SUBMISSION TO THE
NUNAVUT WILDLIFE MANAGEMENT BOARD

FOR

Information: X **Decision:**

Issue

Information on the updated stock structure of Belcher Islands – Eastern Hudson Bay beluga following the 2023 genetic reanalysis.

Background

Belugas from the Hudson Bay-Strait complex have been harvested by Inuit for millennia. Beluga are of profound cultural significance and an important source of food security for northern residents.

Previous studies have suggested that some beluga populations undertake seasonal migrations, demonstrating a strong tendency to return to their natal summering areas every year, while other populations can be considered as resident, remaining in one area year-round. Knowledge of summering grounds and migratory routes are understood to be transmitted from older individuals to juveniles, and from mothers to their offspring, resulting in genetic structures among beluga populations defined by their summering location. There has been compelling evidence that beluga tend not to recolonize suitable summering habitat that was previously used as aggregation areas once they are abandoned or the local population is extirpated. Multiple populations mix at different times of the year, for example, during spring-fall migrations, or they may share overlapping wintering areas.

Beluga sampling programs have been in place in the Hudson Bay-Strait complex since the 1980s. The mitochondrial DNA (mtDNA) in the samples is analyzed to estimate the contribution of each population to the harvest outside of summering grounds and from fall to spring. Analysis of short sequences (234 base pairs haplotypes) from the mtDNA have allowed for the identification of four distinct populations in the Hudson Bay-Strait complex: Western Hudson Bay (WHB); Eastern Hudson Bay (EHB); James Bay (JAM); and Cumberland Sound beluga (CSB). Based on short haplotype analysis, most beluga harvested in Sanikiluaq were considered to be WHB animals. A 2023 reanalysis using longer mtDNA sequences (615 base pairs haplotypes) from the mtDNA identified a fifth distinct population in the Hudson Bay-Strait complex, which is harvested year-round by Sanikiluaq residents and was therefore named the Belcher Islands (BEL) beluga population (TAB 1). This newly identified BEL population summers within the geographic summer distribution area of EHB beluga. The spatial overlap between BEL and EHB beluga prevents estimating the abundance of these two populations separately. Therefore, Fisheries and Oceans Canada (DFO) considers beluga summering between the eastern coast of Hudson Bay and up to 60 km west of the Belcher Islands to be a mixed BEL-EHB stock.

The last BEL-EHB stock assessment, carried out in 2021, suggests the stock has declined from 3,600-3,900 individuals in 2015 to 2,900-3,200 individuals in 2021 (i.e., ~3% per year), and that the decline is primarily attributed to unsustainable harvest levels throughout the BEL-EHB stock range (Tab 2).

Since the mid-1980s, harvesting restrictions have been in place to ease pressures on the Eastern Hudson Bay (EHB) beluga, which has been assessed as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). BEL-EHB beluga are present in multiple jurisdictions. Management measures in the Nunavik Marine Region (NMR) and the shared zone with the Eeyou Marine Region (EMR) are detailed in the 2021-26 Nunavik Beluga Management System and include a total allowable take (TAT) of 20 beluga in the Eastern Hudson Bay Arc management zone and non-quota limitations in the rest of the NMR. The management system aims to ensure a 50% probability that the EHB stock remains stable at 2015 levels (the 2021 population abundance was not available at the time) after 5 years and recommends total annual removals of EHB not exceed 58 individuals. A voluntary summer closure between July 15 and September 30 has been in effect in Sanikiluaq since 2014 with the goal of reducing harvesting pressure on EHB beluga.

Implications

The 2023 genetic reanalysis indicates that a significant portion of beluga harvests previously assigned to the WHB population are instead from the BEL population. As such, the number of annual removals from the joint BEL-EHB stock has been underestimated. The identification of the BEL stock and the reanalysis of previous genetic samples has significant impacts on the harvest proportions in the Hudson Strait during the spring and fall migrations and around the Belcher Islands throughout the year (TAB 3). The genetic reanalysis suggests total removals by Nunavik and Nunavut harvesters of BEL-EHB across their range has been underestimated by over 80% between 1996 and 2022.

Consultations

An updated stock structure has been presented to the Sanikiluaq Hunters and Trappers Organization, the Nunavik Marine Region Wildlife Board (NMRWB), the Nunavik Anguvigaq, Makivvik, and the five Hudson Bay communities in Nunavik. DFO staff are planning a public meeting in Sanikiluaq to present the stock structure to the community, respond to questions, and gather feedback and concerns.

Recommendation

The NWMB may wish to consider scheduling a joint decision making process with the Nunavik Marine Region Wildlife Board (NMRWB) and the Eeyou Marine Region Wildlife Board (EMRWB) on the management of the shared BEL-EHB beluga stock.

Prepared by: Michael Hale – Fisheries Management - Fisheries and Oceans Canada – Arctic Region

Date: December 11, 2024

Attachments:

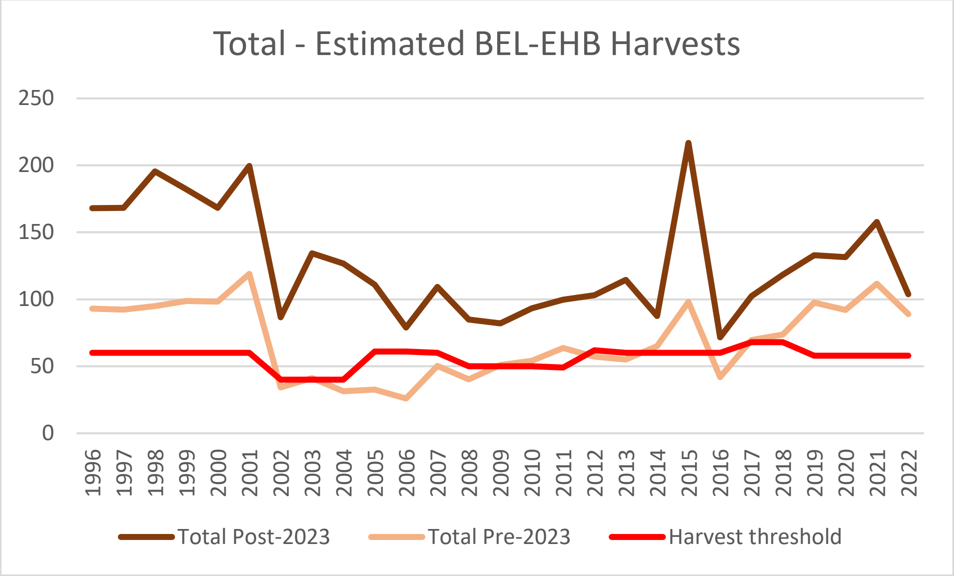
TAB 1 - Re-examining populations of beluga in the Hudson Bay-Strait Complex and assessing the impact on harvests in Nunavik and Sanikiluaq management units

TAB 2 - Recovery Potential Assessment for Beluga (Delphinapterus leucas) Stocks in Nunavik (Northern Quebec)

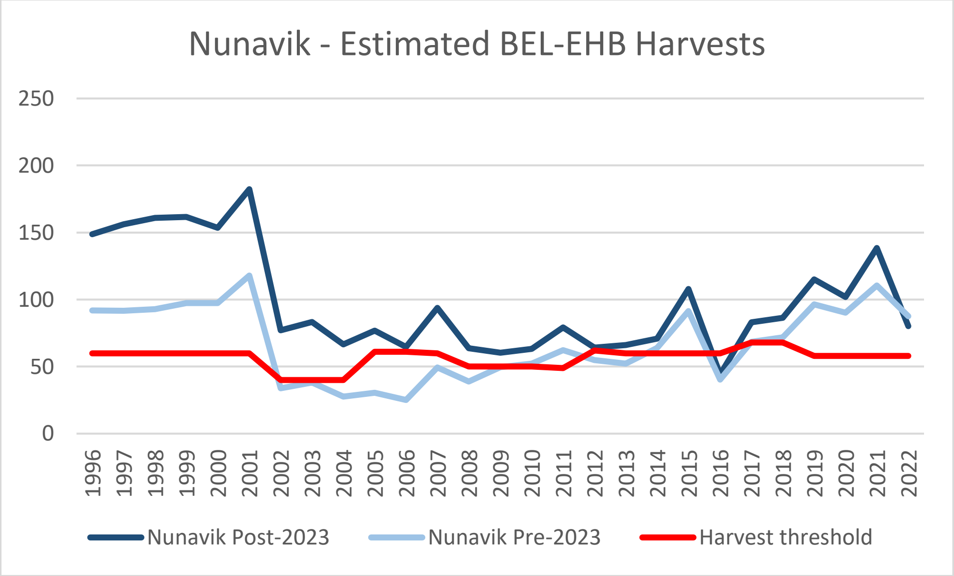
TAB 3 - ANNEX A – Graphs and tables (attached)

ANNEX A – Graphs and tables

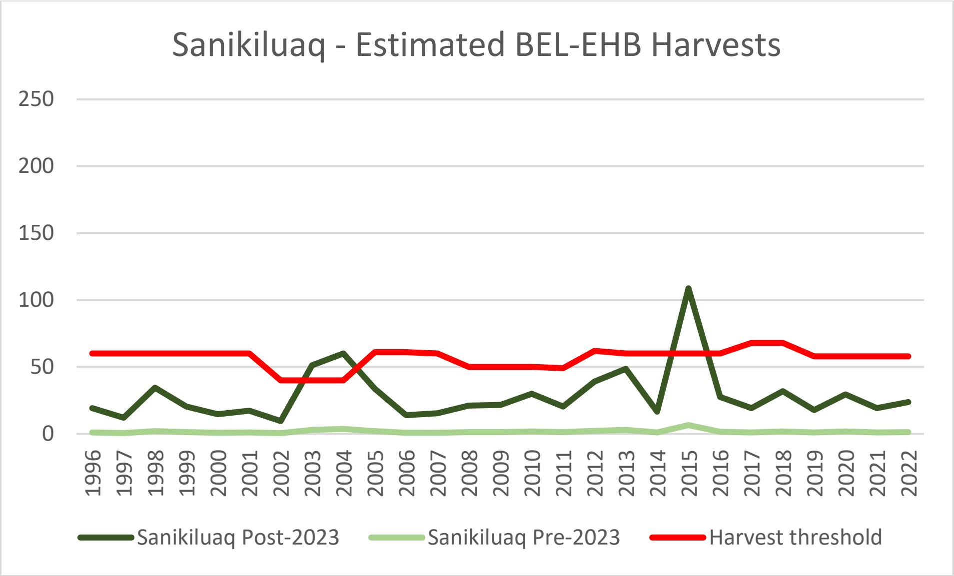
Graphs



Harvest statistics comparing estimated BEL-EHB harvest numbers pre and post 2023 genetic reanalysis. Total estimated BEL-EHB harvests in Nunavik and Sanikiluaq combined post-2023 reanalysis (dark orange) and pre-2023 reanalysis (light orange). The red line represents the Harvest Threshold of BEL-EHB animals, i.e. the maximum number of removals recommended by DFO to meet the management objectives.



Harvest statistics comparing estimated BEL-EHB harvest numbers pre and post 2023 genetic reanalysis. Total estimated BEL-EHB harvests in Nunavik post-2023 reanalysis (dark blue) and pre-2023 reanalysis (light blue). The red line represents the Harvest Threshold of BEL-EHB animals, i.e. the maximum number of removals recommended by DFO to meet the management objectives.



Harvest statistics comparing estimated BEL-EHB harvest numbers pre and post 2023 genetic reanalysis. Total estimated BEL-EHB harvests in Sanikiluaq post-2023 reanalysis (dark green) and pre-2023 reanalysis (light green). The red line represents the Harvest Threshold of BEL-EHB animals, i.e. the maximum number of removals recommended by DFO to meet the management objectives.

Figures and data from (Note: Harvest data from 1974-1995 has been excluded):

Total Abundance and Harvest Impacts on Eastern Hudson Bay and James Bay Beluga 2015– 2022

Tables

Nunavik – BEL-EHB harvest proportions before and after 2023 genetic reanalysis					
		Pre-2023 Reanalysis		Post-2023 Reanalysis	
Season	Zone	%WHB	%EHB	%WHB	%BEL-EHB
Spring (Feb1-Aug31)	Hudson Strait	82.9	11.7	75.7	12.3
	NE Hudson Bay	No data	No data	No data	No data
	Ungava Bay	87.4	6.0	87.8	4.7
Fall (Sep1-Jan31)	Hudson Strait	67.6	29.1	49.6	44.0
	NE Hudson Bay	49.1	44.5	37.3	50.1
	Ungava Bay	No data	No data	No data	No data

Sanikiluaq – BEL-EHB beluga harvest proportions before and after 2023 genetic reanalysis				
	Pre-2023 Reanalysis		Post-2023 Reanalysis	
Season	%WHB	%EHB	%WHB	%BEL-EHB
Spring	77	2	7	63
Summer	62	26*	0	100*
Fall	98	0	28	61
Winter	31	37	44	40

Past genetic mixture analysis (1982-2018) using the Pella-Masuda model to determine the proportions of beluga from WHB or BEL-EHB stock in the harvest of Nunavik and Sanikiluaq management units (format modified, from Hammill et al. 2021; BEL-EHB stock was identified as EHB population in the original document). WHB: Western Hudson Bay, EHB: Eastern Hudson Bay.

