (which was not recorded hourly) was linearly interpolated to obtain hourly wind speed estimates. We used a wind speed threshold of 10 m/s (36 km/h), at a duration threshold of 6 h, to identify storm events. We then calculated the synoptic duration of each event with the inclusion of lulls and shoulder events. Lulls are single observations where hourly wind speed decreased below the wind speed threshold (Atkinson 2005). Shoulder events are the period on either side of the storm event with wind speeds at least 0.7 times the event threshold (26 km/h; Atkinson 2005). For each storm, we also calculated core mean speed, defined as the mean speed of winds in the upper 50th percentile of all hourly wind speeds within an event, and the core duration, defined as the duration of the core wind speeds (Atkinson 2005). We then compared the mean core speed, maximum speed, core duration, and synoptic duration for 2016 with the mean and maximum values for 1995–2015 and 2017. To identify the most common wind direction, we calculated the mean direction of the core speeds for each storm and binned it into one of eight possibilities (N, NE, E, SE, S, SW, W, NW). Due to missing data resulting in uncertain speed and direction measurements for storms between 1990 and 1994, only their durations were used. We then examined air temperature by plotting daily high and low air temperatures for June–August 2016 against mean high and low daily temperatures for 1995–2015 and 2017.

To determine the effect of the 2016 storm on oceanographic conditions, measurements from both moorings (i.e., water temperature, salinity, average wave height, and water depth) were averaged hourly (to match with wind measurements) and plotted over time. Tidal fluctuations were smoothed by calculating a centered moving average of water depth over 13 h to show the changes in water depth resulting from wind speed.

Fig. 2. Long-term spectral average (LTSA) plot with 100 Hz frequency bins averaged over 5 s time intervals for the Mid mooring from 16 June to 12 August 2016. Periods of high beluga presence appear as broadband streaks extending to the top of the plot. Wind and wave activity show primarily below 7 kHz, decreasing in power at higher frequencies. The storm began 18 July 2016, 1400 and ended 22 July 2016, 0500.



Beluga presence

All acoustic recordings were analyzed for beluga presence/absence using a combination of manual and automated detection. Methods are outlined by Scharffenberg et al. (2019). In short, an analyst compared results from an automated click detector — previously used to detect clicks in belugas (Marcoux et al. 2017) and narwhal (Roy et al. 2010) — with long-term spectral average (LTSA; Fig. 2) plots, computed for each hydrophone using the MATLAB® (The MathWorks, Natick, MA, USA) script *Triton* (Scripps Whale Acoustic Lab, San Diego, CA, USA), to determine if beluga vocalizations were present. The detector used a 20 kHz high-pass filter, which limited detections to calls with frequencies above 20 kHz. Although this reduced our spatial detection range (as high frequency sounds do not travel as far) and did not allow for the inclusion of low frequency calls, such as whistles, it limited the effect of wind and waves on detection rate. Previous work in Kugmallit Bay has shown that whistles and broadband pulsed tones regularly occur together (Simard et al. 2014), so focusing on higher frequencies was deemed sufficient for detecting presence/absence. To verify that the storm did not impact our ability to detect beluga vocalizations above 20 kHz, we used the software package PAMGuide (Merchant et al. 2015), which was run in R (R Core Team 2016), to calculate sound pressure levels (SPL, in dB re 1 μPa) at the Mid mooring in the 20–48 kHz bandwidth for each second in 50 randomly selected audio files with beluga presence, 50 randomly selected audio files during the storm, and 10 audio files with quiet conditions (lowest wind speed with no beluga vocalizations). Additionally, all sound files during the storm were analyzed manually. Outputs from the click detector and (or) manual examination were used to quantify the number of hours that were positive for beluga detections per day (detection hours per day, DHPD; to a maximum of 24).

From the beluga harvester dataset, we determined the timing and number of belugas landed every year in Kugmallit Bay from 1990 to 2017. From these dates we determined the longest gap in beluga landings (defined as the number of consecutive days during which no belugas were landed) in July and used Kendall's tau to test if long gaps in landings are historically associated with low harvest years (Kendall 1955). We also used a Mann–Whitney *U* test to determine if wind speed has an effect on hunting success, which was defined as whether or not at least one whale was landed on a given day because "unsuccessful" hunts are not recorded.

Results

Environmental conditions

Twenty July storms were identified from 1990 to 2017, ranging from 0 to 2 per year. The 2016 storm had a synoptic length of 88 h, making it the longest July storm on record from 1990 to 2017, with only two other storms lasting longer than 48 h (10 July 2013: 58 h; 23 July 1998: 49 h; Fig. 3). Wind speeds were in the upper 50th percentile for 62 h (i.e., core duration), also the longest in the period assessed (Fig. 3). The mean (± SD) core speed for the duration of the storm was 44.5 ± 5.4 km/h, which is above the mean for all July storms (40.7 ± 4.3 km/h), but within 1 standard deviation (Table 1). However, mean core speed in 2016 was significantly higher than the mean core speed of the next two longest storms (10 July 2013: 35.8 ± 3.6 km/h; 23 July 1998: 35.6 ± 2.4 km/h; one-way ANOVA: $F = 51.9$, df = 2, $p < 0.001$; post hoc Tukey HSD tested significance at the $p < 0.001$ level).

Prior to the storm in July 2016, air temperatures were warm, with daily high temperatures above the historical average for most of late June and early July, setting study period records on 10 and 14 July (Fig. 4*a*). This steady increase in air temperature combined with calm conditions in early July (Fig. 4*c*) caused water temperatures to rise above 21 °C at both moorings by mid-July (Fig. 4g). Calm conditions also kept salinity low (Fig. 4*f*) and water depth relatively constant at both moorings (Fig. 4*e*).

