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Availability Bias Adjustment for Calculating Aerial Survey Abundance Estimates for Belugas (*Delphinapterus leucas*) in the Eastern Beaufort Sea

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Abundance estimates of whales from aerial surveys need to be adjusted for animals that are underwater during the survey and cannot be counted by survey observers. In 2019, an aerial survey was conducted to estimate the abundance of the Eastern Beaufort Sea beluga (*Delphinapterus leucas*) population. To complement the survey, belugas were equipped with satellite transmitters to record their time at depth and determine adjustment factors for the survey estimate. Two types of adjustments factors, instantaneous and non-instantaneous, were computed depending on the type of survey (photographic vs. with visual observers) and the area surveyed (inshore vs. offshore). The instantaneous adjustment factor was calculated for use in the photographic strata of the survey of the inshore areas based on the proportion of time belugas spent within 1 m of the surface. The non-instantaneous adjustment factor was computed for the observer-based strata of the survey in the offshore areas. The non-instantaneous adjustment factor was based on the proportion of time belugas spent within 5 m of the surface and was computed using the Laake method. The resulting adjustment factors were 1.56 (S.D. = 0.592) for the instantaneous and 1.94 (S.D. = 0.521) for the non-instantaneous.

INTRODUCTION

The abundance of Arctic marine mammals is often estimated using aerial surveys with visual observers and/or photographic analysts (e.g., Marcoux et al. 2016, Matthews et al. 2017, Watt et al. 2020). One problem with these surveys is that a proportion of the animals present in a given area are too deep underwater to be detected by survey observers or photo analysts (Marsh and Sinclair 1989). Therefore, aerial survey estimates usually only count animals at or near the surface, and the estimates need to be adjusted for animals that are not available to be seen by observers when too deep (availability correction factor, C_a). One method to derive an availability correction factor is to use dive information from the target species to calculate the proportion of time animals spend at or near the surface of the water.

From July 21 to August 2 2019, Fisheries and Oceans Canada (DFO) conducted an aerial survey to estimate the size of the Eastern Beaufort Sea (EBS) beluga population. The survey included transect lines in the inshore and offshore areas of the EBS beluga summer home range (Hauser et al. 2014, Figure 1).

A beluga tagging program co-developed in partnership between DFO, the Fisheries Joint Management Committee, and Inuvialuit Game Council (MacPhee et al 2025) was conducted in the summers of 2018 and 2019 to gather information on diving behaviour of EBS beluga, in order to produce an availability adjustment factor for aerial surveys of this population. Adjustment factors derived from the 2018-2019 tag data will be valuable to adjust population abundance estimates obtained from the DFO survey as well as a NOAA survey conducted in the EBS beluga summer home range in 2019 (August 8 to 27, Clarke et al. 2020). As marine mammals change diving patterns depending on their environment, we also explored the differences in diving behaviour between the inshore and offshore areas of the survey zone, and derived specific correction factors for the different areas. Lastly, as turbidity affects the depth at which observers can detect belugas, we calculated correction factors for different depth thresholds. This study represents the first data-driven, area-specific, availability correction factor for the EBS beluga population.

METHODS

TAG DEPLOYMENT

Beluga whales were tagged from a base camp at Hendrickson Island (69º 28′ 41″ N, 133º 37′ 17″ W), near the community of Tuktoyaktuk, within Kugmallit Bay in the Mackenzie River estuary, Inuvialuit Settlement Region, Northwest Territories, Canada during summer 2018 and 2019, using both live-capture and remote-deployment methods. Live-capture tagging involved herding a whale towards a shallow area, encircling the whale with a net for capture and restraint, and guiding the whale to shore for tag placement (Orr et al. 2001).

For tag deployments on live-captured whales, two different tag and attachment configurations were used depending on tag availability. SPLASH10-F-238 tags (Wildlife Computers Ltd., Redmond, WA, USA) were back-mounted by attaching stainless steel cables and lock washers to either side of three Delrin® rods which were inserted trans-dermally, just anterior of the dorsal ridge (Figure 2). In one deployment, a Wildlife Computers SPLASH10-F-321 towed transmitter was tethered to a single Delrin® rod also placed anterior to the dorsal ridge using the same locking washer system, but using a 50 cm long stainless steel tether in a y-shaped bridle (Figure 3).

For the remote deployments, SPLASH10-F-321 tags were attached by Inuvialuit hunters who pursued the target animal to within striking distance of a 1.8 m (6 ft) tag pole made of either wood or telescoping aluminum. When the whale surfaced, a jabbing motion was used to implant a single subdermal toggle-style anchor into the blubber just posterior to the dorsal ridge above the animal's midline such that it was towed and surfaced behind the animal (Figure 4). Anchor design was largely based on the plastic Wilton anchor (Wildlife Computers Inc., WA, USA) with guidance on modifications provided by Inuvialuit beluga hunters inspired by traditional toggle harpoons, resulting in the "Inuvik Dart", a prototype by Wildlife Computers. The Inuvik Dart was tethered to the tag using a 50 cm long, 90.7 kg (200-lb) test monofilament fishing line with aluminum crimps sealed in marine shrink wrap at the anchor and tag nose (Figure 5).

All tags measured depth data at the highest resolution possible which was one depth recording every 75 s (resolution = 0.5 m, accuracy = +/- 1% of depth reading). Depth data were transmitted via satellite in hourly messages. Fastloc GPS locations were collected every 7–30 min, and Argos locations were estimated during each transmission.

DATA MANAGEMENT

Belugas change their dive behaviour according to factors including energy requirement, season, location, habitat, and time of day (Storrie et al. 2022a,b). Therefore, when calculating correction factors for aerial surveys, it is ideal to use data that is specific to the area and timing of the survey to be adjusted. Here, we divided the data into two survey periods. The first period, "July", included data from July 15 to August 2, which corresponds to the planned dates for the DFO 2019 aerial survey (although the survey started on July 21; Marcoux et al. 2025). The second period, "August", included data from August 3 to 27, which matches the period during which the NOAA surveyed the Eastern Beaufort Sea and Amundsen Gulf as part of their 2019 Aerial Surveys of Arctic Marine Mammals (Clarke et al. 2020). Data was converted from Universal Time Coordinated to local time (Mountain Time) and we only included dive data from 8 am to 8 pm to match the time of the day at which the survey took place. We removed the first 24 hours of data after deployment to reduce the potential influence of abnormal behaviour following the tagging of the animal (Shuert et al. 2021).