Tables and data from:

Re-examining populations of beluga in the Hudson Bay-Strait Complex and assessing the impact on harvests in Nunavik and Sanikiluaq management units

Acronyms:

BEL: Belcher Islands beluga

EHB: Eastern Hudson Bay beluga

BEL-EHB: Belcher Islands-Eastern Hudson Bay beluga

WHB: Western Hudson Bay beluga

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Re-examining populations of beluga in the Hudson Bay-Strait Complex and assessing the impact on harvests in Nunavik and Sanikiluaq management units

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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

Belugas from the Hudson Bay-Strait Complex are harvested by hunters from Nunavik and Nunavut communities. In past studies, a genetic mixture analysis (GMA) was used to determine the contribution of animals from the Western Hudson Bay (WHB) and Eastern Hudson Bay (EHB) populations to harvests in the different management units. The population definition of WHB and EHB relied on short haplotypes from the mitochondrial (mt) DNA control region. However, studies with long haplotypes have shown that four populations could be identified in the Hudson Bay-Strait Complex. Here, we aim to 1) revisit the definition of populations within this area by resequencing and comparing short and long haplotypes for the mtDNA control region of 2 861 belugas, and 2) update the relative contribution of the newly-defined reference groups in management units using a GMA. Long haplotypes confirmed the existence of four previously defined populations, WHB, EHB, James Bay (JAM), and Cumberland Sound (CSB). They also allowed for the identification of a fifth population in the Belcher Islands (BEL). For the second objective, we tested the validity of the five populations using a leave-one-out approach and observed a high rate of erroneous assignments between EHB and BEL populations. Misassignments were due to shared genetic matrilineages and possible admixture during summer. Assignments were improved when EHB and BEL populations were combined in as a single reference named BEL-EHB stock. The GMA with the four new reference groups (WHB, JAM, CSB populations and BEL-EHB stock) led to higher proportions of the BEL-EHB stock in the fall harvest in Hudson Strait (5.6%) and Northeastern Hudson Bay (14.9%), and year-round in Sanikiluaq (3.3 to 61.2%), compared to previous studies using only two reference groups. Changes in reference groups, and not resequencing, likely caused most of the variation in the proportional estimate of the BEL-EHB stock in management units. Results from this study have increased the accuracy of the proportional contribution from reference groups to the harvest by the Nunavik and Nunavut (Sanikiluaq) communities.

INTRODUCTION

The beluga is a medium sized cetacean with an Arctic and sub-Arctic circumpolar distribution. Telemetry studies have shown that belugas in some areas undertake seasonal long-distance movements, whereas others can be considered as resident (O'Corry-Crowe et al. 2010). Belugas regularly exhibit philopatry to natal locations, in spite of persistent perturbations (Caron and Smith 1990; Smith et al. 1994; Lewis et al. 2009; Turgeon et al. 2012; Colbeck et al. 2013; Ouellet et al. 2021). The existence of genetic structure among belugas is likely a consequence of cultural and vertical transmission from mothers during repeated use of migratory routes, repeated seasonal movements, and preferred habitat (Brown Gladden et al. 1997; O'Corry-Crowe et al. 1997, 2002, 2010, 2018, 2020; de March et al. 2002, 2004; de March and Postma 2003; Meschersky et al. 2008, 2013; Turgeon et al. 2012; Colbeck et al. 2013; Skovrind et al. 2019). Other studies suggest a structure that is much more complex than just matrilineal dominance (Palsbøll et al. 2002; O'Corry-Crowe et al. 2020). It has been proposed that loss of some population components, particularly older animals, has resulted in loss of ecological knowledge within groups, and consequently limits potential for population recovery (O'Corry-Crowe et al. 2010, 2018, 2020; Colbeck et al. 2013; Whitehead 2017; Brakes et al. 2021; Bonnell et al. 2022).

Within the Hudson Bay-Strait Complex, genetic studies using the mitochondrial (mt) DNA control region (or D-loop) of beluga have identified distinct genetic groups, which are geographically segregated during the summer period (July and August, Fig. 1; de March et al. 2002, 2004; de March and Postma 2003). Early studies using short haplotypes (ca. 234 nucleotides) of the mtDNA control region identified that eastern Hudson Bay (EHB) and western Hudson Bay (WHB) animals had distinct haplotype compositions (Brown Gladden et al. 1997; de March et al. 2002, 2004; de March and Postma 2003). Later studies with longer haplotypes (ca. 609 nucleotides) have also suggested the genetic distinctiveness of individuals summering in James Bay (JAM) and Cumberland Sound (CSB, Turgeon et al. 2009; 2012; Postma et al. 2012; Postma 2017), which are considered to be year-round resident populations in their respective areas, showing little or no seasonal migration (Richard and Stewart 2009; Bailleul et al. 2012; Watt et al. 2020). In the Belcher Islands, both the existence of a local summer population and of an admixture of various beluga populations from Hudson Bay has been suggested (Turgeon et al. 2012; Postma 2017).

Philopatry to summering areas has led to the use of discrete summering aggregations as conservation units in the Hudson Bay-Strait Complex (e.g., Smith and Hammill 1986; Richard et al. 1990; Richard 2010; Mosnier et al. 2017). These conservation units have also been identified as Designatable Units (DUs), namely WHB, JAM, EHB, CSB, by the Committee on the Species of Endangered Wildlife in Canada (COSEWIC). These DUs are considered as discrete and evolutionarily significant units that would, if lost, likely not be replaced through natural dispersion (COSEWIC 2016).

Several Nunavik Inuit communities and some Nunavut communities hunt belugas for subsistence from an admixture of the EHB and WHB populations (Fig. 1). The EHB population numbers around 3,400 animals (Hammill et al. 2021), and was designated as Threatened by COSEWIC (2016). In contrast, the WHB population is an order of magnitude larger with approximately 54,000 animals (Matthews et al. 2017). Beluga harvests in Nunavik (northern Quebec) have been regulated using a combination of Total Allowable Takes (TAT), and seasonal and spatial closures, as defined in management plans, which are re-examined on a regular basis (Lesage et al. 2001).

In both Nunavik and Nunavut, hunters provide tissue samples from some of the belugas they harvest. These samples are haplotyped for the mtDNA control region to estimate the contribution of each population to the harvest in each of the defined management units (Fig. 2, de March and Postma 2003; Turgeon et al. 2009; Doniol-Valcroze et al. 2016; Mosnier et al. 2017). This information is then used to determine removals from the threatened stock summering in the Eastern Hudson Bay to remain within sustainability limits (Mosnier et al. 2017; Hammill et al. 2017; Hammill et al. 2021).

The proportion of belugas from different populations harvested in each of the management units in Nunavik and Nunavut (Sanikiluaq) are estimated using a genetic mixture analysis (GMA). In the past, the GMA was based on short mtDNA haplotypes and assessed the proportions of EHB and WHB populations harvested (Turgeon et al. 2009; Turgeon et al. 2012). This type of analysis was selected due to its robustness even with mtDNA haplotypes shared between populations (Turgeon et al. 2009; Doniol-Valcroze et al. 2016; Mosnier et al. 2017).

Only EHB and WHB populations have been used as references in past GMAs developed for the Nunavik and Sanikiluaq management units. Previous studies using three reference populations, namely WHB, EHB and CSB, suggested that a proportion of the belugas harvested by the southern Hudson Strait were from the CSB population (Turgeon et al. 2009; Turgeon et al. 2012). Those results were considered unlikely as the CSB population is quite small, on the order of ca. 1,000 animals, and is considered to remain in the Cumberland Sound area throughout the year. Instead, those results were attributed to haplotype sharing between WHB and CSB populations (Doniol-Valcroze et al. 2016; Marcoux et Hammill 2016). In recent assessments, WHB and EHB were therefore the only two populations considered in GMAs (Doniol-Valcroze et al. 2016; Mosnier et al. 2017; Hammill et al. 2021).

In this study, we sequenced all available samples collected between 1982 and 2021 to first re-examine the distinctiveness of populations in the Hudson Bay-Strait Complex by comparing short and long mtDNA haplotypes (Fig. 1). Previous studies extended the length of the control region sequenced from 234 to 609 nucleotides, which increased the number of variable nucleotides from 19 to 39 in samples from all of the Canadian DUs (Postma et al. 2012; Postma 2017). Short haplotypes were available on a large proportion of samples from animals harvested in the past four decades in the Nunavik and Sanikiluaq management units. In contrast, long haplotypes were originally only available for a subset of these samples due to time and funding limitations. We then estimated the proportional contribution of each of the newly-defined genetic groups to the harvest conducted in Nunavik and Sanikiluaq management units (Fig. 2). We contrasted these results with those obtained using only two reference populations and short haplotypes, and assessed the effect of resequencing on harvest allocations.

This document presents concepts from evolutionary biology and resource management, that can cause confusion in definitions. The terms “population” and “stock” have been associated with variable meanings in biology (e.g., Waples and Gaggiotti 2006; Stewart 2008; Cadrin 2020). In evolutionary biology, the term “population” is often used to define a group of interbreeding individuals that exist together in space and time (Waples and Gaggiotti 2006). For beluga, this definition of “population” captures the strong family genetic structure present geographically during the summer and the gregarious migration within the Hudson Bay-Strait Complex (Brown Gladden et al. 1997; de March et al. 2002, 2004; de March and Postma 2003; Turgeon et al. 2012). The expression “populations of belugas” also corresponds to the DUs used by COSEWIC for conservation efforts in Canada. In contrast, a stock is defined here as animals located in a management unit and may include more than one population. We consider a management unit as defined by a geographic area, restricted temporally, as used for harvest management. Note that the stock definition varies within the primary literature and DFO documents.

METHODS

SAMPLES

Tissues from 2,861 belugas harvested, biopsy sampled, or tagged between 1982 and 2021 in or close to the Hudson Bay-Strait Complex were selected (Fig. 1). The exact location where each animal was harvested was usually unknown and was attributed to the area in which the harvest event occurred (Table 1, see Table S1 for detailed information on each sample). Sampling metadata is usually provided for each sample but for some, only harvest month and year were available.

Most tissues were preserved in a saturated salt solution containing 20% dimethyl sulphoxide (DMSO) and 0.5 mol/L ethylene diamine tetraacetic acid (EDTA, Seutin et al. 1991). Some samples were only frozen while others were frozen first and preserved later using the DMSO solution.

HAPLOTYPING

DNA was extracted from all samples using DNeasy Blood and Tissue kit (QIAGEN, Valencia, USA). The long (615 nucleotides) sequences of the control region of mtDNA were amplified using primers and PCR conditions from Postma et al. (2012), with Multiplex PCR Kit (QIAGEN, Valencia, USA). Sequencing was processed as in Postma et al. (2012) using an ABI 3130 sequencer (Applied Biosystems Inc., Foster City, USA) at Maurice Lamontagne Institute.

Consensus sequences using the forward and the reverse sequencing outputs were produced and manually edited using Geneious Prime 2020.1 (Biomatters, Ltd, Auckland, New Zealand). Sequences were then aligned using the *muscle* algorithm available for the package Biostrings 2.62.0 (Pagès et al. 2021, penalties for gap opening: 10000, extension: 400) in R (R Core team 2022). The limits of the short and long haplotypes corresponded to the following positions in the complete mtDNA control region (Lillie et al. 1996): 126 and 359 (short), and 38 and 652 (long). Single nucleotide polymorphism (SNPs) were identified using the R package adegenet 2.1.5 (Jombart 2008; Jombart and Ahmed 2011). Haplotypes were defined using sequences without missing base pairs or ambiguities at SNPs. Both short and long haplotype were designated with unique numbers according to sequence libraries (Table S2, Table S3).

DEFINING AND VALIDATING REFERENCE POPULATIONS

To define reference populations, we first characterized the genetic composition of each summering area with a haplotype network (statistical parsimony network, PopART, Leigh and Bryant 2015) and in terms of number of polymorphic sites, number of haplotypes, private haplotypes (i.e., haplotypes specific to a summering area or a reference population), and haplotype diversity (adegenet and pegas 1.1 packages in R, Jambort 2018; Paradis 2010). The genetic distinctiveness between summering areas was also assessed with principal component analyses (PCAs) using haplotype frequencies (ade4 1.7.16 package, Dray and Dufour 2007).

We then evaluated the validity of genetically distinct populations as reference groups for a genetic mixture analysis (GMA). A self-assignment test was performed using the leave-one-out procedure (Anderson et al. 2008), which is available within the rubias 0.3.2 R package (Moran and Anderson 2019). Unique numbers of long haplotypes were used as input to the leave-one-out algorithm. The output is the posterior probability (hereafter, probability) of assigning a specimen to each reference group. We used the results to quantify the proportion of specimens that were correctly assigned to their original reference population at four probability thresholds: ≥95%, ≥80%, ≥60%, and ≥40%. In an ideal system, a well-defined reference population would result in a high accuracy (probability threshold ≥80%) of assignment for a high proportion (e.g. >80%) of the specimens. However, such accuracy is rarely achievable using a single genetic marker.