Based on our criteria, the storm began 18 July at 1400, although wind speed had previously exceeded 36 km/h for 3 h the night before (Fig. 4*c*). The storm was dominated by winds from the west–northwest, which dropped air temperatures to 1 °C (Fig. 4*a*) and caused water temperatures in the middle of the bay to drop to 7.5 °C (Fig. 4g). Water depth, which had begun to increase as wind speeds increased prior to the official start of the storm, was about 1 m higher at peak storm surge than pre-storm levels (Fig. 4*e*). The storm surge also resulted in an approximately 4.5 increase in salinity at the Mid mooring (Fig. 4*f*). After the storm, water depth steadily decreased for several days (Fig. 4*e*). Air temperatures fluctuated for the rest of the season, and water temperature at both moorings did not return to the pre-storm highs. Periodic increases in salinity occurred at the Mid mooring from late July through mid-August. These were triggered by wind events, and increased in magnitude as discharge from the Mackenzie River decreased (Figs. 4*b* and 4*f*).

Beluga detections

Belugas were first detected on 17 June 2016, and detections were made regularly (>12 DHPD) within 2 days (Fig. 4*h*). Detection rate was highest during an 18-day period from 21 June to 8 July with at least 23 DHPD at the Mid mooring. Following this, detection rate dropped slightly, but did not dip below 12 DHPD until 16 July. At the Inner mooring, detections per day began to decline in early July. There were no beluga vocalizations during the storm. After the storm, beluga vocalizations were first detected on 23 July at 0800 at both the Inner and Mid locations, 27 h after wind speeds decreased below 26 km/h. Substantial

Fig. 3. Core and synoptic duration of all storms identified in the month of July between 1990 and 2016 at the Tuktoyaktuk weather station. Core duration is the duration where wind speeds were in the top 50th percentile of all wind speeds in each event. Synoptic duration is the total duration of the event, including shoulder observations. The date given is the date of the last observation within each storm.

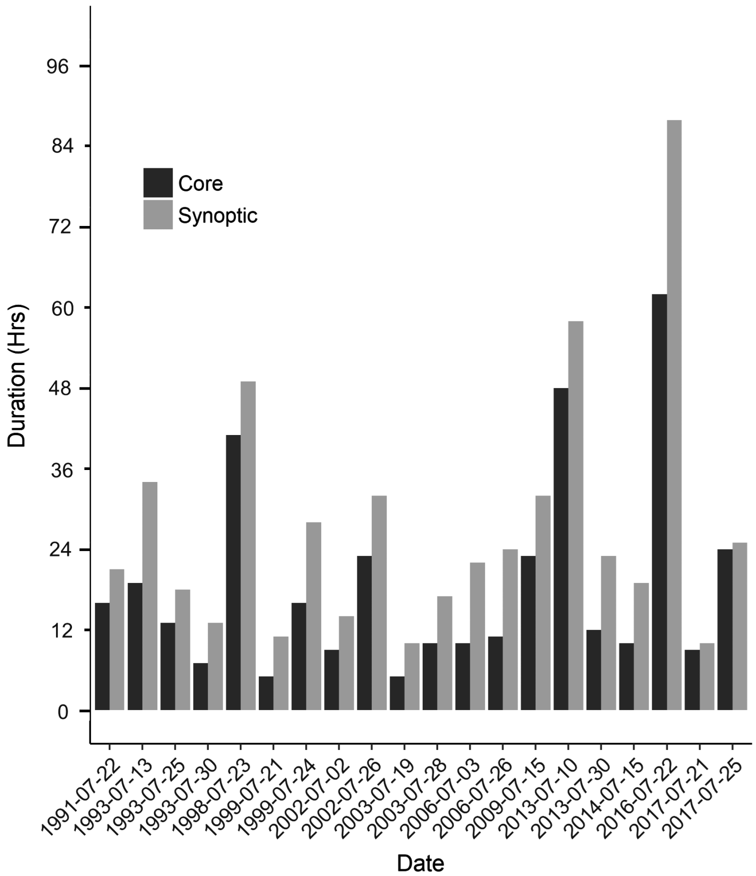


Table 1. Speed and duration of July storms.

	Mean	SD	Max	2016
Core mean speed	40.7	4.3	47.0	44.5
Max speed	47.3	6.1	61	60
Core duration	17.1	12.8	48	62
Synoptic duration	24.9	13.8	58	88
Wind direction	NW[a]			NW

Note: Mean ± SD and maximum characteristics of July storms identified at the Tuktoyaktuk weather station between 1995–2017 and 2016. Core mean speed is the mean of the speed values in the top 50th percentile of all speeds in each event, whereas max speed is the maximum wind speed in each event. Core duration is the duration of the core speeds and synoptic duration is the duration of the event, including shoulder observations.

[a]For wind direction the most common direction between 1995–2015 and 2017 is given.

Fig. 4. (*a*) Daily high and low air temperatures for each day from June to August 2016 (black), against air temperatures recorded from 1995 to 2015 and 2017; record maximum and minimum temperatures between 1995 and 2017 (light grey); mean maximum and mean minimum temperatures (dark grey) and the mean temperature during 1995–2015 and 2017 (dark line). (*b*) Mean daily discharge (daily flow; m^3/s) of the Mackenzie River recorded at Inuvik from 16 June to 22 August 2016. (*c*) Hourly maximum wind speed recorded at the Tuktoyaktuk weather station from 16 June to 22 August 2016. (*d*) Hourly mean wave height recorded at the Mid (red) and Inner (blue) moorings. (*e*) Hourly mean water depth recorded at the Mid (red) and Inner (blue) moorings; the grey line is actual water depth, and the coloured line is a smoothed 13 h moving average. (*f*) Hourly mean salinity recorded at the Mid (red) and Inner (blue) moorings (note the Inner mooring did not rise above 0.2). (*g*) Hourly mean water temperature recorded at the Mid (red) and Inner (blue) moorings. (*h*) Beluga detection hours per day (DHPD) at the Mid (red) and Inner (blue) moorings in 2016 and 2017. The dotted box highlights the start and end of the storm, the dashed box highlights the gap in beluga landings.