LOCATION DATA FILTERING

Location data were filtered by first removing Argos locations with no associated ellipse error, and Fastloc GPS locations with residual values >35 (Dujon et al. 2014). The Argos and GPS locations were then combined and the sdafilter function from the 'argosfilter' package (Freitas et al. 2008) in R v3.6.0 (R Development Core Team 2019) was used to filter the locations which required swimming speeds >3 m/s. Locations requiring greater swimming speeds were retained if they occurred <5 km from the previous location, to enable retention of locations arising from faster swimming over short distances (Freitas et al. 2008). Tracks of belugas were overlayed on top of the shapefiles of the inshore and offshore areas of the survey (Figures 6 and 7) to determine the portions of the tracks, and associated dives, that took place in the two different areas.

ZERO-CROSSING CORRECTION

The pressure sensors on time-depth recorders often drift over time due to temperature changes and other factors resulting in errors in depth readings. This problem becomes exacerbated when we compute the availability bias correction factor because we need precise and accurate depth measurements for the top 5 meters of water. Therefore, we implemented the zero offset correction developed by Luque and Fried (2011) to correct the depth data. This method involves using a series of quantile filters to smooth the data and to detect the surface of the water. Data were first smoothed using a 0.5 quantile (median) moving window of 225 sec (3 samples) (Figure 8b). This step removed some of the noise in the data. A second filter with a moving window size of 30 minutes (24 samples) and a 0.05 quantile filter was applied to the smoothed data (Figure 8c). This step was done to extract the surface signal and assumes that belugas come up to the surface at least every 30 minutes. For the last step, the surface signal (0.05 quantile filtered data) was subtracted from the smoothed data (Figure 8d). The method relies on the 'runquantile' function from the package 'caTools' (Tuszynski 2021) in R (R Development Core Team 2019).

DIVE IDENTIFICATION

We used the package diveMove (Luque 2007) to identify separate dives and extract the time that belugas spent near the surface. This package identifies dive and surface intervals according to a depth threshold criterion. Dives are defined as departures from the surface below the threshold to maximum depth and the subsequent return to the surface threshold. Surface intervals are defined as intervals between subsequent dives. The timing of the beginning and the end of a dive are calculated as the middle time point between the last data point above the dive threshold and the first point below the dive threshold (for the beginning of the dive) and the last data point below the threshold and the first data point above the dive threshold (for the end of the dive; Figure 8e).

Based on an experiment with modeled live-sized belugas, it was estimated that adult belugas are visible from a plane at depths up to 5 m in clear water (Richard et al. 1994). However, in murky waters, such as those in estuaries, previous studies have assumed that belugas cannot be seen at depths greater than 2 m (Richard 2013). After visual inspection of the photos and based on comments from visual observers from DFO 2019 EBS beluga survey, it was concluded that in the estuaries of the Beaufort Sea study area, the water was sufficiently murky for belugas to not be seen unless within 1 m from the surface. Therefore, we used three different dive thresholds (1 m, 2 m, and 5 m) to estimate the time that belugas spent near the surface and could be visible by survey observers depending on water clarities.

After manual inspection of dive profiles, we observed issues related to missing transmission of depth data. There was a maximum volume of data that tags were able to transmit per day depending on satellite and tag location. As a result, there were bouts of 60 minutes continuous data missing in our dataset, over which diveMove extrapolated the duration of the previous dive or surface period to include the missing 60 minutes. To alleviate this issue, we removed dive and surface times longer than 60 minutes to eliminate potential erroneous dive phases that might be caused by these gaps in the data.

CALCULATION OF CORRECTION FACTORS FOR AVAILABILITY BIAS

For each beluga, we first calculated the average time they spent near the surface ($E(s)$) and in dives $E(d)$ for the three depth categories (1 m, 2 m, and 5 m). The ratio of time belugas spent near the surface for each category was calculated by dividing the time spent near the surface to the total time of the dive cycle (surface time plus dive time). We calculated the average ratio spent at the surface for the time period of July (July 15 to Aug 2) and August (Aug 3 to 27), and ratios specific for the inshore and offshore area of the survey (Figure 1).

For each of the combination of dive depth, month, and survey areas, we calculated availability correction factors for instantaneous sightings (e.g., for photographic surveys; C_{aI}) based on the proportion of time that beluga are available at the surface (Pa_I) using the following formula:

$$Pa_I = \frac{E(s)}{E(s) + E(d)}$$

And

$$C_{aI} = 1/Pa_I$$

However, when sightings are not instantaneous, i.e., when visual observers have time to detect animals, the instantaneous correction factor results in a positive bias. Here, we calculated the availability of whales at a perpendicular distance, $Pa(x)$, based on the equation developed by McLaren (1961) and improved by Laake et al. (1997) that takes into account the surface behaviour of whales and amount of time an object at distance x at the surface of the water remains in the field of view of the observer ($w(x)$).

$$Pa(x) = \frac{E(s)}{E(s)+E(d)} + \frac{E(d)\left[1-e^{-w(x)/E(d)}\right]}{E(s)+E(d)}$$

$w(x)$ was calculate based on the aircraft speed, and the search angle of the observers based on the formula from Forcada et al. (2004) and Gómez de Segura et al. (2006):

$$\widehat{w}(x) = \frac{x}{v}\left[\cot(\emptyset_1) + \cot(\emptyset_2)\right]$$

For the DFO survey, the backward ($\emptyset_1$) and forward ($\emptyset_2$) viewing angles used were 90° and 20°, respectively (corresponding to a viewing angle of 20° to 90°, with 0° being dead ahead and 90° perpendicular to the transect line). The speed of the plane (v) was 100 knots or 51.39 m/s (Marcoux et al. 2025) and x were the perpendicular distances of the detections of the DFO survey. The resulting average time-in-view was 13.87 sec.

The resulting correction factor, C_{aLaake}, was calculated as:

$$C_{aLaake} = 1/Pa(x)$$

RESULTS

A total of 13 beluga were equipped with satellite tags that transmitted depth time series data for at least 13 days, and were used for calculating the correction factor in both the inshore and offshore regions. Ten of these belugas were live-captured (2018 n=6, 2019 n=4) and three were tagged using the remote method (2018 n=0, 2019 n=3, Table 1). All belugas that were live-captured were large males ranging from 4.06 m to 4.70 m in length (Table 1). It was not possible to determine the sex and length of the belugas tagged remotely with certainty but they were most likely adult males based on the knowledge of the local Inuvialuit hunters that tagged the whales.