GENETIC MIXTURE ANALYSES (GMA) OF HARVESTS IN MANAGEMENT UNITS

The proportions of individuals belonging to reference groups per management unit or per period were estimated with a GMA performed using SPAM version 3.7b (Debevec et al. 2000; Alaska Department of Fish and Game 2003) as in Turgeon et al. (2009a).

Standard errors were also computed using a leave-one-out jackknife resampling procedure to remove, at each iteration, individuals hunted on the same date in the same area and account for autocorrelation between samples (as previously done by Doniol-Valcroze et al. 2016).

The Pella-Masuda Bayesian mixture analysis method was selected in SPAM to allow for the possible occurrence of unknown reference groups (see Mosnier et al. 2017). Unknown reference groups may contribute to the harvested belugas, as in previous assessments.

In Hammill et al. (2021), GMA reference groups EHB and WHB were based on 206 and 132 individuals, respectively. In 2022, we used the sequences from 186 and 318 reference individuals for EHB and WHB, respectively. Reference individuals used in Hammill et al. (2021) and this study were identical for 98% for EHB (N = 183) and for 13% (N = 41) for WHB.

RESULTS

HAPLOTYPING

We obtained 2,861 high quality (no ambiguity) haplotypes from samples collected in 12 areas (Fig. 1, Table 1). A total of 43 short and 126 long unique haplotypes were identified from the 2,861 sequences (Table S1, Table S2, Table S3). Individuals from South Hudson Strait (SHS) and South West Hudson Bay (SWH) represented the largest (N = 1,372) and smallest number (N = 17) of individuals per area (Table 1), respectively.

From the 2,861 individuals, a subset of 1,600 individuals were haplotyped for the short control region by both the Freshwater Institute (FWI) and Maurice Lamontagne Institute (MLI) facilities. The FWI and MLI facilities identified 35 and 33 short haplotypes, respectively. Thirty haplotypes, the most common haplotypes, were common to both datasets. Differences in haplotyping increased steeply from 1.5% for the two most abundant haplotypes to 4.9% for the six most abundant haplotypes, and 7.0% for all possible comparisons (i.e., 25 haplotypes with two or more samples; Fig. 3).

REVALUATING POPULATION STRUCTURE IN THE HUDSON BAY-STRAIT COMPLEX

Multiple complementary approaches were used to identify populations of beluga in the Hudson Bay-Strait Complex. Using a subset of 1,136 individuals sampled during July and August from 11 areas (Table 1) we first investigated the haplotypic specificity of animals within summering areas using networks with both haplotype lengths. Eastern and western haplogroups were separated by two and four mutations for the short and the long haplotype networks, respectively (Fig. 4). In both the long and short haplotype networks, the vast majority of Eastern Hudson Bay (EHB) beluga samples had a haplotype from the eastern haplogroup (77% for both lengths).

The western haplogroup included mostly samples from Western Hudson Bay (WHB; North Hudson Bay: NHB, North West Hudson Bay: NWH, and South West Hudson Bay: SWH) but also those from all other summering areas. Haplotypes highly specific to Cumberland Sound (CSB) were observed in both networks in the western haplogroup (e.g., short: HS014; long: HL024; Fig. 4). Haplotypes highly specific to James Bay (JAM) and Long Island (LON) were observed in both haplogroups (e g., short: western HS029, eastern HS017, Fig. 4a; long: western HL070, eastern HL038, Fig. 4b). In all regions, the number of haplotypes, the haplotype diversity, and the number and proportion of private (only present in one summer area, Fig. 1) haplotypes were higher for long than short haplotypes (Table 2). The highest proportion of private haplotypes for both haplotype lengths was observed in CSB (Table 2). The haplotypic diversity in JAM was the lowest using both haplotype lengths. For the short haplotype, only CSB had a proportion of private alleles > 5%. For the long haplotypes, CSB, LON, NWH, and EHB all had proportions of private haplotypes > 5% (Table 2). Using long haplotypes, the high haplotypic specificity of animals within summering areas suggests that WHB, JAM, LON, EHB, and CSB form different populations.

The principal component analyses (PCAs) identified different numbers of distinct summering aggregations using frequencies of short and long haplotypes. For the short haplotypes, the PCA results showed three groups, consisting of EHB, JAM/LON, and all other summer aggregations (Fig. 5a). For the long haplotypes, EHB, JAM, LON, and Belcher Islands (BEL) were each separated from all other summering aggregations (NHB, NWH, SWH, South Hudson Strait: SHS, Ungava Bay: UNG, Frobisher Bay: FRB, CSB), indicating five distinct genetic groups (Fig. 5b). For the long haplotypes, JAM and LON have very similar haplotype frequencies (Table S4). In addition, the two most abundant haplotypes in JAM and LON were the same (HL008, HL070; Fig. 5b, Table S4). These results suggest that JAM and LON form a single population (JAM population will include LON individuals hereafter). In contrast, the two most abundant haplotypes in EHB (HL009, HL016) are different from those of BEL (HL001, HL022; Table S4). We tested further if BEL animals differed from other genetic groups with a third PCA of long haplotype frequencies from populations (EHB, WHB, JAM, CSB) and from management units (considering areas and seasons; Fig. 2). In this PCA, WHB, JAM, EHB, and CSB populations separated from each other (Fig. 6). Haplotype frequencies from BEL across the four seasons formed a separate cluster from other genetic groups in the PCA (Fig. 6), also suggesting that a distinct population inhabits the Belcher Islands.

Five populations were identified within the summering areas with long haplotypes, namely WHB, JAM, EHB, BEL, and CSB. The leave-one-out approach showed an increasing proportion of correct assignment to reference groups with decreasing threshold of posterior probability, except for the CSB population which plateaued at 39.1% at a ≥ 60% probability threshold. Such a result is expected since the CSB population shares multiple haplotypes with WHB (Fig. 6). A large proportion (> 75%) of individuals was assigned correctly to WHB and JAM populations at a ≥ 40% probability threshold (Table 3). In contrast, lower proportions of individuals were assigned to the EHB (69.4%) and BEL (19.7%) populations at a ≥ 40% probability threshold (Table 3). Grouping EHB and BEL populations as BEL-EHB stock increased the proportion of reassignments to BEL-EHB stock (84%) at a ≥ 40% probability threshold (see “Four populations and BEL-EHB stock” in Table 3). Proportions of correct assignments were identical for WHB, JAM and CSB at all probability thresholds for both assignment tests (Table 3).

ESTIMATING HARVESTED PROPORTIONS OF REFERENCE GROUPS IN MANAGEMENT UNITS

We estimated the proportions of new reference groups (WHB population, JAM population, BEL-EHB stock, and CSB population) harvested by the Nunavik and Sanikiluaq communities in the different management units using the long haplotypes. The proportions of animals from the BEL-EHB stock harvested in Hudson Strait (12.3%) and Ungava Bay (4.7%) in spring were similar to previous estimates (Hudson Strait: 11.7%, Ungava Bay: 6.0%, Tables 4 and 5). Increases of proportion EHB beluga harvested were observed in the fall for Hudson Strait (44.0%) and Northeastern Hudson Bay (50.1%), respectively, compared with the previous estimates (Hudson Strait: 29.1%, Northeastern Hudson Bay: 44.5%, Tables 4 and 5). In Hudson Strait, dividing the fall samples into a finer time scale did show that the proportion of BEL-EHB stock in harvest declines late in November (Table 7). We observed the largest increases, ca. 60%, in the proportion of BEL-EHB stock harvested, in samples from the spring and fall from Sanikiluaq (Tables 4 and 5). Similar proportions of harvested BEL-EHB stock were observed between the current estimates and the previous assessments (Tables 4 and 5).

The JAM or CSB populations represented small proportions of harvested animals in the Northeastern Hudson Bay, Hudson Strait, and Ungava Bay management units (Table 5). In these management units, the highest proportion of JAM and CSB populations were harvested in Northeastern Hudson Bay in fall and Hudson Strait in spring, respectively. In Sanikiluaq, the JAM population was more frequent in spring and winter harvests compared to those of fall (Table 5). No CSB animals were harvested in Sanikiluaq (Table 5).

In all management areas, the proportion of individuals associated with an unknown population is significantly lower than in the last assessment, especially Sanikiluaq in spring and winter. (Tables 4 and 5). The proportions of unknown were still the highest in the Sanikiluaq management units with the current estimates (Table 5).

QUANTIFYING THE EFFECT OF CHANGES ON GMA

We quantified the effect of resequencing and changes in reference populations on estimates of the proportion of BEL-EHB stock in the harvest per management unit (short haplotypes from 1,517 individuals). The resequencing effect resulted on average in a 4.3% (± SEM 1.0%) change in the estimated proportion of BEL-EHB stock harvested per management unit. The largest resequencing effect (12.0%) on the proportion of BEL-EHB stock harvested was observed in Sanikiluaq during winter (Table 6).

DISCUSSION

In this study, we revisited the short and long mtDNA control region sequences and refined the number of populations from four to five within the Hudson Bay-Strait Complex. Our results using the long haplotypes confirm that WHB, JAM, EHB, and CSB are distinct populations. It also identifies that beluga harvested around the Belcher Islands (BEL), have a genetic composition that is distinct from WHB. From a conservation perspective, the BEL population should be considered as a newly described distinct evolutionary unit, i.e. another Arctic beluga population. However, the performance of the GMA when BEL and EHB populations were used as independent references was reduced by haplotype sharing between the two. It is also currently impossible to separately estimate the abundance of BEL and EHB beluga since they overlap spatially and temporally during summer surveys. Therefore, a more parsimonious approach is to consider the combined abundance of the BEL and EHB populations as a BEL-EHB stock from both stock assessment and management perspectives. The greatest impact of combining the BEL and EHB populations was the increased proportions of BEL-EHB stock animals harvested year-round in Sanikiluaq management unit. In Nunavik, the increase in estimates of BEL-EHB stock harvested over the season is variable, but it is larger in fall in northeastern Hudson Bay compared to the Hudson Strait. Altogether, this study provides a more reliable tool for the management of all of the DUs in the Hudson Bay-Strait Complex (COSEWIC 2016).

FIVE POPULATIONS IN THE HUDSON BAY-STRAIT COMPLEX

Our results confirm that the mtDNA control region can characterize population structure of beluga summering populations in the Hudson Bay-Strait complex (Brown Gladden et al. 1997; de March and Postma 2003; Turgeon et al. 2012; Postma 2017). They also confirm the separation of haplotypes into two haplogroups that are broadly geographically restricted, i.e., western and eastern haplogroups (Postma 2017). WHB and EHB populations were detected, confirming results from past studies (Turgeon et al. 2009; Turgeon et al. 2012). Our findings also highlight the necessity to consider three new populations in the Hudson Bay-Strait Complex, namely JAM, CSB, and BEL. Their genetic composition using the long haplotypes is distinct from those of WHB and EHB.

Analyses of long haplotypes highlighted the specificity of the JAM population, which was also observed in previous studies (Postma et al. 2012; Postma 2017). Our study also showed the similarity between the haplotype frequencies of JAM and LON individuals during summer. Previous studies suggested the presence of individuals with haplotypes from the EHB haplogroup in LON area during summer (Postma et al. 2012; Postma 2017). Although this is consistent with our results, JAM and LON have similar most abundant haplotypes, which are different from those of EHB. JAM and LON have highly specific haplotypes from both western (e.g., HL070, HL072, HL074) and eastern haplogroups (e.g., HL038). Together, those results suggest that the majority of individuals harvested from LON are part of the JAM population. This is consistent with the current management framework which groups catches from the Long Island area with those from James Bay (Fig. 1b).

The CSB population had the highest proportion of private haplotypes with both the short and long haplotypes. There was also a large proportion of haplotypes shared with the WHB population, which is consistent with previous studies (de March et al. 2002, 2004; Turgeon et al. 2009; Turgeon et al. 2012; Postma 2017). Satellite telemetry data indicate that CSB beluga whales form a distinct population that inhabits the area year round (Richard and Stewart 2009). Alternatively, traditional knowledge indicates that different types of beluga whales visit CSB each year (Kilabuk 1998; Watt et al. 2020). The mixed composition observed in the summer in CSB could reflect both telemetry and traditional knowledge information, and may suggest the occurrence of both migratory and resident individuals.