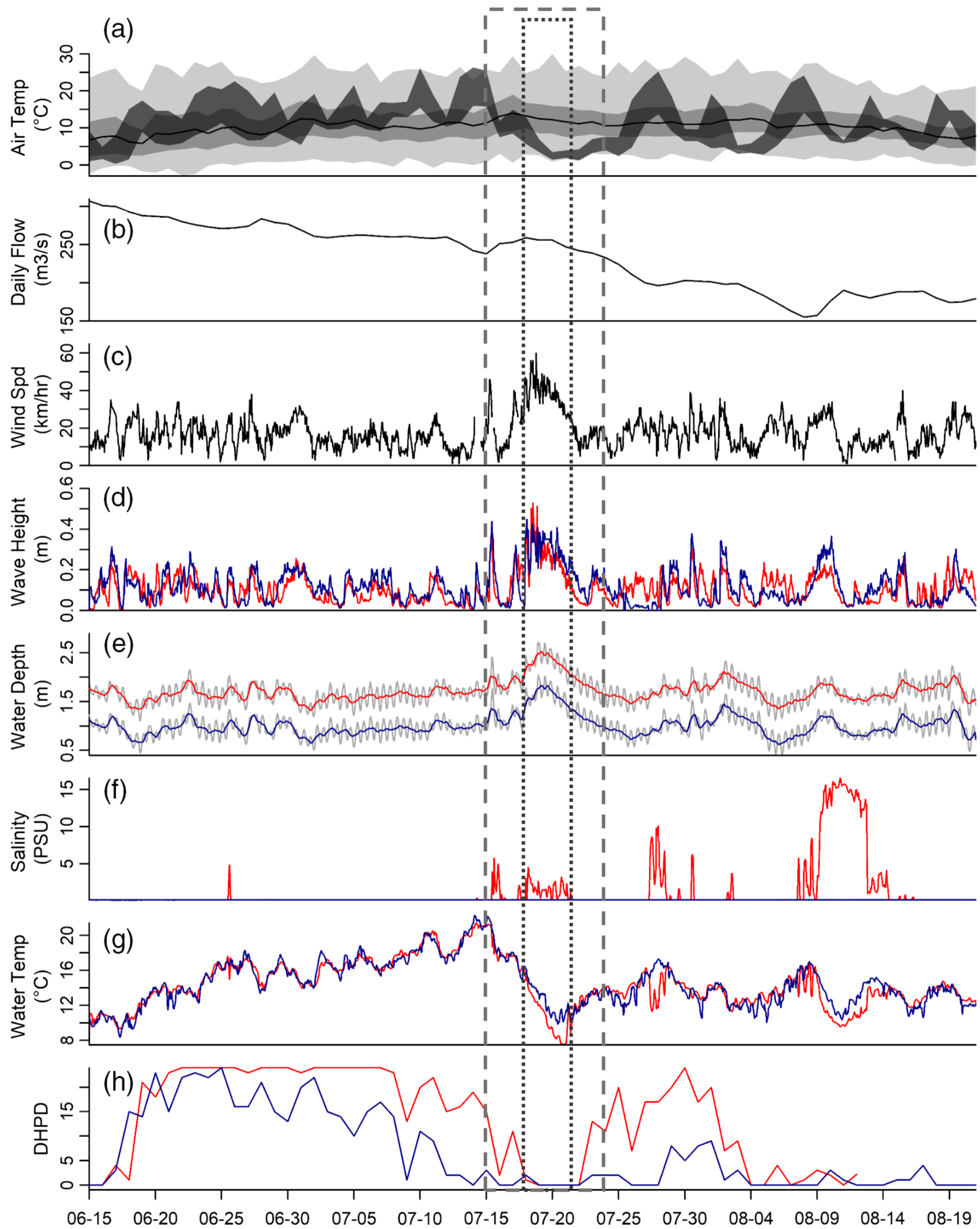
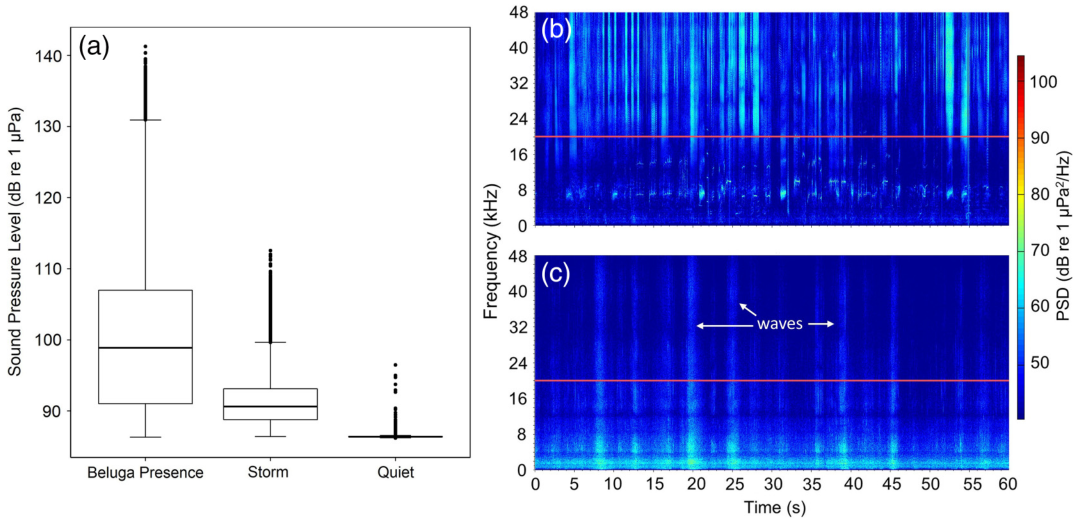


Fig. 5. (*a*) Distribution of 1 s sound pressure level (SPL) measurements in the 20–48 kHz band for 50 randomly chosen 15-min audio files with beluga presence, 50 randomly chosen 15-min audio files during the storm, and ten 15-min files with quiet conditions (no beluga vocalizations, calm conditions). Results are shown as boxplots showing the 25th percentile, median, and 75th percentile. Outliers are SPL measurements that are beyond 1.5× the interquartile range. (*b*) Spectrogram showing 1 min example of the soundscape at the Mid mooring during typical beluga presence; a red line is shown at 20 kHz. (*c*) Spectrogram showing 1 min example of the soundscape at the Mid mooring during the storm; a red line is shown at 20 kHz. PSD, power spectral density.