The average time belugas spent within 1 m, 2 m, and 5 m from the surface and diving below these thresholds for all dives regardless of dive location are given in Table 2. In general, belugas spent more time at the surface during the July survey period than the August survey period. When looking specifically at dives that were performed within the survey areas (Figures 6 and 7), belugas spent more time at the surface in the inshore areas than the offshore areas when comparing dives with the same depth threshold (Table 3; Figure 9). The non-instantaneous correction factors calculated using the Laake (1997) equation were lower than the instantaneous correction factors (Table 3) resulting in a smaller corrected population estimate.

DISCUSSION

The correction factors for availability bias (C_a) calculated in this study are similar to correction factors computed for belugas from other populations. Kingsley and Gauthier (2002) studied the diving behaviour of groups of belugas from a hovering helicopter in the St Lawrence estuary to calculate a correction factor of 2.22. Marcoux et al. (2016) calculated a similar factor of 2.06 for the 0–2 m surface threshold for Cumberland Sound belugas, and 2.54 for the 0–5 m based on data from three belugas equipped with satellite-linked transmitters. For the Western Hudson Bay beluga, Matthews et al. (2017) calculated a correction factor of 1.24 (S.E.= 0.05) for offshore areas (based on the time spent within the 5 m from the surface) and 1.71 (S.E.= 0.11; based on time spent within 2 m of the surface) for the inshore area based on data from eight tagged belugas. Lastly, Heide-Jørgensen et al. (1998) estimated that belugas spent 39.1% of their time within 5 m of the surface (equivalent to a correction factor of 2.56) based on data from satellite-linked transmitters deployed on six beluga near Devon Island, Nunavut.

The tags in this study were set to record depth every 75 sec. We did not estimate how well our methods detected surface or dive bouts shorter than 75 sec, and how many bouts would have been missed. In addition, it is not clear how this bias influenced our correction factors. While other studies have estimated dive duration for belugas (Heide-Jørgensen et al. 1998, Lemieux Lefebvre et al. 2018), the definition of a dive from the other studies differed from our study, and time that belugas spent at the surface was not reported elsewhere. As a consequence, it is hard to directly compare the duration of the surface and dive duration times from this study to other studies.

The concurrent collection of survey and tagging data allowed us to decrease the spatial and temporal uncertainty in our understanding of beluga diving behaviour. However, our study has some limitations. The data in this study come from large males only (assuming that the three remotely tagged belugas were males, which is likely, based on the knowledge of the hunters that tagged the whales) that were tagged in only one location. Beluga from different sex and age classes are likely to exhibit different diving behaviours. In a study of belugas from the High Arctic and the Cumberland Sound beluga populations, female belugas with a dependent calf spent more time at the surface than females without calves (Heide-Jørgensen et al. 2001). Larger belugas also spend less time at the surface than smaller belugas (Heide-Jørgensen et al. 2001). Therefore, our availability bias correction is likely negatively biased and might result in an overestimate of the population abundance. While we consider our availability correction factor to be appropriate for the 2019 EBS beluga survey at the time it was conducted, we caution that it is based on a limited sample of belugas tagged in one location assumed to represent the behaviour of the entire population.

The availability adjustment factor used in this study was based on individual beluga diving behaviour and does not take into account that most belugas in the aerial survey were encountered in groups. There is uncertainty on synchronicity of the diving behaviour of belugas within a group. However, it is likely that belugas do not dive in perfect synchrony and that the availability adjustment factor we estimate is an underestimate resulting in a positively biased abundance estimate. This is consistent with studies on gregarious coastal dolphins where the availability estimate increased with the size of the group (Sucunza et al. 2018, Brown et al. 2022).

For the 2019 DFO aerial survey of the EBS beluga population, we recommend using two different correction factors for the inshore and offshore areas based on July data. For the inshore areas, which were covered by a photographic survey, we recommend the instantaneous correction factor based on the 1 m dive threshold (C_{aI} = 1.56, S.D= 0.592). For the offshore areas, which were are covered with visual observers, we recommend the non-instantaneous correction factor based on the Laake method and the 5 m dive threshold (C_{aLaake}) = 1.94, S.D. = 0.521).

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TABLES

Table 1. Tag deployment information for the belugas included in the present study. All tagged individuals were male. Capture method indicates whether the tag was deployed using the live-capture (LC) or remote-deployment (RD) method. Beluga length was measured for live-captured animals only. Start date represents the date the tag switched on and started collecting data, on occasions this was up to three days after tag attachment due to low salinity estuarine waters failing to trigger the conductivity switch.

Year	Capture method	Tag PTT	Beluga length (m)	Tag type	Start date	End date	Tag duration (unique days)
2018	LC	174965	4.20	SPLASH10-F-238	03/07/18	02/01/19	184
2018	LC	174967	4.70	SPLASH10-F-238	06/07/18	19/06/19	349
2018	LC	174962	4.06	SPLASH10-F-238	08/07/18	15/12/18	161
2018	LC	174963	4.44	SPLASH10-F-238	08/07/18	07/06/19	335
2018	LC	174966	4.40	SPLASH10-F-238	08/07/18	29/06/19	357
2018	LC	174969	4.25	SPLASH10-F-238	12/07/18	19/12/18	161
2019	LC	174972	4.20	SPLASH10-F-238	29/06/19	15/11/19	140
2019	LC	174964	4.25	SPLASH10-F-238	30/06/19	03/08/19	35
2019	LC	174976	4.06	SPLASH10-F-238	03/07/19	21/08/19	50
2019	LC	179901	4.20	SPLASH10-F-321	10/07/19	16/09/19	69
2019	RD	179902	NA	SPLASH10-F-321	13/07/19	11/08/19	30
2019	RD	179904	NA	SPLASH10-F-321	13/07/19	28/07/19	16
2019	RD	179899	NA	SPLASH10-F-321	13/07/19	25/07/19	13

Table 2. Summary data for the dives of belugas according to the 1 m, 2m and 5 m threshold for the definition of a dive. The number of belugas indicate the number of individuals for which data were available for the analysis, the number of dives is the average number of dives exhibited per beluga, the surface time is the average duration of the portion of the dives that were above the dive threshold (in minutes), the dive time is the average duration of the portion of the dives that were below the dive thresholds (in minutes), the proportion at surface was the average surface time divided by the sum of the surface and dive time and its associated standard deviation (S.D.), as well as the coefficient of variation (C.V.) of the surface ratio (calculated as the S.D. divided by the ratio).