The analyses of the long haplotypes identified BEL individuals as forming a distinct population. With the short haplotype, the BEL population was grouped with the WHB population, mostly due to haplotype sharing. However, the long haplotype showed that the most abundant haplotypes from the western haplogroup differed between the WHB (HL003) and BEL (HL001) populations. Moreover, BEL did not share its two most abundant haplotypes with EHB, although they shared a few non-abundant haplotypes that are part of the eastern haplogroup. These results support those from previous studies showing that 20% of individuals harvested in the Belcher Islands had private or highly specific long haplotypes or mitogenomes (Turgeon et al. 2012; Postma 2017). The larger sample sizes used in the present study show that the Belcher Islands belugas form a distinct population, similar to other DUs of beluga in the Arctic (COSEWIC 2016).

No reference population was identified in other summering areas, namely SHS, UNG and FRB. In these areas, the two most abundant haplotypes were HL001, and HL003, which are abundant haplotypes in the WHB population. There were no or few private haplotypes detected for the long sequences in SHS, UNG, and FRB, suggesting that there are no endemic populations summering in these areas. The Hudson Strait is acknowledged as a migration corridor and a wintering area for the WHB and EHB populations (Finley et al. 1982; Bailleul et al. 2012). However, it also appears that individuals form a mixture of the WHB and EHB populations summer in the Hudson Strait area. These represent very few animals detected in summer aerial surveys in Hudson Strait during the 1980s, 2008 and 2010, but survey effort has been limited in this area (Fig. 7, Finley et al. 1982; Gosselin et al. 2009; Gosselin, J.-F. personal observations).

FOUR REFERENCE GROUPS IN THE HUDSON BAY-STRAIT COMPLEX

We identified four valid reference groups for the GMA when considering a ≥ 40% probability threshold for self-assignment rates: the WHB, JAM, and CSB populations and the BEL-EHB stock. Self-assignment rates were high for WHB and JAM either with five reference populations or four reference groups. These results are in agreement with previous studies highlighting that WHB and JAM populations had distinct genetic compositions (Turgeon et al. 2012; Postma et al. 2012; Postma 2017). With both sets of reference groups, CSB self-assignment rates were lower (39%) than those of WHB and JAM at a ≥ 40% probability threshold. Private haplotypes and a large proportion of haplotypes shared with WHB explain these low self-assignment rates for CSB, which are also consistent with previous studies (Turgeon et al. 2009; Turgeon et al. 2012). Self-assignment rates were poor (19.7%) for the BEL population and acceptable (69.4%) for the EHB population when considering five reference populations. This is likely due to sharing between the BEL and EHB populations of multiple non-abundant haplotypes from the eastern haplogroup. Haplotype sharing between BEL and EHB populations may be due to shared lineages. Alternatively, telemetry research has shown movement between the mainland and the Belcher Islands (Bailleul et al. 2012).

The use of EHB and BEL summering individuals as a single reference group, identified as a BEL-EHB stock, considerably improved the self-assignment rates. The term “BEL-EHB stock” is used here to define the grouping of BEL and EHB populations and describe the genetic composition of animals summering in eastern Hudson Bay that are counted during aerial surveys (St-Pierre et al. in prep.[1]). In past documents (e.g., Hammill et al. 2017; 2021), the animals summering in these areas were described under the term “EHB stock”. The use of the term “BEL-EHB stock” now captures the change in the definition of the genetic composition of those animals, indicating the combination of two populations within a same space (eastern Hudson Bay).

HARVESTED BEL-EHB STOCK INCREASED IN SOME MANAGEMENT UNITS

The large increases in the proportions of beluga harvested from the BEL-EHB stock observed in Sanikiluaq was mainly due to the addition of the BEL population to the BEL-EHB stock. The capacity of the long haplotype to discriminate BEL from WHB populations allowed for an improved genetic definition of belugas summering in the eastern Hudson Bay region. Using short haplotypes, previous assessments identified animals harvested year round in the Belcher Islands mostly as WHB animals (e.g. Hammill et al. 2021). Results from this study using long haplotypes support the hypothesis that harvests of beluga by the Sanikiluaq community are mostly from a population specific to the Belcher Islands (Turgeon et al. 2012; Postma 2017). This analysis also shows that previous analyses have likely underestimated the impact of harvesting on animals summering in the eastern Hudson Bay area.

Within Nunavik management units, the proportion of belugas harvested during the spring hunt in Ungava Bay and Hudson Strait pertaining to the BEL-EHB stock were similar to past estimates. The 4.7% BEL-EHB stock estimated in the Ungava Bay spring hunt corresponds approximately to the 6% ratio in abundance estimates between the BEL-EHB stock and WHB populations

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[1] St-Pierre, A.P., Gosselin, J.-F., Mosnier, A. and Hammill, M.O. Abundance estimates for beluga (*Delphinapterus leucas*) in James Bay and the Belcher Islands-eastern Hudson Bay area in summer 2021. DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

(6% = 3300/(3300+54000), Matthews et al. 2017; Hammill et al. 2021). However, the proportions of BEL-EHB stock estimated in the spring hunt in Hudson Strait and in the fall hunt in Hudson Strait or Northeastern Hudson Bay were larger. In the latter areas, approximately half of the harvested animals are estimated to belong to the BEL-EHB stock, representing a much greater proportion than expected based on the relative size of the BEL-EHB and WHB populations. The estimated proportion of BEL-EHB stock animals in the fall hunt in Hudson Strait and Northeastern Hudson Bay is also higher than in the previous assessment. Considering that the BEL population is now contributing to the definition of the genetic composition of the BEL-EHB stock, this result suggests that a fraction of the BEL population may also migrate out of the Hudson Bay along with individuals from the EHB population. The other fraction of the BEL population likely overwinters in the Belcher Islands, as animals harvested during winter had similar genetic composition to those harvested in summer. In Hudson Strait, sample sizes were large enough to test for changes in the proportion of BEL-EHB stock animals in the hunt during November. Proportions of BEL-EHB stock were high (51.5%; 95% confidence interval: 39.0-63.9%) in early November and decreased to 10.4% late November (95% confidence interval: 0.9-29.5%; Table 7).

PROPORTIONS OF JAM, CSB, AND PUTATIVE OTHER POPULATIONS WERE LOW IN ALL MANAGEMENT UNITS

Small proportions of JAM and CSB populations were harvested in Hudson Strait, Ungava Bay, and Northeastern Hudson Bay, while a larger proportion of the JAM population was harvested by the Sanikiluaq community during the spring and winter. Some individuals of the JAM population may overwinter near Belcher Islands in areas of loose ice (polynya) (McDonald et al. 1997). We also observed smaller proportions of the JAM population in Hudson Strait in spring and in Northeastern Hudson Bay in fall, suggesting the movement of some JAM belugas outside of James Bay and Belcher Island areas. These results contrast with telemetry data obtained from 23 animals tagged in James Bay that showed no seasonal migration (Bailleul et al 2012); however, the number of tagged animals was small relative to the overall estimated population of 19,200 animals and likely captures only a fraction of the possible movement patterns of animals in this population (Hammill et al. in prep.[2]). In contrast, we did not detect any individuals from the CSB population in Hudson Bay, in agreement with a previous study (Turgeon et al. 2012). The presence of CSB animals in Hudson Strait and Ungava Bay is interesting and has been reported elsewhere. This underlines the complexity of beluga social behavior where some animals may be resident, while others may undertake larger scale migrations (Richard and Orr 1986; de March et al. 2004; O'Corry-Crowe et al. 2010, 2020). Note that the GMA may underestimate harvest of the CSB population for individuals bearing frequent haplotypes in the WHB population. We did not encounter a bias from the WHB population towards the CSB population with the GMA, whereas this bias was important for the management regions from the Eastern Hudson Bay in a past study (Doniol-Valcroze et al. 2016). The larger number of reference individuals from WHB has likely limited this effect.

Proportions of unknown reference groups were lower than those from the past genetic mixture analyses in most management units. This can be explained by the incorporation of the BEL population into the BEL-EHB stock. Still, proportions of unknown reference groups were larger in the Sanikiluaq management units. We examined the haplotype frequencies of Sanikiluaq harvest samples in spring, fall, and winter. The large proportion of HL001, BEL's most abundant

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[2] Hammill, M.O., St-Pierre, A.P., Mosnier, A., Parent, G.J., and Gosselin, J.-F. Total abundance and harvest impacts on Eastern Hudson Bay and James Bay beluga 2015–2022. DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

haplotype, across seasons, suggests that some components of the local population (BEL) may overwinter in the Belcher Islands area. We also identified haplotypes (i.e., HL036, HL037, HL089, HL131, HL132, HL133, HL134, HL135) harvested only in the Sanikiluaq spring, fall, and winter management units, suggesting that additional unknown populations may overwinter around the Belcher Islands. We know of at least two other groups of beluga that have been observed in the south of Hudson Bay, which have little to no genetic data available for analysis. In this study, the SWH summer aggregation is represented by a small sample size (N = 17) and previous studies have suggested some genetic specificity in that region (Turgeon et al. 2009; Postma 2017). There is also a large group of beluga whales often observed in the northwestern part of James Bay during aerial surveys (Gosselin et al. 2013), which has never been characterized genetically.

NEW REFERENCE POPULATIONS/STOCK, NOT RESEQUENCING, HAD THE LARGEST EFFECT ON HARVESTED PROPORTIONS

Resequencing explained a small change in the proportions of the BEL-EHB stock harvested (4.3%). Differences in sequencing results between the two facilities (FWI and MLI) can be explained mostly by changes in methodologies over the last 20 years. The haplotyping program for beluga management started in approximately 2000 at the FWI (de March and Postma 2003). In the early stage of haplotyping, error rates associated with Taq polymerase or sequencing technologies were higher. Consequently, singleton (unique haplotype) grouping with most abundant haplotypes was a procedure undertaken each year to improve the performance of GMA and avoid bias due to rare, potentially erroneous, haplotypes. With the years, Taq polymerase and sequencing technology error rates improved, while reducing haplotype grouping. We did not perform haplotype grouping with the MLI dataset, as error rates were likely negligible since all of the sequences were synthesized in the last year. Furthermore, the error rate was overall lower with the MLI database as all sequences were produced using consensus sequences, with forward and reverse sequencing outputs. To reduce cost, only forward sequencing was conducted for harvest samples at the FWI. Chromatogram interpretation is another potential source of error. At the FWI, a single technician reviewed the chromatograms, which reduces the error rate. At the MLI, we generated a standard operating procedure for the production of consensus sequences that could be transferred to any sequencing facility in the future. Since the resequencing effect was low, we can conclude that the major differences observed between results from previous GMA (Hammill et al. 2021) and those from this study were caused by the change in number of newly-defined reference groups, from two to four.

IMPROVING GENETIC CLASSIFICATION IN THE FUTURE

Genetic characterization of individuals from southern Ungava Bay was not possible in this study. The Ungava population experienced excessive commercial whaling in the late 19th and early 20th century and is currently designated as Endangered (COSEWIC 2016). This population has high site fidelity to the southern part of Ungava Bay in an area where hunting is restricted. A project started in 2018 in collaboration with the Nunavik Hunting, Fishing and Trapping Association (Regional Nunavimmi Umajulirijiit Katujjiqatigininga; RNUK), and conducted a few biopsies (n = 3) on beluga from this area, but there are not enough samples for inclusion in population structure analyses. Environmental DNA sampling is now being developed for beluga haplotying to limit the impact of harvest on these animals.

New genetic markers (mitogenomes, SNPs from the nuclear genome) may improve classification and assignment to reference populations of the Hudson Bay-Strait Complex. The mtDNA sequence cannot discriminate between seasonal migrants (not reproducing with the local population) or effective migrants (reproducing with the local population). Genetic markers derived from nuclear DNA could discriminate between the two types of migrants, if populations are genetically distinct at nuclear loci. Past studies using nuclear markers indicated some genetic differentiation between CSB or JAM with other populations, but not between WHB and EHB populations, which may interbreed (Turgeon et al. 2012).

Other proxies may also improve classification to reference populations of the Hudson Bay-Strait Complex. A previous study combining stable isotopes and trace elements was successful in defining summering stocks and their relative contributions to subsistence harvest in Nunavik (Rioux et al. 2012). Combining the characterization of stable isotopes, trace elements, and mtDNA haplotypes for control regions in each reference individual could help to identify different types of migrants and further reduce the uncertainty around classification of the WHB population and the BEL-EHB stock. Combining proxies while using these new reference populations based on the extended mtDNA sequence may complement genetic assignment and refine classification while reducing uncertainty.

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REFERENCES CITED

Alaska Department of Fish and Game. 2003. SPAM Version 3.7: Statistics Program for Analyzing Mixtures. Alaska Department of Fish and Game, Commercial Fisheries Division, Gene Conservation Lab. Software available at: Gene Conservation Laboratory SPAM Download, Division of Commercial Fisheries, Alaska Department of Fish and Game

Anderson, E.C., Waples, R.S. and Kalinowski, S.T. 2008. An improved method for predicting the accuracy of genetic stock identification. Can. J. Fish. Aquat. Sci. 65 : 1475–1486. doi:10.1139/F08-049

Bailleul, F., Lesage, V., Power, M., Doidge, D.W. and Hammill, M.O. 2012. Differences in diving and movement patterns of two groups of Beluga Whales in a changing Arctic environment reveal discrete populations. Endanger. Species Res. 17 : 27–41. doi:10.3354/esr00420.