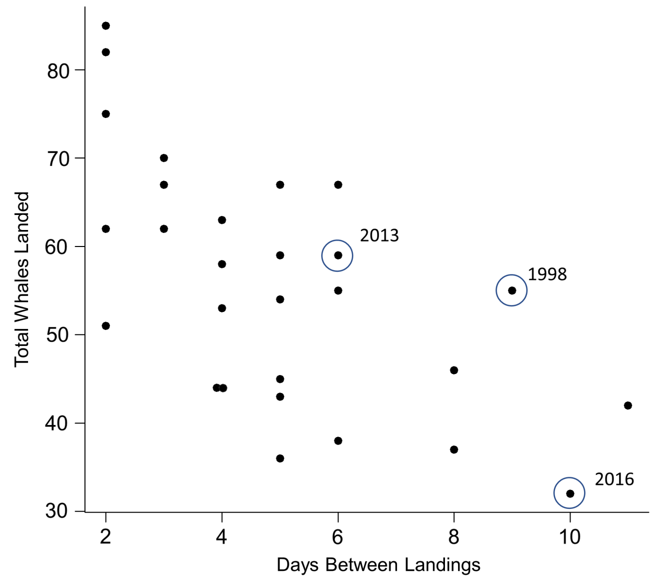
use (defined as >2 consecutive hours with detections) was first observed after the storm on 23 July at 1700 at the Mid mooring, but not until 29 July at 0700 at the Inner mooring. At the Mid mooring, the detection rate returned to pre-storm levels until early August but remained low at the Inner mooring for the rest of the season (Fig. 4*h*).

To test our ability to detect belugas during the storm, SPL in the 20–48 kHz band was measured at the Mid mooring during beluga presence, the storm, and quiet conditions (Fig. 5*a*). During beluga presence, the median SPL was 8.2 dB higher than during the storm (Mann–Whitney test: $U = 6\ 097\ 200\ 000$, $p < 0.0001$) and 12.6 dB higher than during quiet conditions (Mann–Whitney test: $U = 1\ 452\ 200\ 000$, $p < 0.0001$). During the storm, the highest SPLs were created by waves; these sounds were intermittent and distinguishable from beluga vocalizations during manual analysis (Fig. 5).

Beluga harvest

Between 1990 and 2017 (excluding 2016), the number of belugas landed per year in Kugmallit Bay ranged from 36 to 85. Thirty-two belugas were harvested in Kugmallit Bay during 2016, the lowest number since records began in 1978. In 2016, belugas were landed between 2 and 30 July, with 20 belugas landed before the storm, 0 during, and 9 after (the landing dates for three whales were not recorded). Following the storm, the first beluga was not landed until 25 July, resulting in a 10-day gap between landings (Fig. 4*h*). Between 1990 and 2017, landings in high-harvest years were spread evenly throughout July, with short gaps (i.e., 2–3 days); years with long gaps in harvest date tended to have lower harvest numbers (Fig. 6), with the longest gap in beluga harvesting during July negatively correlated with total number of belugas landed (Kendall's tau = −0.425, $p = 0.003$). A Mann–Kendall trend test showed no significant change in the duration of harvest gaps over time for 1990–2017 (excluding 2016; tau = −0.0063, $p = 0.98$). Of the other two July storms lasting

Fig. 6. Scatterplot showing the total number of belugas landed in Kugmallit Bay per year from 1990 to 2017, and the longest number of consecutive days between beluga landings in July for each year. The circles indicate the three longest storms.



longer than 48 h, both coincided with the longest beluga harvest gap in July for that year: the 49-h storm in 1998 occurred during a 9-day gap in beluga landings, and the 58-h storm in 2013 occurred during a 6-day gap in beluga landings (Fig. 6). It should be noted that many gaps were not the result of storms; in particular, an 11-day gap in 1990 could not be attributed to any wind event and we were unable to determine the cause (Fig. 6). However, the Mann–Whitney test showed that from 1990 to 2017, wind speed was significantly lower on days when at least one beluga was landed (mean = 14.0 km/h, SD = 4.4 km/h) than days when no belugas were landed (mean = 19.1 km/h, SD = 5.8 km/h; $U = 144\ 350$, $p < 0.0001$).

Discussion

The July 2016 storm allowed us the unique opportunity to study the effect of a large storm on beluga habitat use during their summer aggregation in the Mackenzie Estuary. It was especially unique in duration as the longest July storm in the past 28 years, and had an extreme effect on the oceanographic conditions in Kugmallit Bay, causing increases in water depth, decreased water and air temperatures, and significant flooding at the East Whitefish hunting camp (Gordon et al. 2016). It also resulted in the absence of belugas from typically high-use areas in Kugmallit Bay (i.e., the Inner and Mid mooring sites) for several days. This, in turn, impacted the beluga hunt, creating a gap in huntable days (due to poor hunting conditions and the absence of belugas) and was likely a key contributor to the lowest beluga harvest on record for Kugmallit Bay.