Depth (m)	# beluga	# dives	Surface time (min)	Dive time (min)	Proportion at surface ± S.D	C.V.
July						
1	13	1173	4.29	5.96	0.424 ± 0.0880	0.208
2	13	1113	4.53	6.15	0.429 ± 0.0798	0.186
5	13	995	5.10	6.54	0.440 ± 0.0526	0.120
August						
1	10	912	4.52	7.88	0.376 ± 0.0993	0.264
2	10	889	4.89	7.90	0.388 ± 0.1170	0.302
5	10	850	5.39	8.09	0.398 ± 0.1167	0.293

Table 3. Summary data for the dives of belugas according to the 1 m, 2 m and 5 m thresholds for the definition of a dive for the survey period of July (July 15 to Aug 02) and August (Aug 03 to 27 Aug), and for the inshore and offshore areas of the EBS beluga survey (Figure 1). The number of belugas indicates the number of individuals for which we had data for the analysis, the number of dives is the average number of dives belugas exhibited, the ratio is the average surface time divided by the sum of the surface and dive time, the correction factor is over the surface ratio, and the standard deviation (s.d.) of the correction factor. Bolded correction factors recommended for DFO 2019 survey.

	1 m	**2 m**	**5 m**
July Inshore			
# beluga	6	6	6
# dive	71	17	NA
Surface time (min)	6.74	11.25*	NA
Dive time (min)	1.97	1.67*	NA
Proportion at surface ± s.d.	0.703 ± 0.202	0.894 ± 0.153*	1 ± 0*
Instantaneous correction ± s.d.	**1.56 ± 0.592**	1.15 ± 0.234*	1 ± 0*
July Offshore			
# beluga	8	8	8
# dive	1933	1768	1466
Surface time (min)	4.01	4.59	5.38
Dive time (min)	5.47	5.63	6.14
Proportion at surface ± s.d.	0.434 ± 0.0903	0.462 ± 0.0923	0.475 ± 0.105
Instantaneous correction ± s.d.	2.42 ± 0.619	2.28 ± 0.575	2.21 ± 0.555
Availability at surface (Laake) ± s.d.	0.480 ± 0.102	0.509 ± 0.106	0.516 ± 0.115
Non-instantaneous correction (Laake) ± s.d	2.08 ± 0.583	1.97 ± 0.546	**1.94 ± 0.521**
August Offshore			
# beluga	4	4	4
# dive	982	860	729
Surface time (min)	4.52	5.40	6.37
Dive time (min)	7.64	7.88	8.40
Proportion at surface ± s.d.	0.403 ± 0.176	0.424 ± 0.208	0.430 ± 0.212
Instantaneous correction ± s.d.	2.81 ± 1.05	2.75 ± 1.11	2.72 ± 1.11
Availability at surface (Laake) ± s.d.	0.442 ± 0.203	0.460 ± 0.232	0.462 ± 0.229
Non-instantaneous correction (Laake) ± s.d	2.26 ± 0.984	2.17 ± 1.03	2.16 ± 1.02

**Of the 6 tagged belugas that occupied the Inshore strata in July, the maximum dive depths recorded by 3 individuals was more than 2 m, and 3 individuals only occupied depths shallower than 2 m. As none of the belugas dove below the 5 m threshold, the surface ratio and instantaneous correction factor were 1 and the associated standard deviations were 0.*