Bonnell, T.R., Michaud, R., Dupuch, A., Lesage, V. and Chion, C. 2022. Extracting spatial networks from capture-recapture data reveals individual site fidelity patterns within a marine mammal's spatial range. Ecol. Evol. 12(2) : e8616. doi:10.1002/ece3.8616

Brakes, P., Carroll, E.L., Dall, S.R.X., Keith, S.A., McGregor, P.K., Mesnick, S.L., Noad, M.J., Rendell, L., Robbins, M.M., Rutz, C., Thornton, A., Whiten, A., Whiting, M.J., Aplin, L.M., Bearhop, S., Ciucci, P., Fishlock, V., Ford, J.K.B., Notarbartolo di Sciara, G., Simmonds, M.P., Spina, F., Wade, P.R., Whitehead, H., Williams, J. and Garland, E.C. 2021. A deepening understanding of animal culture suggests lessons for conservation. Proc. R. Soc. B. 288 : 20202718. doi:10.1098/rspb.2020.2718

Brown Gladden, J.G., Ferguson, M.M. and Clayton, J.W. 1997. Matriarchal genetic population structure of North American Beluga Whales *Delphinapterus leucas* (Cetacea: Monodontidae). Mol. Ecol. 6 : 1033–1046. doi:10.1046/j.1365-294x.1997.00275.x

Cadrin, S.X. 2020 Defining spatial structure for fishery stock assessment. Fish. Res. 221 : 105397. doi:10.1016/j.fishres.2019.105397

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* Smith, T.G., St. Aubin, D.J. and Geraci, J.R. (ed.). Advances in research on the Beluga Whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224 : 69–79.

Colbeck, G.J., Duchesne, P., Postma, L.D., Lesage, V.L., Hammill, M.O. and Turgeon, J. 2013. Groups of related Belugas (*Delphinapterus leucas*) travel together during their seasonal migrations in and around Hudson Bay. Proc. R. Soc. B. 280 : 20122552. doi:10.1098/rspb.2012.2552

COSEWIC. 2016. Designatable Units for Beluga Whales (*Delphinapterus leucas*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 73 p.

de March, B.G.E. and Postma, L.D. 2003. Molecular genetic stock discrimination of Belugas (*Delphinapterus leucas*) hunted in eastern Hudson Bay, Northern Quebec, Hudson Strait, and Sanikiluaq (Belcher Islands), Canada, and comparisons to adjacent populations. Arctic 56 : 111–124. doi:10.14430/arctic607

de March, B., Maiers, L.D. and Friesen, M.K. 2002. An overview of genetic relationships of Canadian and adjacent populations of Belugas (*Delphinapterus leucas*) with emphasis on Baffin Bay and Canadian eastern Arctic populations. NAAMCO Sci. Publ. 4 : 17–38. doi:10.7557/3.2835

de March, B., Stern, G. and Innes, S. 2004. The combined use of organochlorine contaminant profiles and molecular genetics for stock discrimination of White Whales (*Delphinapterus leucas*) hunted in three communities on southeast Baffin Island. J. Cetacean Res. Manage. 6 : 241–250.

Debevec, E. M., Gates, R.B., Masuda, M., Pella, J., Reynolds, J. and Seeb, L. W. 2000. SPAM (Version 3.2): Statistics Program for Analyzing Mixtures. J. Hered. 91 : 509–510. doi:10.1093/jhered/91.6.509

Doniol-Valcroze, T., Hammill, M.O., Turgeon, S. and Postma, L.D. 2016. Updated analysis of genetic mixing among Nunavik Beluga summer stocks to inform population models and harvest allocation. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/008. iv + 13 p.

Dray, S. and Dufour, A. 2007. The ade4 Package: Implementing the Duality Diagram for Ecologists. J. Stat. Softw. 22 : 1–20. doi:10.18637/jss.v022.i04

Finley, K.J., Miller, G.W., Allard, M., Davis, R.A. and Evans, C.R. 1982. The Belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Fish. Aquat. Sci. 1123: v + 57 p.

Gosselin, J.F., Hammill, M.O., Lesage, V. and Bourdages, H. 2002. Abundance indices of Beluga in James Bay, eastern Hudson Bay and Ungava Bay in summer 2001. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/042. 27 p.

Gosselin, J.-F., Lesage, V. and Hammill, M.O. 2009. Index estimates of abundance for Beluga in eastern Hudson Bay, James Bay and Ungava Bay in Summer 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/006. iv + 25 p.

Gosselin, J.-F., Doniol-Valcroze, T. and Hammill, M.O. 2013. Abundance estimate of Beluga in eastern Hudson Bay and James Bay, summer 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/016. vii + 20 p.

Hammill, M.O., Mosnier, A., Gosselin, J.-F., Matthews, C.J.D., Marcoux, M. and Ferguson, S.H. 2017. Management approaches, abundance Indices and total allowable harvest levels of Belugas in Hudson Bay. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/062. iv + 43 p.

Hammill, M.O., Mosnier, A. and Bordeleau, X. 2021. An update of impacts of harvesting on the abundance of Nunavik Beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/003. iv + 21 p.

Hobbs, R.C., Reeves, R.R., Prewitt, J.S. and others. 2019. Global review of the conservation status of Monodontid stocks. Mar. Fish. Rev. 81 : 1–53.

Jombart, T. 2008. adegenet: a R package for the multivariate analysis of genetic markers. Bioinformatics. 24(11) : 1403–1405. doi:10.1093/bioinformatics/btn129

Jombart, T. and Ahmed, I. 2011. adegenet 1.3–1: new tools for the analysis of genome–wide SNP data. Bioinformatics. doi: 10.1093/bioinformatics/btr521

Kilabuk, P. 1998. A study of Inuit knowledge of the Southeast Baffin Beluga. The Southeast Baffin Beluga Management Committee. 74 p.

Leigh, J.W. and Bryant, D. 2015. PopART: Full-feature software for haplotype network construction. Methods Ecol. Evol. 6 : 1110–1116. doi:10.1111/2041-210X.12410

Lesage, V., Doidge, D.W. and Fibich, R. 2001. Harvest statistics for Beluga Whales in Nunavik, 1974–2000. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/022. 35 p.

Lewis, A., Hammill, M.O., Power, M., Doidge, D.W. and Lesage, V. 2009. Movement and aggregation of eastern Hudson Bay Beluga Whales (*Delphinapterus leucas*): a comparison of patterns found through satellite telemetry and Nunavik traditional ecological knowledge. Arctic 62 : 1–24. doi:10.14430/arctic109

Lillie, W.R., Gladden, J.G.B. and Tretiak, D.N. 1996. Amplification and sequencing of control region mitochondrial DNA from the Beluga Whale, *Delphinapterus leucas*. Can. Tech. Rep. Fish. Aquat. Sci., 2080, 8 p.

Marcoux, M. and Hammill, M.O. 2016. Model estimates of Cumberland Sound Beluga (*Delphinapterus leucas*) population size and total allowable removals. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/077. iv + 35 p.

Matthews, C.J.D., Watt, C.A., Asselin, N.C., Dunn, J.B., Young, B.G., Montsion, L.M., Westdal, K.H., Hall, P.A., Orr, J.R., Ferguson, S.H. and Marcoux, M. 2017. Estimated abundance of the Western Hudson Bay Beluga stock from the 2015 visual and photographic aerial survey. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/061. v + 20 p.

McDonald, M., Arraqutainaq, L. and Novalinga, Z. 1997. Voices from the bay: traditional ecological knowledge of Inuit and Cree in the Hudson Bay bioregion. Canadian Arctic Resources Committee ; Environmental Committee of Municipality of Sanikiluaq. Ottawa; Sanikiluaq. 98 p.

Meschersky, I.G., Kholodova, M.V. and Zvychaynaya, E.Y. 2008. Molecular genetic study of the Beluga (*Delphinapterus leucas*: Cetacea, Monodontidae) summering in the southern Sea of Okhotsk as compared to North American populations. Genetika. 44 : 1105–1110. doi:10.1134/S1022795408090147

Meschersky, I.G., Shpak, O.V., Litovka and others. 2013. A genetic analysis of the Beluga Whale *Delphinapterus leucas* (Cetacea: Monodontidae) from summer aggregations in the Russian Far East. Russ. J. Mar. Biol. 39 : 125–135. doi:10.1134/S1063074013020065

Moran, B.M. and Anderson, E.C. 2019. Bayesian inference from the conditional genetic stock identification model. Can. J. Fish. Aquat. Sci. 76 : 551–560. doi:10.1139/cjfas-2018-0016

Mosnier, A., Hammill, M.O., Turgeon, S. and Postma, L. 2017. Updated analysis of genetic mixing among Beluga stocks in the Nunavik marine region and Belcher Islands area: information for population models and harvest allocation. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/016. v + 15 p.

O'Corry-Crowe, G., Suydam, R.S., Rosenberg, A., Frost, K.J. and Dizon, A.E. 1997. Phylogeography, population structure and dispersal patterns of the Beluga Whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Mol. Ecol. 6 : 955–970. doi:10.1046/j.1365-294X.1997.00267.x

O'Corry-Crowe, G.A., Dizon, E., Suydam, R.S. and Lowry, L.F. 2002. Molecular genetic studies of population structure and movement patterns in a migratory species: the Beluga Whale, *Delphinapterus leucas*, in the western Arctic. *In* Molecular and cell biology of marine mammals. Edited by C.J. Pfeiffer. Krieger Publ. Co., Malabar, Fla. pp. 53–64.

O'Corry-Crowe, G., Lydersen, C., Heide-Jørgensen, M.P., Hansen, L., Mukhametov, L.M., Dove, O. and Kovacs, K.M. 2010. Population genetic structure and evolutionary history of North Atlantic Beluga Whales (*Delphinapterus leucas*) from West Greenland, Svalbard and the White Sea. Polar Biol. 33 : 1179–1194. doi:10.1007/s00300-010-0807-y

O'Corry-Crowe, G., Suydam, R., Quakenbush, L., Potgieter, B., Harwood, L., Litovka, D., Ferrer, T., Citta, J., Burkanov, V., Frost, K. and Mahoney, B. 2018. Migratory culture, population structure and stock identity in North Pacific Beluga Whales (*Delphinapterus leucas*). PLoS ONE 13 : e0194201. doi:10.1371/journal.pone.0194201

O'Corry-Crowe, G., Suydam, R., Quakenbush, L., Smith, T.G., Lydersen, C., Kovacs, K.M., Orr, J., Harwood, L., Litovka, D. and Ferrer, T. 2020. Group structure and kinship in Beluga Whale societies. Sci. Rep. 10 : 11462. doi:10.1038/s41598-020-67314-w

Ouellet, J.-F., Michaud, R., Moisan, M. and Lesage, V. 2021. Estimating the proportion of a Beluga population using specific areas from connectivity patterns and abundance indices. Ecosphere. 12 : e03560. doi:10.1002/ecs2.3560

Pagès, H., Aboyoun, P., Gentleman, R. and DebRoy, S. 2021. Biostrings: efficient manipulation of biological strings. R package version 2.62.0.

Palsbøll, P.J., Heidi-Jøgensen, M.P. and Bérubé, M. 2002. Analysis of mitochondrial control region nucleotide sequences from Baffin Bay Belugas (*Delphinapterus leucas*): detecting pods or subpopulations? NAMMCO Sci. Publ. 4 : 39–50.

Paradis, E. 2010. Pegas: an R package for population genetics with an integrated-modular approach. Bioinformatics. 26 : 419–420. doi:10.1093/bioinformatics/btp696

Postma, L.D. 2017. Genetic diversity, population structure and phylogeography among Belugas (*Delphinapterus leucas*) in Canadian waters: broad to fine-scale approaches to inform conservation and management strategies (PhD Thesis). University of Manitoba, Winnipeg (Manitoba). 314 p.

Postma, L.D., Petersen, S.D., Turgeon, J., Hammill, M.O., Lesage, V. and Doniol-Valcroze, T. 2012. Beluga Whales in James Bay: a separate entity from eastern Hudson Bay Belugas? DFO Can. Sci. Advis. Sec. Res. Doc. 2012/074. iii + 23 p.

R Core Team. 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Richard, P.R. 2010. Stock definition of Belugas and Narwhals in Nunavut. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/022. iv + 14 p.

Richard, P. and Orr, J.R. 1986. A review of the status and harvest of White Whales (Delphinapterus leucas) in the Cumberland Sound area, Baffin Island. Can. Tech. Rep. Fish. Aquat. Sci. 1447. iv + 25 p.

Richard, P.R. and Stewart, D.B. 2009. Information relevant to the identification of critical habitat for Cumberland Sound Belugas (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2008/085. 28 p.

Richard, P.R., Orr, J.R. and Barber, D.G. 1990. The distribution and abundance of Belugas, *Delphinapterus leucas*, in eastern Canadian subarctic waters: a review and update. *In* Smith, T.G., D.J. St. Aubin, and J.R. Geraci (ed.). Advances in research on the Beluga Whale, *Delphinapterus leucas*. Can. Bull. Fish. Aquat. Sci. 224 : p. 23–38.