Impact on environmental conditions

The 2016 storm was unusual in its timing and duration. Historically, the month of July has the second lowest storm count in the Beaufort region (June has the lowest), and July storms, on average, have been the shortest in duration, with longer storms occurring in late summer and into autumn (Solomon et al. 1994; Atkinson 2005). As a single event, we cannot attribute this storm to climate change. Arctic storms, however, are widely predicted to increase in intensity and duration as the Arctic warms (Manson and Solomon 2007; Vermaire et al. 2013). Indeed, storm surge activity historically has followed temperature and sea-ice trends (Vermaire et al. 2013), and the summer minimum sea ice extent in 2016 tied for the second lowest on record (NSIDC 2016), and the breakup date of the landfast ice bridge in Kugmallit Bay occurred earlier than any year on record (Loseto et al. 2018). This event also provided valuable information on the oceanographic and biological system in Kugmallit Bay during storms. Interestingly, this storm did not result in the increased salinity observed during smaller storms/wind events later in the season and in 2017 (Scharffenberg et al. 2019). Oceanic conditions of the Beaufort Sea and warm fresh conditions of the Mackenzie River are typically balanced in the Mackenzie Delta by river discharge and wind direction (Carmack and Macdonald 2002). Overall, river discharge decreases over the season, but varies based on the timing of ice-breakup and precipitation (Yang et al. 2015). So, although increased water depth and wave height, along with decreased water temperature, may be common features of all summer storms, the southern extent to which saline oceanic water reaches into the bay likely depends on the timing of the storm, dominant wind direction, and river discharge. As such, other storms may have greater potential to cause changes to ocean chemistry in the bay.

Influence on beluga

The direct influence of the storm on beluga habitat use was immediately apparent, with absence of beluga detections at both moorings for the duration of the storm. Given that belugas are normally a notoriously vocal species (Sjare and Smith 1986), even more so in turbid waters (Castellote et al. 2013) and when under stress (Vergara et al. 2010), it is highly unlikely that belugas were present and not vocalizing for the duration of the storm. Furthermore, if belugas had been vocalizing near the moorings, we would have detected them based on ambient noise conditions during the storm. The turbulent water and drastic drop in temperature associated with the storm would both have been likely deterrents for belugas in Kugmallit Bay (Scharffenberg et al. 2019). Warm fresh waters are likely part of the appeal of estuaries for belugas (Sergeant 1973; St. Aubin et al. 1990; Watts et al. 1991; Smith et al. 1992), so a decrease in temperature may mean there is no reason for belugas to stay in the estuary. Furthermore, conditions were likely too rough for belugas to remain in the area, as such shallow (about 2 m) conditions would not have allowed the opportunity to dive below the influence of the waves. This would have been especially taxing on young belugas that likely require calmer conditions, similar to other species (Elwin and Best 2004). There is surprisingly little research on the responses of cetaceans to increased wave height, although belugas are thought to select more sheltered areas during increased wind speed in other areas (Caron and Smith 1990; Mymrin and Huntington 1999), and Dittmann et al. (2016) found that Hector's dolphins leave nearshore areas following days of rough weather. As we did not detect any belugas during the storm, we could not determine where the belugas went. Findings from 2017 suggest they do not use the other hotspot to the west of Hendrickson Island during high speed wind events (Scharffenberg et al. 2019), so it is highly unlikely that belugas congregated there during the 2016 storm. Aerial survey data from the 1970s and 1980s do not offer an explanation, as surveys were not flown in high speed winds (Fraker et al. 1979). It could be that belugas moved to deeper waters where they could avoid the turbulence at the surface, or that they moved closer to Richards Island or a more sheltered bay.

Following the storm, belugas quickly returned to the middle of the bay, and the detection rate returned to the same level as observed during a similar time in 2017 (Scharffenberg et al. 2019). Although there was a short recovery time, this suggests that belugas are flexible enough to return to normal use of the estuary after an unusual storm event. In other situations, belugas have proven to be a resilient species, able to return to areas quickly following a disturbance like hunting (Caron and Smith 1990), and responding quickly to environmental conditions, following tides to access new areas (Ezer et al. 2008) and timing their migrations with varying spring sea-ice conditions (Fraker et al. 1979; Barber et al. 2001). This suggests that the effects of future storms on belugas will be related to the storms' effect on oceanographic conditions, and that they are not likely to discourage belugas from using the estuary once conditions return to normal. As such, the low detection rate at the Inner mooring following the storm suggests that the area was undesirable following the storm. This could be the result of increased levels of sedimentation changing the substrate composition, or the presence of woody debris. Alternatively, use of the area near the Inner mooring may have been unnecessary because oceanic influxes, which appeared to drive belugas farther into the bay late in the summer in 2017 (Scharffenberg et al. 2019), may not have been strong enough to drive belugas that far into the bay in 2016. Additional years of monitoring would be necessary to determine whether the low detection rate at the Inner mooring following the storm was due to the aftermath of the storm or to the distribution of salt water in the bay.

Despite the quick response to the end of the storm, it is not known what effect a multi-day period of estuary inaccessibility may have on belugas. On average, individual belugas appear to spend only a few days in the estuary (Richard et al. 2001), and it is not known what triggers their entry, so it is possible that a period of inaccessibility could have a negative effect on belugas needing to use the estuary at that time. For example, if belugas are waiting for a biological cue to enter the estuary to moult (St. Aubin et al. 1990; Watts et al. 1991), an unpredictable event like a storm could disrupt that critical time, potentially making moulting more difficult. Similarly, if female belugas are using the estuary to provide a thermal advantage to their young calves (Sergeant 1973), this period of inaccessibility could lead to decreased growth during a critical time in the calf's life.