FIGURES

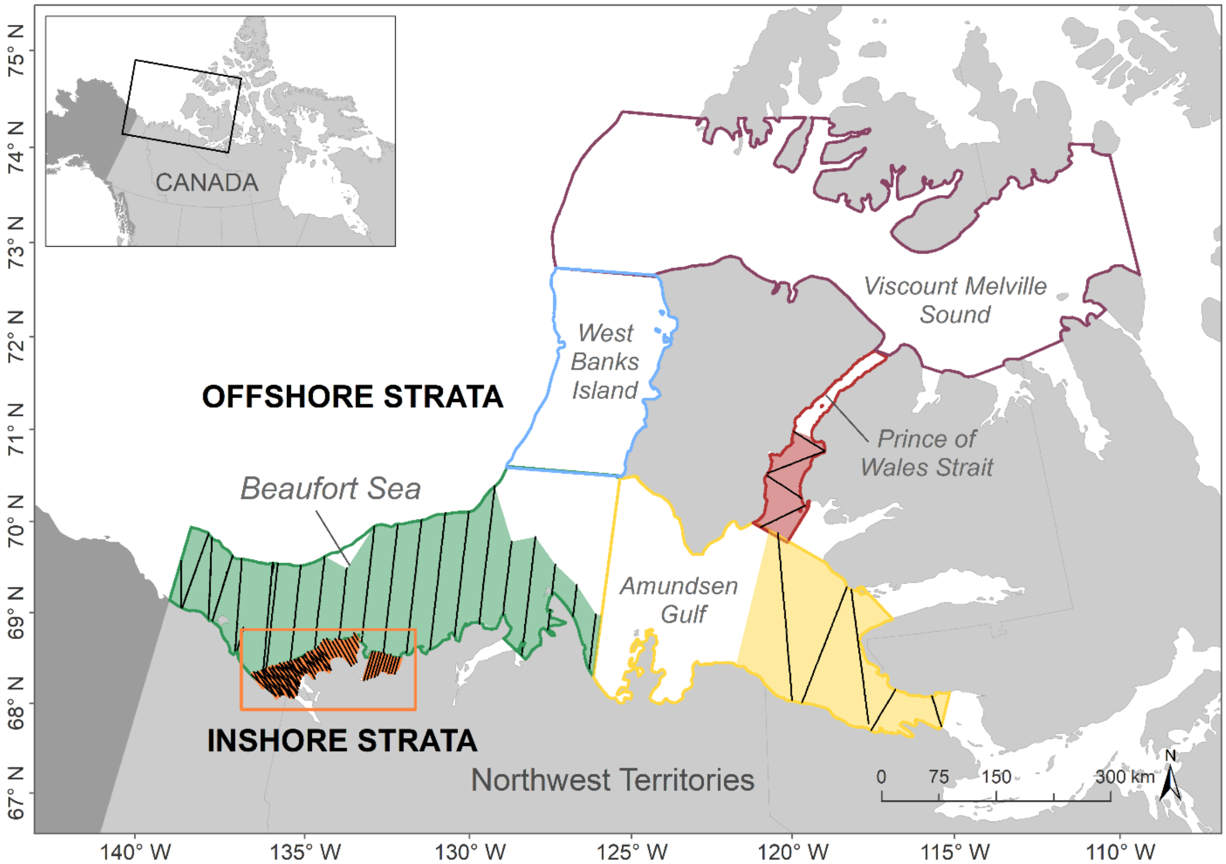

Figure 1. Map of the planned (colored contour) and realized (shaded polygons) strata and transects flown (black lines) from the 2019 aerial survey of the Eastern Beaufort Sea beluga population. Survey was divided between inshore (in the orange box) and offshore strata.

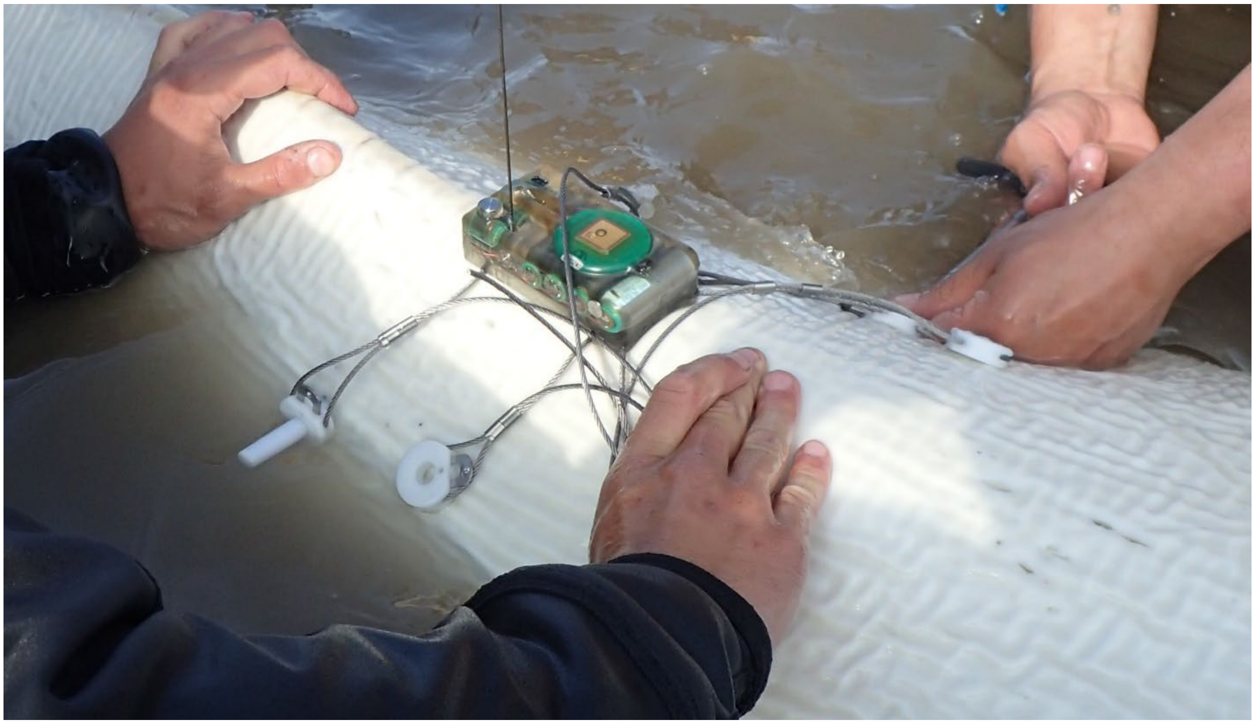

Figure 2. A Wildlife Computers SPLASH10-F-238 tag being mounted onto the dorsal ridge of a beluga whale at Hendrickson Island, Northwest Territories, in July 2019. Photo credit: Dennis Arey.

Figure 3. A Wildlife Computers SPLASH10-F-321 tag tethered to a single transdermal implant rod on the dorsal ridge of a beluga whale at Hendrickson Island, Northwest Territories, in July 2019. Photo credit: Lisa Loseto.

Figure 4. Remote deployment of a Wildlife Computers SPLASH10-F-321 including pursuit (top, aerial view) and tag attachment (middle, harpooner point-of-view) by Inuvialuit beluga whalers Dennis Arey and Dwayne Benoit. Also shown is the tag surfacing (red arrow, bottom) behind the tagged animal. Photo credits: Greg Elias (top, bottom) and Dwayne Benoit (middle).

Figure 5. The Wildlife Computers Inuvik Dart toggle anchor prototype mounted on a telescoping aluminum tag pole and tethered to a Wildlife Computers SPLASH10-F-321 transmitter. Photo Credit: Lisa Loseto.