Rioux, È., Lesage, V., Postma, L., Pelletier, É., Turgeon, J., Stewart, R.E.A., Stern, G. and Hammill, M.O. 2012. Use of stable isotopes and trace elements to determine harvest composition and wintering assemblages of Belugas at a contemporary ecological scale. Endang. Species Res. 18 : 179–191. doi:10.3354/esr00445

Seutin, G., White, B.N. and Boag, P.T. 1991. Preservation of avian blood and tissue samples for DNA analyses. Can. J. Zool. 69 : 82–90. doi:10.1139/z91-013

Skovrind, M., Castruita, J.A.S., Madsen, T.B., Postma, L. and Lorenzen, E.D. 2019. Patterns of mtDNA variation in relation to currently recognized stocks of Beluga Whales, *Delphinapterus leucas.* Mar. Fish. Rev. 81 : 87–97.

Stewart, R.E.A. 2008. Redefining Walrus stock in Canada. Arctic 61(3) : 292–308. doi:10.14430/arctic26

Smith, T.G. and Hammill, M.O. 1986. Population estimates of White Whale, *Delphinapterus leucas*, in James Bay, Eastern Hudson Bay and Ungava Bay. Can. J. Fish. Aquat. Sci. 43 : 1982–1987. doi:10.1139/f86-243

Smith, T.G., Hammill, M.O. and Martin, A.R. 1994. Herd composition and behaviour of White Whales (*Delphinapterus leucas*) in two Canadian Arctic estuaries. Medd. Grønl. Bioscience, 39 : 175–184.

Turgeon, J. Duchesne, P. Postma, L.D. and Hammill, M.O. 2009. Spatiotemporal distribution of Beluga stocks (*Delphinapterus leucas*) in and around Hudson Bay: Genetic mixture analysis based on mtDNA haplotypes. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/011. iv + 14 p.

Turgeon, J., Duchesne, P., Colbeck, G.J.C., Postma, L. and Hammill, M.O. 2012. Spatiotemporal segregation among summer stocks of Beluga (*Delphinapterus leucas*) despite nuclear gene flow: implication for an endangered population in eastern Hudson Bay (Canada). Conserv. Genet. 13(2) : 419–433. doi:10.1007/s10592-011-0294-x

Waples, R.S. and Gaggiotti. O. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Mol. Ecol. 15 : 1419–1439. doi:10.1111/j.1365-294X.2006.02890.x

Watt, C.A., Marcoux, M., Ferguson, S.H., Hammill, M.O. and Matthews, C.J.D. 2020. Population dynamics of the threatened Cumberland Sound Beluga (*Delphinapterus leucas*) population. Arct. Sci. 7(2) : 545–566. doi:10.1139/as-2019-0030

Whitehead, H. 2017. Gene-culture coevolution in Whales and Dolphins. Proc. Natl. Acad. Sci. U.S.A. 114 : 7814–7821. doi:10.1073/pnas.1620736114

FIGURES

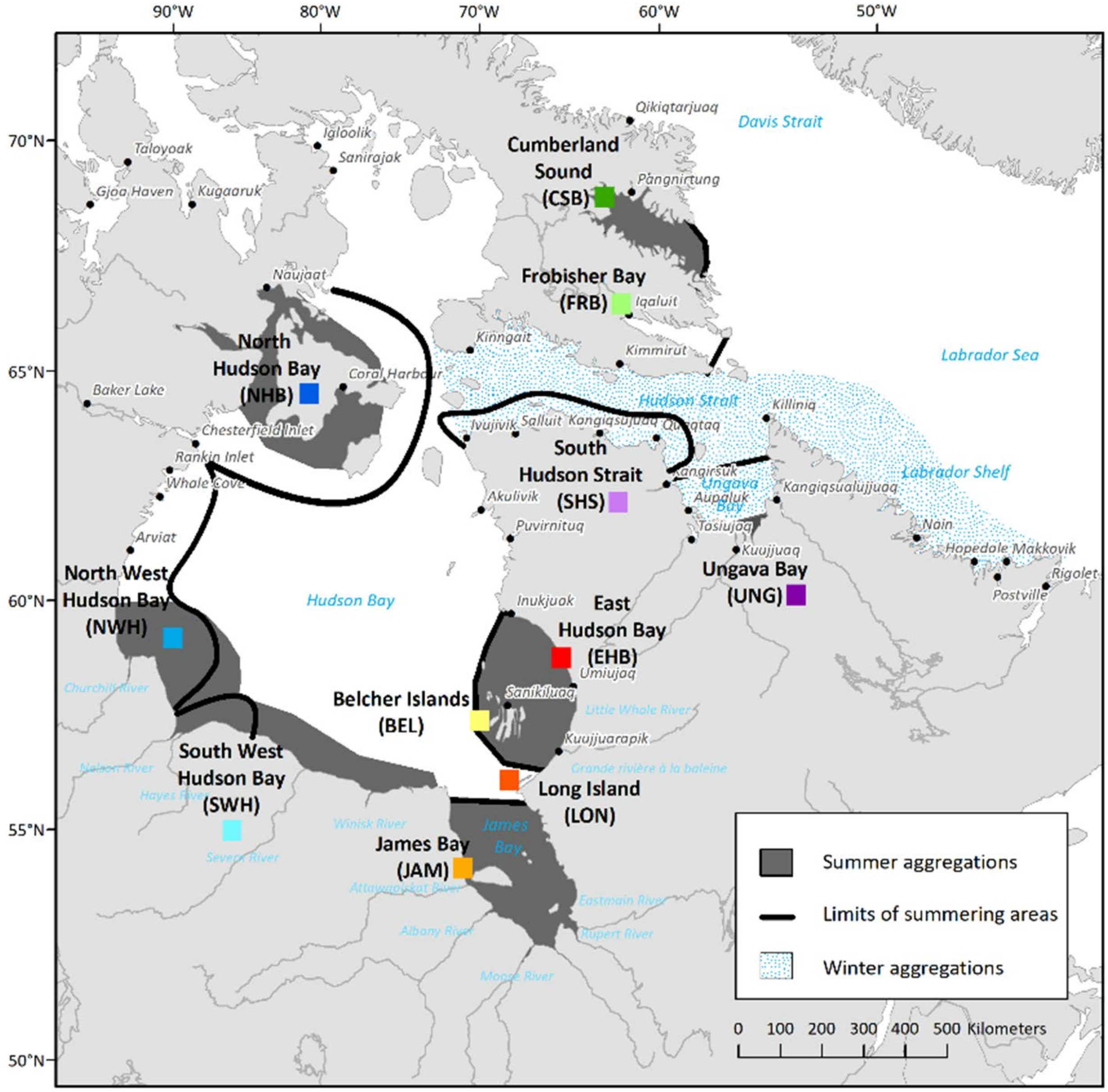

Figure 1. Geographic delimitation of summering areas investigated for population structure of beluga in the Hudson Bay-Strait Complex. Major Inuit communities (also harvest locations in Table 1) considered in each area are indicated but may not reflect all of the hunting regions of Inuit communities. The four largest summering aggregations indicated in dark grey (a) are western Hudson Bay (WHB), James Bay (JAM), eastern Hudson Bay (EHB) and Cumberland Sound (CSB, see Table 1 for all acronyms for summering areas). The WHB and the EHB are migrating through the Hudson Strait to the hypothetical winter area (dotted blue). Summering and wintering aggregations adjacent to Hudson Bay are reproduced from DFO (2002) or Hobbs et al. (2019).

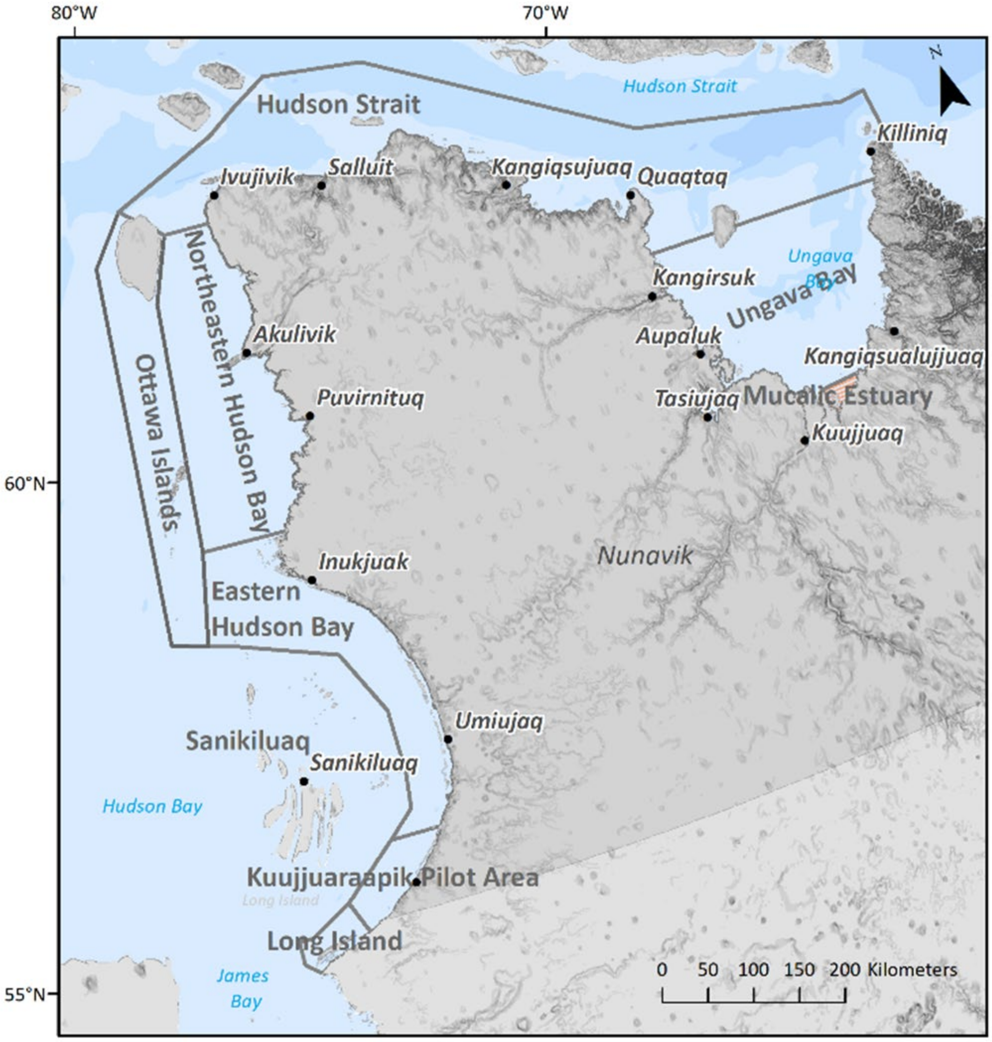

Figure 2. Nunavik management areas. The smaller management areas of the Nastapoka River and Little Whale River are not presented due to the scale of the map. There are no official geographic limits to the Sanikiluaq management area.

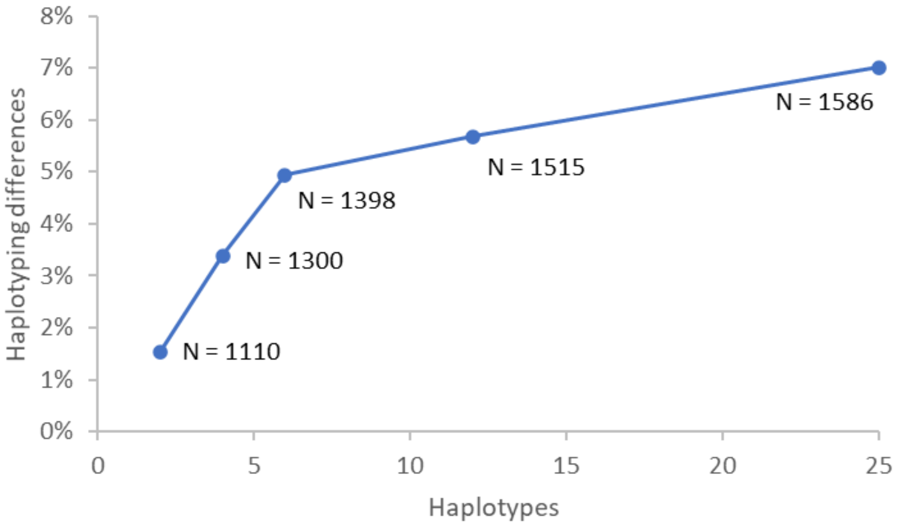

Figure 3. Increasing haplotyping differences with haplotype rarity between databases from the FWI and MLI facilities. Sample size are indicated as cumulative values for more abundant haplotypes (to the left) and combined with rarer haplotypes (to the right). This figure shows that haplotype discrepancies between both databases are not for the two most abundant haplotypes (N = 1110 samples) but for the 3 to 6 more abundant haplotypes. Rarer haplotypes also increase haplotyping differences but to a lesser extent due to their low sample sizes.