Socio-economic impact on the hunt

The 2016 storm likely impacted the beluga harvest, creating a 10-day gap in beluga landings, due to both inaccessibility for hunters during the storm, and a lack of belugas. Although our results show that belugas did return a day after wind speed reduced below storm levels, hunters suggested that belugas were more difficult to find in the days following the storm (A. Gordon, L. Loseto, personal communication, 2018). Increases in the frequency and intensity of winds has been cited as a cause for missed harvesting days (Waugh et al. 2018) and is suggested as the primary reason that the end of the hunt has occurred later in the season in recent years, where hunters try to make up for missed days by going later in the season (Harwood et al. 2015). However, we found that landings in high harvest years tend to be spread evenly throughout July, with short gaps (i.e., 2–3 days), suggesting that harvesters are limited in their ability to make up for lost days by increasing effort on other days. Stresses affecting food security, as well as societal changes to language and land-based skills, are growing concerns across the Arctic and have been examined in numerous studies (Condon et al. 1995; Harder and Wenzel 2012; Collings et al. 2016). The annual beluga harvest provides a nutritionally superior alternative to store-bought products (Hoover et al. 2016) and provides an opportunity to pass on traditional hunting and land-based skills to younger generations (Pearce et al. 2011). Increased storm activity has the potential to negatively affect this tradition, not only through the deterrence of belugas, but by reducing the number of huntable days and potentially contributing to declining interest in the hunt. However, we should stress that although the 2016 storm likely contributed to fewer belugas landed, it was not the only cause for the lowest harvest count on record; the hunt has been declining since the 1970s (Harwood et al. 2015) and other factors, including declining interest and the increasingly high cost of hunting equipment and fuel (Harwood et al. 2002), likely contributed.

Acknowledgements

Funding for this project was provided by Fisheries and Oceans Canada, Natural Resources Canada, the W. Garfield Weston Foundation, ArcticNet, the Northern Scientific Training Program, and the Fisheries Joint Management Committee with field support provided by the Polar Continental Shelf Program and the Aurora Research Institute. We would like to acknowledge the partnerships with the Fisheries and Joint Management Committee, the Inuvialuit Game Council and the Hunters and Trapper's Committees of the ISR communities who supported the collection of data. We would also like to thank S. MacPhee and A. Gordon for field support, our camp hosts C. Day and R. Day, as well as Y. Simard and N. Roy for the automated detector. The authors have no conflicts of interest to report.

References

Atkinson, D.E. 2005. Observed storminess patterns and trends in the circum-Arctic coastal regime. Geo-Marine Lett. **25**(2–3): 98–109. doi: 10.1007/s00367-004-0191-0.

Barber, D.G., Saczuk, E., and Richard, P.R. 2001. Examination of beluga-habitat relationships through the use of telemetry and a geographic information system. Arctic, **54**(3): 305–316. doi: 10.14430/arctic790.

Belikov, R.A., and Bel'kovich, V.M. 2006. High-pitched tonal signals of beluga whales (*Delphinapterus leucas*) in a summer assemblage off Solovetskii Island in the White Sea. Acoust. Phys. **52**(2): 125–131. doi: 10.1134/S1063771006020023.

Berkes, F., and Jolly, D. 2001. Adapting to climate change: social-ecological resilience in a Canadian western Arctic community. Conserv. Ecol. **5**(2): 18. doi: 10.5751/ES-00342-050218.

Carmack, E.C., and Macdonald, R.W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: a setting for marine life. Arctic, **55**(1): 29–45. doi: 10.1126/science.100.2596.291.

Caron, L.M.J., and Smith, T.G. 1990. Philopatry and site tenacity of belugas, *Delphinapterus leucas*, hunted by the Inuit at the Nastapoka Estuary, eastern Hudson Bay. *In* Advances in research on the beluga whale, *Delphinapterus leucas*. *Edited by* T.G. Smith, D.J. St. Aubin, and J.R. Geraci. Canadian Bulletin of Fisheries and Aquatic Sciences No. 224. Department of Fisheries and Oceans. Ottawa, Ont., Canada. pp. 69–79.

Castellote, M., Leeney, R.H., O'Corry-Crowe, G., Lauhakangas, R., Kovacs, K.M., Lucey, W., et al. 2013. Monitoring white whales (*Delphinapterus leucas*) with echolocation loggers. Polar Biol. **36**: 493–509. doi: 10.1007/s00300-012-1276-2.

Collings, P., Marten, M.G., Pearce, T., and Young, A.G. 2016. Country food sharing networks, household structure, and implications for understanding food insecurity in Arctic Canada. Ecol. Food Nutr. **55**(1): 30–49. doi: 10.1080/03670244.2015.1072812. PMID: 26595315.

Condon, R.G., Collings, P., and Wenzel, G. 1995. The best part of life: subsistence hunting, ethnicity, and economic adaptation among young adult Inuit males. Arctic, **48**(1): 31–46. doi: 10.14430/arctic1222.

Dittmann, S., Dawson, S., Rayment, W., Webster, T., and Slooten, E. 2016. Hector's dolphin movement patterns in response to height and direction of ocean swell. New Zeal. J. Mar. Freshw. Res. **50**(2): 228–239. doi: 10.1080/00288330.2015.1119165.

Elwin, S.H., and Best, P.B. 2004. Environmental factors influencing the distribution of southern right whales (*Eubalaena australis*) on the South Coast of South Africa II: within bay distribution. Mar. Mamm. Sci. **20**(3): 583–601. doi: 10.1111/j.1748-7692.2004.tb01181.x.

Ezer, T., Hobbs, R., and Oey, L. 2008. On the movement of beluga whales in Cook Inlet Alaska: simulations of tidal and environmental impacts using a hydrodynamic inundation model. Oceanography, **21**(4): 186–195. doi: 10.5670/oceanog.2008.17.

Fisheries Joint Management Committee. 2013. Beaufort Sea beluga management plan. 4th amended printing. Fisheries Joint Management Committee, Inuvik, N.W.T., Canada.

Ford, J.K.B., Koot, B., Vagle, S., Hall-Patch, N., and Kamitakahara, G. 2010. Passive acoustic monitoring of large whales in offshore waters of British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences No. 2898. Department of Fisheries and Oceans, Nanaimo, B.C., Canada. v + 30 pp. Available from http://www.dfo-mpo.gc.ca/Library/342320.pdf.

Fraker, M.A., Gordon, C.D., McDonald, J.W., Ford, J.K.B., and Cambers, G. 1979. White whale (*Delphinapterus leucas*) distribution and abundance and the relationship to physical and chemical characteristics of the Mackenzie Estuary. Fisheries & Marine Service Technical Report No. 863. F.F. Slaney & Company Ltd., Vancouver, B.C., Canada.