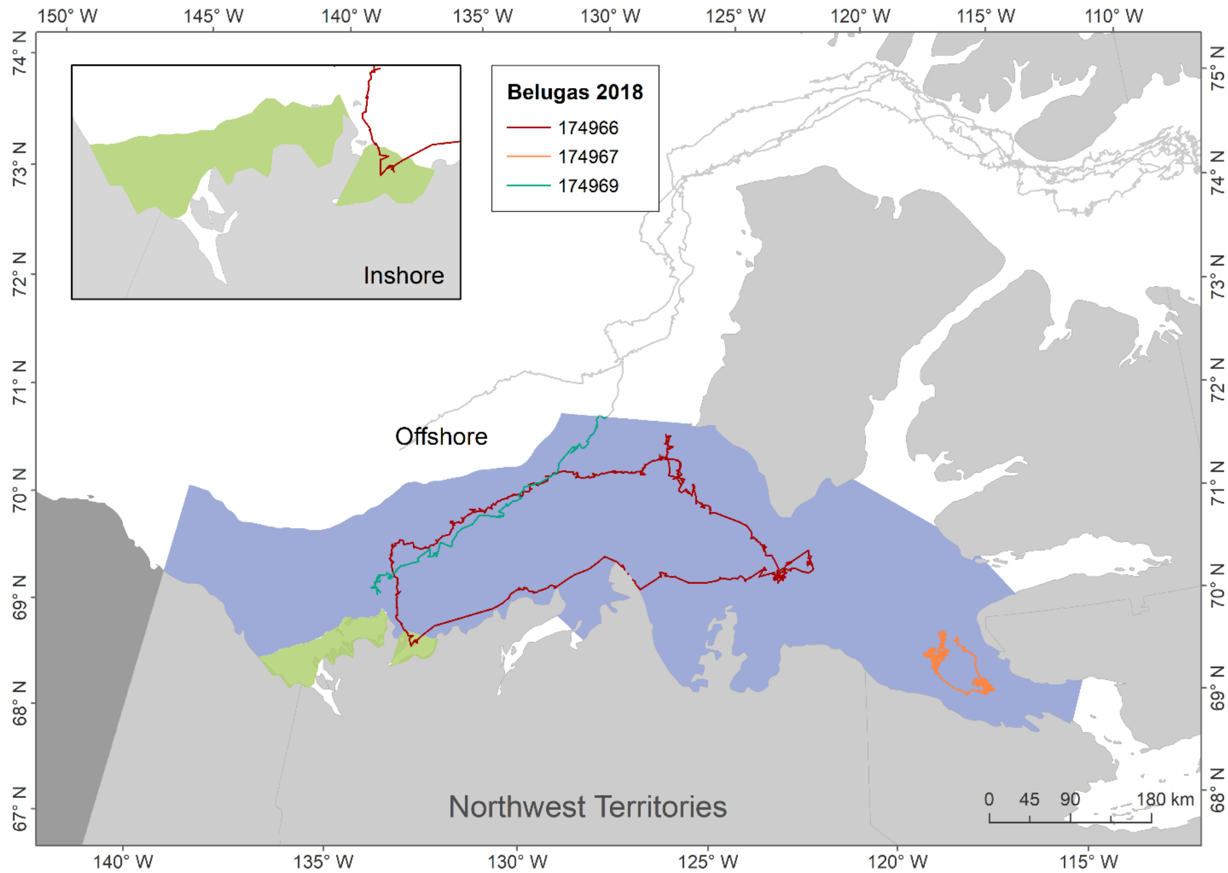

Figure 6. Location of beluga tagged in 2018 during the July survey period (July 15 to Aug 02) overlayed on top of the strata of aerial survey to estimate the size of the Eastern Beaufort Sea beluga population.

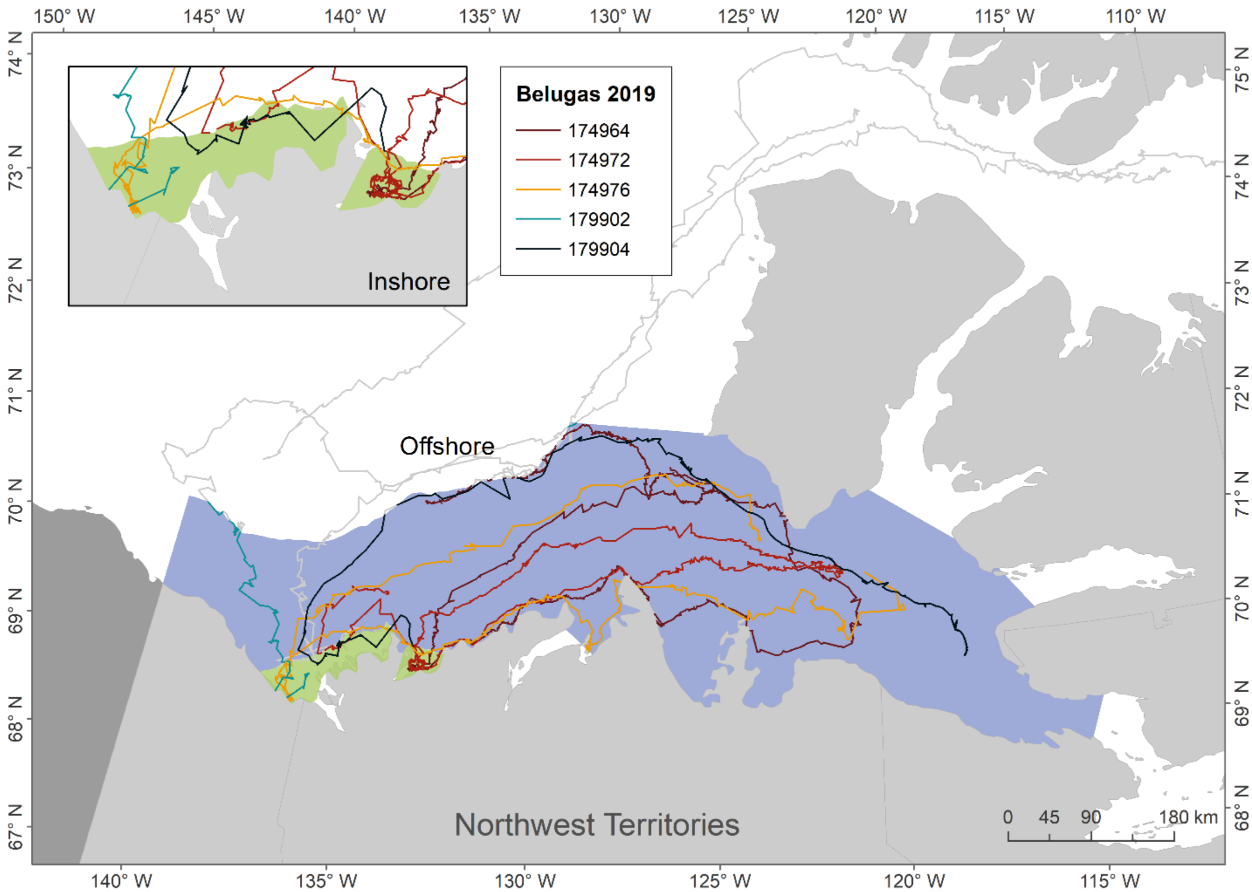

Figure 7. Location of beluga tagged in 2019 during the July survey period (July 15 to Aug 02) overlayed on top of the strata of aerial survey to estimate the size of the Eastern Beaufort Sea beluga population.