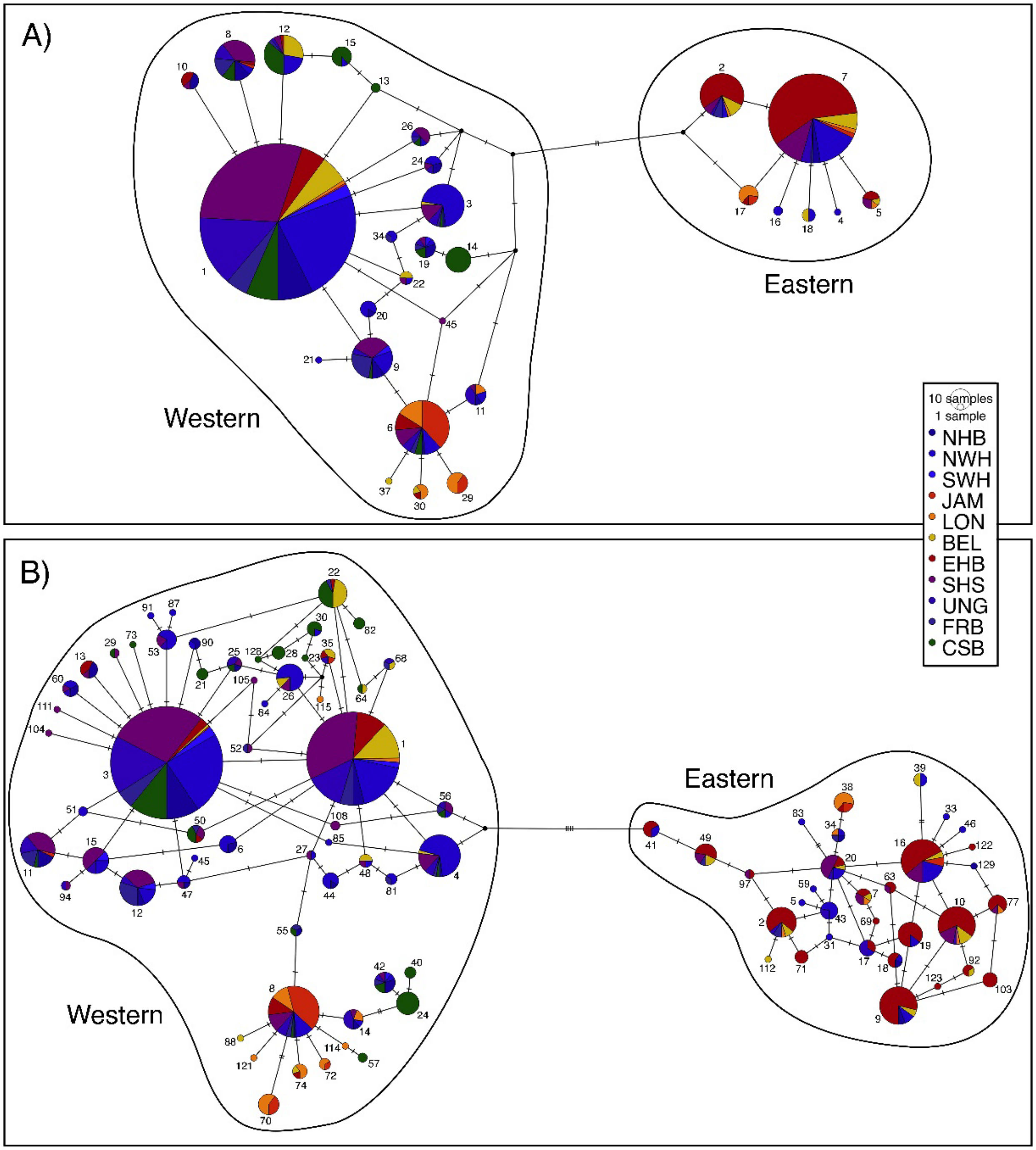

Figure 4. Haplotype networks of the mitochondrial DNA control region short (234 nucleotides, A) or long (615 nucleotides, B) haplotypes for belugas from the summering areas in the Hudson Bay-Strait Complex. Geographic limits of summering areas are described in Fig. 1 and acronyms defined in Table 1. A statistical parsimony (TSC) network using PopArt is presented. Small perpendicular bars along lines between two haplotypes indicate the number of mutations between haplotypes. Black circles lacking haplotype numbers indicate missing haplotypes in the evolution of the network. In both panels, the western and the eastern haplogroups are presented in the left and right, respectively.

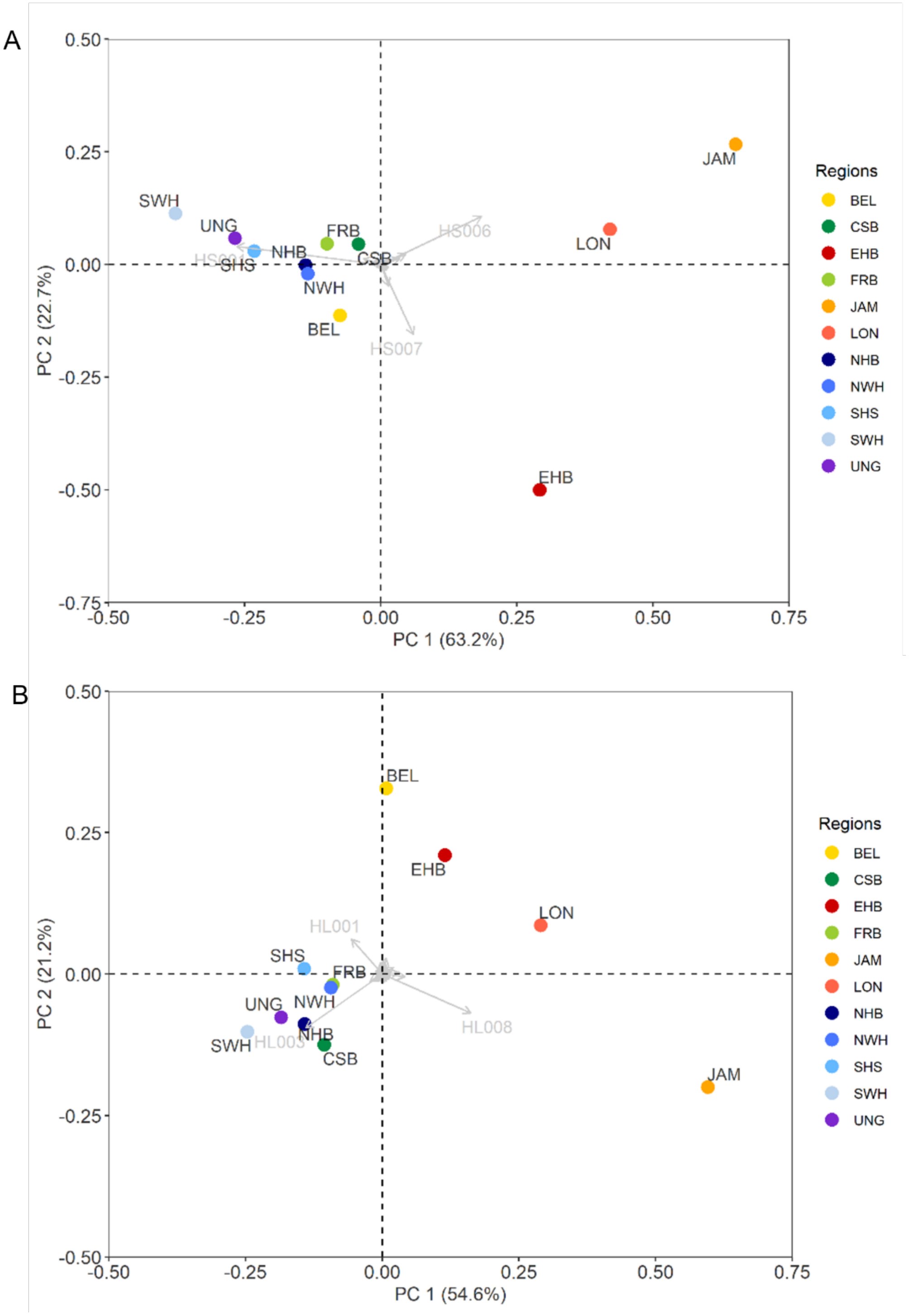

Figure 5. Biplot from the principal component analyses (PCA) using haplotype frequencies of the short (A, 234 nucleotides) or long (B, 615 nucleotides) mitochondrial DNA control region for belugas from the summer areas in the Hudson Bay-Strait Complex (see Table 1 for acronyms). The length and direction of arrows explain the effect of the haplotypes on the distance between summer aggregations.

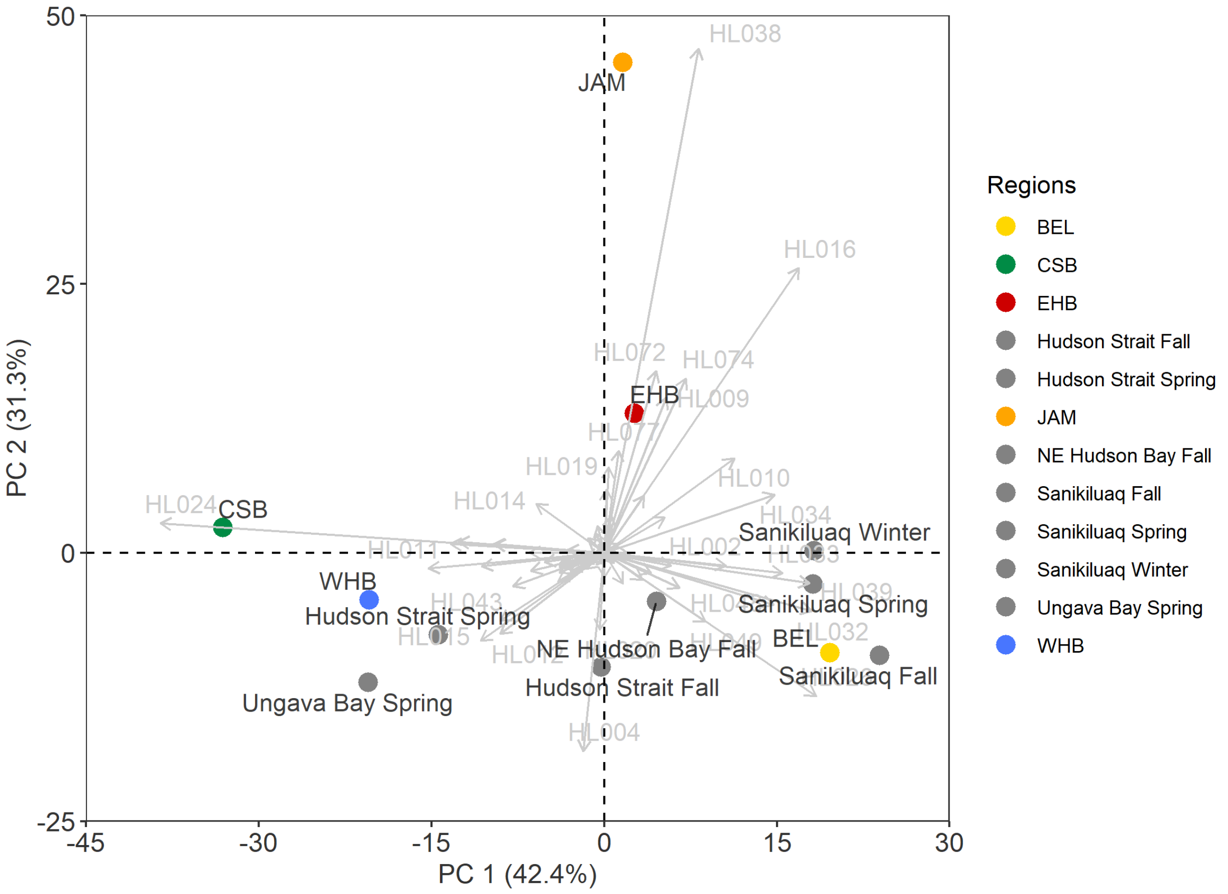

Figure 6. Biplot from the principal component analysis (PCA) using haplotype frequencies of the long haplotype (615 nucleotides) for the mitochondrial DNA control region for belugas from five populations (in color; WHB, JAM, EHB, BEL, CSB; see Table 1 for acronyms) and from Nunavik or Sanikiluaq management units (in grey, see Fig. 1b for locations, NE: Northeastern). The length and direction of arrows explain the effect of the haplotypes on the distance between summer aggregations.