Gordon, A., Whalen, D., MacPhee, S., Pascal, J., Owen, C., Amos, E., and Loseto, L. 2016. Monitoring the impacts of wind on water levels at Kugmallit Bay, NWT. *In* ArcticNet Annual Science Meeting, 2016, Winnipeg, Man., Canada. 5–9 December 2016. pp. 87–88.
Harder, M.T., and Wenzel, G.W. 2012. Inuit subsistence, social economy and food security in Clyde River, Nunavut. Arctic, **65**(3): 305–318. doi: 10.14430/arctic4218.
Harwood, L.A., Innes, S., Norton, P., and Kingsley, M.C.S. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea, and west Amundsen Gulf during late July 1992. Can. J. Fish. Aquat. Sci. **53**: 2262–2273. doi: 10.1139/f96-180.
Harwood, L.A., Norton, P., Day, B., and Hall, P.A. 2002. The harvest of beluga whales in Canada's western Arctic: hunter-based monitoring of the size and composition of the catch. Arctic, **55**(1): 10–20. doi: 10.1016/0044-8486(86)90370-4.
Harwood, L.A., Kingsley, M.C.S., and Pokiak, F. 2015. Monitoring beluga harvests in the Mackenzie Delta and near Paulatuk, NT, Canada: harvest efficiency and trend, size and sex of landed whales, and reproduction, 1970–2009. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 3059. Department of Fisheries and Oceans, Winnipeg, Man., Canada. vi + 32 pp. doi: 10.13140/RG.2.1.2133.4644.
Hauser, D.D.W., Laidre, K.L., Suydam, R.S., and Richard, P.R. 2014. Population-specific home ranges and migration timing of Pacific Arctic beluga whales (*Delphinapterus leucas*). Polar Biol. **37**(8): 1171–1183. doi: 10.1007/s00300-014-1510-1.
Hoover, C., Ostertag, S., Hornby, C., Parker, C., Hansen-Craik, K., Loseto, L., and Pearce, T. 2016. The continued importance of hunting for future Inuit food security. Solutions, **7**(4): 40–51.
Kendall, M.G. 1955. Rank correlation methods. 2nd ed. Hafner Publishing Co., New York, N.Y., USA.
Kokelj, S.V., Lantz, T.C., Solomon, S., Pisaric, M.F.J., Keith, D., Morse, P., et al. 2012. Using multiple sources of knowledge to investigate northern environmental change: regional ecological impacts of a storm surge in the outer Mackenzie Delta, N.W.T. Arctic, **65**(3): 257–272. doi: 10.14430/arctic4214.
Lammers, M.O., Castellote, M., Small, R.J., Atkinson, S., Jenniges, J., Rosinski, A., et al. 2013. Passive acoustic monitoring of Cook Inlet beluga whales (*Delphinapterus leucas*). J. Acoust. Soc. Am. **134**(3): 2497–2504. doi: 10.1121/1.4816575. PMID: 23968047.
Larsen, J.N., Anisimov, O.A., Constable, A., Hallowed, A.B., Maynard, N., Prestrud, P., et al. 2014. Polar regions. *In* Climate Change 2014: impacts, adaptation, vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Edited by* V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, et al. Cambridge University Press, Cambridge, UK and New York, N.Y., USA. pp. 1567–1612.
Loseto, L.L., Hoover, C., Ostertag, S., Whalen, D., Pearce, T., Paulic, J., et al. 2018. Beluga whales (*Delphinapterus leucas*), environmental change and marine protected areas in the Western Canadian Arctic. Estuar. Coast. Shelf Sci. **212**: 128–137. doi: 10.1016/j.ecss.2018.05.026.
Manson, G.K., and Solomon, S.M. 2007. Past and future forcing of Beaufort Sea coastal change. Atmos.-Ocean, **45**(2): 107–122. doi: 10.3137/ao.450204.
Marcoux, M., Ferguson, S., Roy, N., Bedard, J., and Simard, Y. 2017. Seasonal marine mammal occurrence detected from passive acoustic monitoring in Scott Inlet, Nunavut, Canada. Polar Biol. **40**: 1127–1138. doi: 10.1007/s00300-016-2040-9.
Merchant, N., Fristrup, K., Johnson, M., Tyack, P., Witt, M., Blondel, P., and Parks, S. 2015. Measuring acoustic habitats. Methods Ecol. Evol. **6**: 257–265. doi: 10.1111/2041-210X.12330.
Muto, M.M., Helker, V.T., Angliss, R.P., Allen, B.A., Boveng, P.L., Breiwick, J.M., et al. 2016. Alaska marine mammal stock assessments, 2015. NOAA Technical Memorandum NMFS-AFSC-323. National Technical Information Service. Springfield, Va., USA. 300 pp. doi: 10.7289/V5/TM-AFSC-323.
Mymrin, N.I., and Huntington, H.P. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the Northern Bering Sea, Chukotka, Russia. Arctic, **52**(1): 62–70. doi: 10.14430/arctic910.
National Snow and Ice Data Center (NSIDC). 2016. 2016 ties with 2007 for second lowest Arctic sea ice minimum. Available from http://nsidc.org/arcticseaicenews/2016/09/2016-ties-with-2007-for-second-lowest-arctic-sea-ice-minimum/.
Pearce, T., Smit, B., Duerden, F., Ford, J.D., Goose, A., and Katauyak, F. 2010. Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada. Polar Rec. **46**(237): 157–177. doi: 10.1017/S0032247409008602.
Pearce, T., Wright, H., Notaina, R., Kudlak, A., Smit, B., Ford, J., and Furgal, C. 2011. Transmission of environmental knowledge and land skills among Inuit men in Ulukhaktok, Northwest Territories, Canada. Hum. Ecol. **39**(3): 271–288. doi: 10.1007/s10745-011-9403-1.
Pisaric, M.F.J., Thienpont, J.R., Kokelj, S.V., Nesbitt, H., Lantz, T.C., Solomon, S., and Smol, J.P. 2011. Impacts of a recent storm surge on an Arctic delta ecosystem examined in the context of the last millennium. Proc. Natl. Acad. Sci. USA, **108**(22): 8960–8965. doi: 10.1073/pnas.1018527108. PMID: 21576496.
R Core Team. 2016. R: a language and environment for statistical computing. Version 3.3.0. R 600 Foundation for Statistical Computing, Vienna, Austria.
Richard, P.R., Martin, A.R., and Orr, J.R. 2001. Summer and autumn movements of belugas of the eastern Beaufort Sea stock. Arctic, **54**(3): 223–236. doi: 10.14430/arctic783.
Risch, D., Castellote, M., Clark, C.W., Davis, G.E., Dugan, P.J., Hodge, L.E., et al. 2014. Seasonal migrations of North Atlantic minke whales: novel insights from large-scale passive acoustic monitoring networks. Mov. Ecol. **2**(1): 24–41. doi: 10.1186/s40462-014-0024-3. PMID: 25709833.