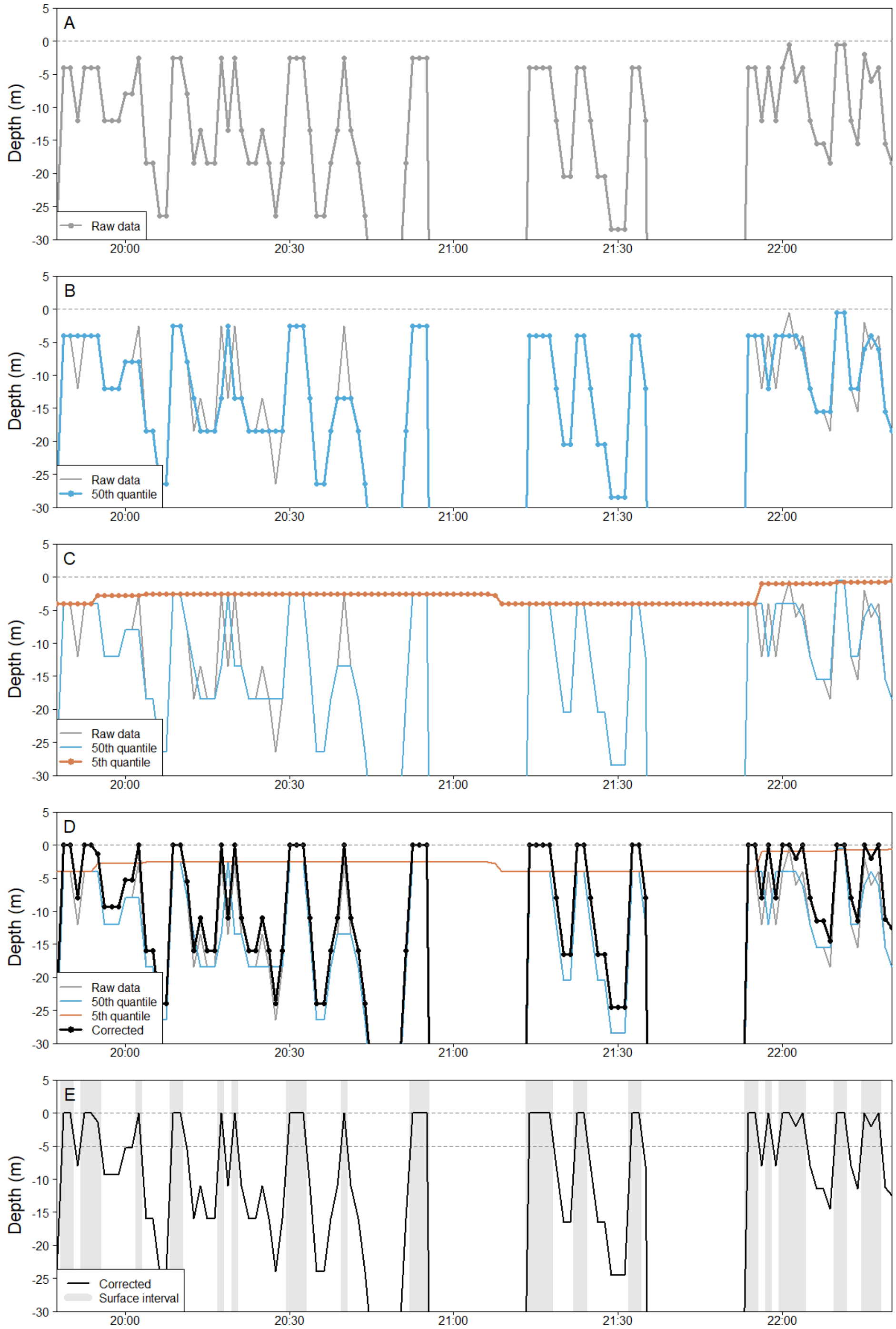

Figure 8. Example dive profile and zero-crossing correction for beluga PTT 174962. A 2.5 hours subset and the top 30 meters of the profile are presented to better represent the proportion of time at the surface. A) Raw data, B) raw data from A filtered with a 50th quantile (median) moving window of 225 sec (3 samples), C) data from B filtered with 5th quantile moving window of 30 minutes (24 samples), D) corrected data obtained by subtracting the filtered data in C from the filtered the data in B, E) surface interval detection based on a threshold of 5 m. Horizontal grey dashed lines at 0 m and 5 m represent the surface of the water and the threshold for the definition of a dive, respectively.