Roy, N., Simard, Y., and Gervaise, C. 2010. 3D tracking of foraging belugas from their clicks: experiment from a coastal hydrophone array. Appl. Acoust. **71**: 1050–1056. doi: 10.1016/j.apacoust.2010.05.008.

Scharffenberg, K., Whalen, D., Marcoux, M., Iacozza, J., Davoren, G., and Loseto, L. 2019. Environmental drivers of beluga whale *Delphinapterus leucas* habitat use in the Mackenzie Estuary, Northwest Territories, Canada. Mar. Ecol. Prog. Ser. **626**: 209–226. doi: 10.3354/meps13011.

Sepp, M., and Jaagus, J. 2011. Changes in the activity and tracks of Arctic cyclones. Clim. Change, **105**: 577–595. doi: 10.1007/s10584-010-9893-7.

Sergeant, D.E. 1973. Biology of white whales (*Delphinapterus leucas*) in Western Hudson Bay. J. Fish. Res. Board Can. **30**: 1065–1090. doi: 10.1139/f73-178.

Simard, Y., Loseto, L., Gautier, S., and Roy, N. 2014. Monitoring beluga habitat use and underwater noise levels in the Mackenzie Estuary: application of passive acoustics in summers 2011 and 2012. Canadian Technical Report of Fisheries and Aquatic Sciences No. 3068. Fisheries and Oceans Canada, Mont-Joli, Que., Canada. vi + 49 pp.

Sjare, B.L., and Smith, T.G. 1986. The vocal repertoire of white whales, *Delphinapterus leucas*, summering in Cunningham Inlet, Northwest Territories. Can. J. Zool. **64**: 407–415. doi: 10.1139/z86-063.

Smith, T.G., St. Aubin, D.J., and Hammill, M. 1992. Rubbing behaviour of belugas, *Delphinapterus leucas*, in a high Arctic estuary. Can. J. Zool. **70**: 2405–2409. doi: 10.1139/z92-322.

Solomon, S.M., Forbes, D.L., and Kierstead, B. 1994. Coastal impacts of climate change: Beaufort Sea erosion study. Natural Resources Canada, Geological Survey of Canada, Ottawa, Ont., Canada. Available from http://publications.gc.ca/pub?id=9.820125&sl=0.

St. Aubin, D.J., Smith, T.G., and Geraci, J.R. 1990. Seasonal epidermal moult in beluga whales, *Delphinapterus leucas*. Can. J. Zool. **68**: 359–367. doi: 10.1139/z90-051.

Stroeve, J.C., Serreze, M.C., Holland, M.M., Kay, J.E., Malanik, J., and Barrett, A.P. 2012. The Arctic's rapidly shrinking sea ice cover: a research synthesis. Clim. Change, **110**: 1005–1027. doi: 10.1007/s10584-011-0101-1.

Usher, P.J. 2002. Inuvialuit use of the Beaufort Sea and its resources, 1960–2000. Arctic, **55**(1): 18–28. doi: 10.14430/arctic732.

Vergara, V., Michaud, R., and Barrett-Lennard, L.G. 2010. What can captive whales tell us about their wild counterparts? Identification, usage, and ontogeny of contact calls in belugas (*Delphinapterus leucas*). Int. J. Comp. Psychol. **23**: 278–309.

Vermaire, J.C., Pisaric, M.F.J., Thienpont, J.R., Courtney Mustaphi, C.J., Kokelj, S.V., and Smol, J.P. 2013. Arctic climate warming and sea ice declines lead to increased storm surge activity. Geophys. Res. Lett. **40**(7): 1386–1390. doi: 10.1002/grl.50191.

Wang, Z., Nachtigall, P.E., Akamatsu, T., Wang, K.-X., Wu, Y.-P., Liu, J.-C., et al. 2015. Passive acoustic monitoring the diel, lunar, seasonal and tidal patterns in the biosonar activity of the Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Pearl River. PLoS ONE, **10**(11): e0141807. doi: 10.1371/journal.pone.0141807.

Watts, P.D., Draper, B.A., and Henrico, J. 1991. Preferential use of warm water habitat by adult beluga whales. J. Therm. Biol. **16**(1): 57–60. doi: 10.1016/0306-4565(91)90053-5.

Waugh, D., Pearce, T., Ostertag, S.K., Pokiak, V., Collings, P., and Loseto, L.L. 2018. Inuvialuit traditional ecological knowledge of beluga whale (*Delphinapterus leucas*) under changing climatic conditions in Tuktoyaktuk, NT. Arct. Sci. **4**: 242–258. doi: 10.1139/as-2017-0034.

Yang, D., Shi, X., and Marsh, P. 2015. Variability and extreme of Mackenzie River daily discharge during 1973–2011. Quat. Int. **380**–**381**: 159–168. doi: 10.1016/j.quaint.2014.09.023. PMID: 28066132.