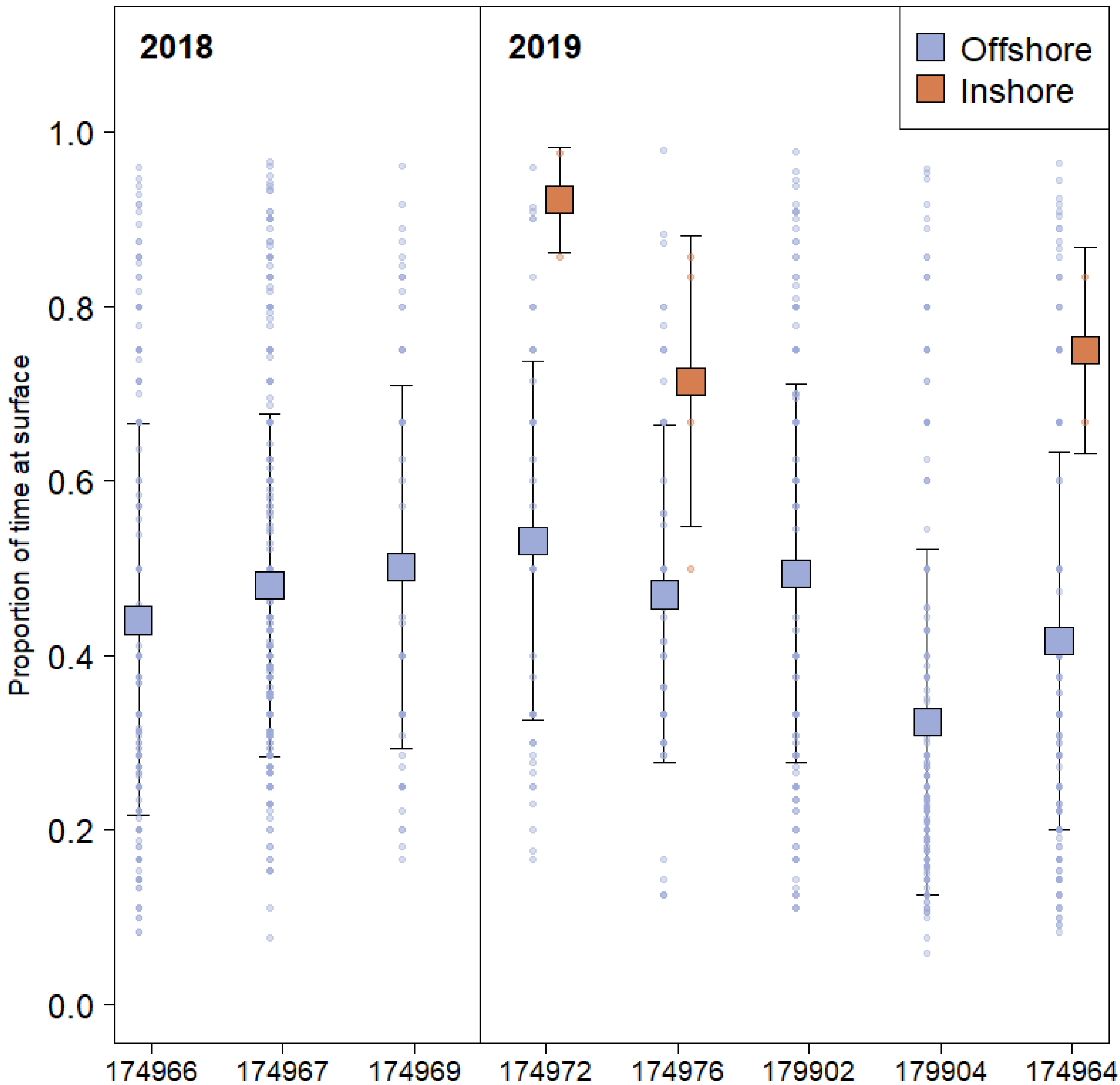

Figure 9. Proportion of time belugas equipped with time-depth recorders in 2018 and 2019 spent at the surface (dive threshold definition of 2 m) in the inshore (blue) and offshore (orange) areas of the 2019 Eastern Beaufort Sea beluga survey. Squares represent mean, error bars represent standard deviation and points represent raw data. There was not enough dive data recorded in close temporal proximity to a location to estimate the proportion of time for the inshore strata in 2018 and there was only data for 3 belugas in the inshore strata in 2019.

APPENDIX A

Table A1. Dive statistics for 8 belugas equipped with time-depth recorders in the Eastern Beaufort Sea (EBS) during the July period (July 15 to August 02) that visited the inshore areas of the 2019 DFO EBS beluga survey. Dives were defined according to a 1 m, 2 m and 5 m threshold. S and D indicate average surface and dive time in minutes. R indicates the average ratio of time each individual spent near the surface of the water and #D indicates the number of dives for each category.

Year	PTT	1 m				2 m				5 m			
		S	D	R	#D	S	D	R	#D	S	D	R	#D
2018	174967	-	-	-	-	-	-	-	-	-	-	-	-
	174966	1.25	2.08	0.375	3	-	-	-	-	-	-	-	-
	174969	-	-	-	-	-	-	-	-	-	-	-	-
2019	174972	9.13	1.51	0.858	24	25.00	1.25	0.952	7	-	-	-	-
	174964	7.88	1.35	0.853	12	4.38	1.25	0.778	4	-	-	-	-
	174976	5.47	2.57	0.680	17	4.38	2.50	0.636	6	-	-	-	-
	179902	3.33	2.50	0.571	4	-	-	-	-	-	-	-	-
	179904	13.38	1.82	0.880	11	-	-	-	-	-	-	-	-

Table A2. Dive statistics for 8 belugas equipped with time-depth recorders in the Eastern Beaufort Sea (EBS) during the July period (July 15 to August 02) that visited the offshore areas of the 2019 DFO EBS beluga survey. Dives were defined according to a 1 m, 2 m and 5 m threshold. S and D indicate average surface and dive time in minutes. R indicates the average ratio of time each individuals spent near the surface of the water and #D indicates the number of dives for each category.

Year	PTT	1 m				2 m				5 m			
		S	D	R	#D	S	D	R	#D	S	D	R	#D
2018	174967	6.45	7.63	0.458	526	6.68	7.74	0.463	514	7.20	8.13	0.470	478
	174966	3.67	5.78	0.388	298	4.56	6.20	0.424	256	5.41	6.99	0.437	200
	174969	3.03	3.70	0.450	97	3.96	3.51	0.530	90	5.23	3.93	0.571	58
2019	174972	3.31	3.62	0.478	95	4.40	3.67	0.546	76	5.16	5.17	0.500	38
	174964	3.05	4.91	0.383	255	3.28	5.08	0.392	233	3.31	5.02	0.398	208
	174976	5.29	3.95	0.572	120	5.37	4.74	0.531	78	4.98	5.20	0.489	64
	179902	3.63	4.01	0.475	212	4.34	3.77	0.535	204	7.27	4.10	0.640	124
	179904	3.66	10.19	0.264	330	4.11	10.37	0.284	317	4.48	10.62	0.297	296

Table A3. Dive statistics for 8 belugas equipped with time-depth recorders in the Eastern Beaufort Sea (EBS) during the August period (Aug 03 to 27) that visited the offshore areas of the 2019 DFO EBS beluga survey. Dives were defined according to a 1 m, 2 m and 5 m threshold. S and D indicate average surface and dive time in minutes. R indicates the average ratio of time each individuals spent near the surface of the water and #D indicates the number of dives for each category.

Year	PTT	1 m				2 m				5 m			
		S	D	R	#D	S	D	R	#D	S	D	R	#D
2018	174967	6.38	8.91	0.417	315	5.47	7.90	0.409	385	4.91	7.28	0.403	441
	174966	4.89	10.32	0.322	304	4.61	10.06	0.314	319	4.54	10.09	0.310	320
	174969	-	-	-	-	-	-	-	-	-	-	-	-
2019	174972	3.49	10.43	0.250	24	3.49	10.43	0.250	24	3.49	10.43	0.250	24
	174964	-	-	-	-	-	-	-	-	-	-	-	-
	174976	10.71	3.93	0.732	86	8.03	3.11	0.721	132	5.14	2.78	0.649	197
	179902	-	-	-	-	-	-	-	-	-	-	-	-
	179904	-	-	-	-	-	-	-	-	-	-	-	-