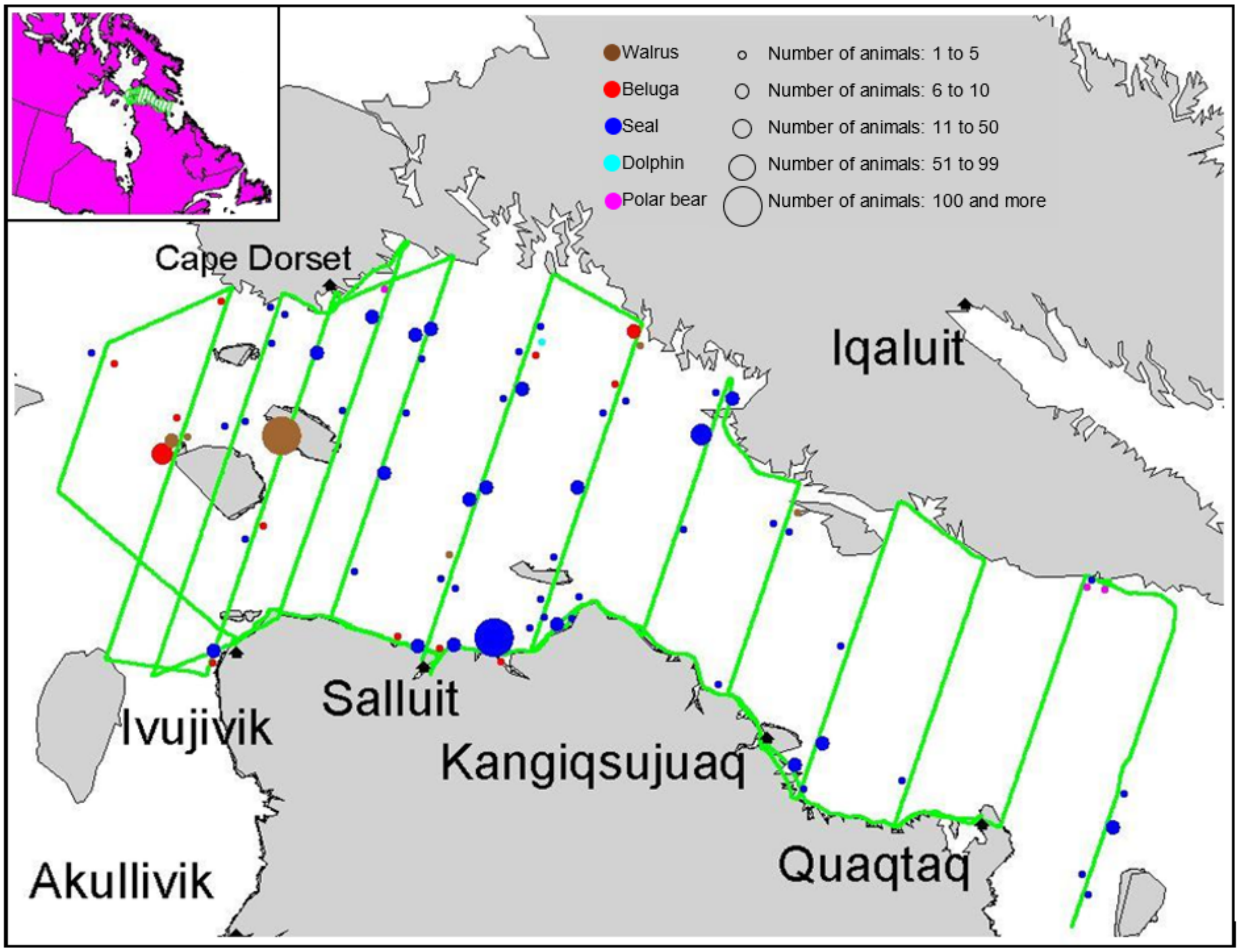

Figure 7. Marine mammal observations from systematic aerial surveys flown 9-12 August, 2010. A total of 69 belugas were counted (J-F Gosselin, personal observations).

TABLES

Table 1. Summarized metadata of all samples and a subset of summer samples. Table S1 provides more details on each individual.

Areas	All samples			Summer aggregations		
	Month range	Year range	N	Month range	Year range	N
North Hudson Bay (NHB)	Apr.–Nov.	1989–2009	90	Jul.–Aug.	1993–2009	67
North West Hudson Bay (NWH)	Jun.–Oct.	1985–2015	264	Jul.–Aug.	1985–2015	234
South West Hudson Bay (SWH)	Jul.–Aug.	2002–2005	17	Jul.–Aug.	2002–2005	17
James Bay (JAM)	Jul.–Oct.	2002–2016	45	Jul.–Aug.	2003–2016	38
Long Island (LON)	Jun.–Oct.	2003–2018	59	Jul.–Aug.	2003–2018	37
Belcher Islands (BEL)	Jan.–Dec.	1993–2021	422	Jul.–Aug.	1994–2020	66
South East Hudson Bay (EHB)	May–Oct.	1990–2020	230	Jul.–Aug.	1994–2019	183
North East Hudson Bay (NEH)	May–Oct.	1998–2019	48	-	-	0
South Hudson Strait (SHS)	May–Nov.	1994–2021	1372	Jul.–Aug.	1995–2020	241
North Ungava Bay (UNG)	Jun.–Dec.	1994–2020	157	Jul.–Aug.	1994–2020	113
Frobisher Bay (FRB)	Jun.–Aug.	1991–2004	53	Jun.–Aug.	1991–2004	53
Cumberland Sound (CSB)	May–Aug.	1982–2018	104	Jun.–Aug.	1982–2018	87
Total	-		2861	-		1136

Table 2. Genetic composition from the 11 summering areas of belugas from or close to the Hudson Bay-Strait Complex using short (234 nucleotides) and long (615 nucleotides) mtDNA control region sequences (haplotype). See table 1 for acronyms of summer aggregations and sample sizes. Polymorphic sites (S) were quantified with adegenet 2.1.5 (Jombart 2008; Jombart and Ahmed 2011), haplotype diversity (Pi) was estimated with the hap.div function of pegas 1.1 (Paradis 2010), whereas the number of haplotypes (H), private haplotypes (i.e., only present in one summering aggregation, Hp) and the proportion of private haplotypes (Hp%) were calculated manually.

Summering aggregations	Short haplotype					Long haplotype				
	S	H	Pi	Hp	Hp%	S	H	Pi	Hp	Hp%
NHB	13	11	0.61	0	0.0	22	20	0.81	1	1.5
NWH	16	20	0.66	3	1.7	31	42	0.87	12	5.6
SWH	5	3	0.32	0	0.0	8	5	0.74	0	0.0
JAM	9	6	0.52	0	0.0	19	8	0.56	0	0.0
LON	11	9	0.85	0	0.0	23	15	0.91	3	8.1
EHB	13	10	0.61	0	0.0	23	29	0.92	5	6.6
BEL	12	10	0.71	1	1.5	21	21	0.83	2	3.0
SHS	15	16	0.52	1	0.4	25	34	0.80	4	2.1
UNG	12	12	0.46	0	0.0	22	21	0.75	0	0.0
FRB	13	11	0.72	0	0.0	20	17	0.86	0	0.0
CSB	10	11	0.76	2	19.5	19	22	0.84	9	34.5
Total	17	29	0.72	7	2.0	39	90	0.89	36	5.8

Table 3. Estimating robustness of the reference groups for harvested belugas from the Hudson Bay-Strait Complex using the package rubias in R (more details in methods; Moran and Anderson 2019). Results should be read in rows, i.e., 15.1% of the WHB reference individuals were reassessed to WHB at probability equal or greater than 95%. Random probabilities of reassignment are 25 and 20% for 4 and 5 reference groups, respectively.

Reference groups	N	≥95%	≥80%	≥60%	≥40%
Five populations					
WHB population	318	15.1	27.0	71.4	87.1
JAM population	75	28.0	70.7	74.7	77.3
EHB population	183	0.0	11.5	26.8	69.4
BEL population	66	0.0	0.0	3.0	19.7
CSB population	87	13.8	35.6	39.1	39.1
Four populations and BEL-EHB stock					
WHB population	318	15.1	27.0	71.4	87.1
JAM population	75	28.0	70.7	74.7	77.3
BEL-EHB stock	249	2.4	23.3	43.0	84.7
CSB population	87	13.8	35.6	39.1	39.1

Table 4. Past genetic mixture analysis (1982-2018) using the Pella-Masuda model to determine the proportions of beluga from WHB or BEL-EHB stock in the harvest of Nunavik and Sanikiluaq management units (format modified, from Hammill et al. 2021; BEL-EHB stock was identified as EHB population in the original document). Ns: number of individual samples; Nv: number of different hunt dates (events); P: proportion; WHB: Western Hudson Bay, EHB: Eastern Hudson Bay, UNK: Unknown; CI: confidence interval based on variance among hunting events; CV: coefficients of variation based on individual samples (CVs) / hunting events (CVv). ND: not determined (sample size < 10).

Nunavik communities

Season	Ns/Nv	WHB population (%)		BEL-EHB stock (%)		CVs/CVv	UNK P (%)
		P	95% CI	P	95% CI		
Spring (Feb.1–Aug.31)							
Hudson Strait	770/347	82.9	78.5–87.0	**11.7**	8.1–16.0	0.2/0.2	5.3
NE Hudson Bay	2/1	ND	-	**ND**	-	-	-
Ungava Bay	122/76	87.4	77.8–94.6	**6.0**	0.8–15.8	0.6/0.7	6.6
Fall (Sep.1–Jan.31)							
Hudson Strait	454/180	67.6	60.3–74.5	**29.1**	22.4–36.3	0.1/0.1	3.3
NE Hudson Bay	31/14	49.1	26.4–72.0	**44.5**	23.5–66.5	0.3/0.3	6.5
Ungava Bay	4/4	ND	-	**ND**	-	-	ND

Sanikiluaq

Season	Ns/Nv	WHB population (%)		BEL-EHB stock (%)		CVs/CVv	UNK P (%)
		P	95% CI	P	95% CI		
Spring (Apr.1–Jun.30)	301/107	76.8	69.2–83.7	**1.6**	0.0–6.6	0.1/0.1	12.6
Ext. Spring (Apr.14–Jul.1)	31/18	75.1	67.2–82.2	**4.6**	1.1–10.2	0.4/0.5	20.4
Summer (Jul.1–Aug.31)	45/30	61.5	32.8–86.2	**25.6**	4.9–56.0	0.4/0.5	12.9
Fall (Sep.1–Nov.30)	45/30	97.8	91.8–99.9	**0.0**	-	-	2.2
Winter (Dec.1–Mar.31)	56/7	31.3	6.1–65.6	**36.6**	9–70.7	0.2/0.5	32.1

Table 5. Updated genetic mixture analysis using the long haplotypes (MLI database) and new reference groups for harvested belugas from Nunavik communities, and Sanikiluaq. NE Hudson Bay: Northeastern Hudson Bay; Ns: number of individual samples; Nv: number of different hunt dates (events); P: proportion; WHB: Western Hudson Bay, EHB: Eastern Hudson Bay, JAM: James Bay, CSB: Cumberland Sound, UNK: Unknown; CI: confidence interval based on variance among hunting events; CV: coefficients of variation based on individual samples (CVs) / hunting events (CVv). ND: not determined (sample or event size < 10).

Nunavik communities

Season	Ns/Nv	WHB population (%)			BEL-EHB stock (%)			JAM population (%)			CSB population (%)			UNK P (%)
		P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	
Spring (Feb.1–Aug.31)														
Hudson Strait	824/364	75.7	70.5–80.6	0.0/0.0	**12.3**	8.6–16.5	0.1/0.2	2.6	0.6–5.9	0.5/0.6	6.5	3.6–10.2	0.2/0.3	2.9
NE Hudson Bay	2/1	ND	-	-	**ND**	-	-	ND	-	-	ND	-	-	-
Ungava Bay	143/87	87.8	76.5–95.7	0.1/0.1	**4.7**	0.8–11.8	0.6/0.6	1.1	0.0–8.1	2.3/2.2	5.1	0.7–13.3	0.6/0.7	1.3
Fall (Sept 1–Jan. 31)														
Hudson Strait	512/202	49.6	40.0–59.2	0.1/0.1	**44.0**	35.1–53.0	0.1/0.1	0.0	-	-	2.8	0.7–6.1	0.5/0.5	3.6
NE Hudson Bay	45/19	37.3	18.0–59.0	0.3/0.3	**50.1**	23.9–76.2	0.2/0.3	8.2	0.4–26.3	0.8/0.9	-	-	-	4.4
Ungava Bay	6/6	ND	-	-	**ND**	-	-	ND	-	-	-	-	-	ND

Sanikiluaq

Season	Ns/Nv	WHB population (%)			BEL-EHB stock (%)			JAM population (%)			CSB population (%)			UNK P (%)
		P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	
Spring (Apr.1–Jun.30)	229/99	7.2	2.1–14.8	0.5/0.5	**62.8**	51.5–73.4	0.1/0.1	17.4	9.4–27.2	0.2/0.3	-	-	-	12.6
Fall (Sep.1–Nov.30)	49/35	28.4	9.6–52.6	0.4/0.4	**61.0**	35.1–83.9	0.2/0.2	2.4	0.0–16.1	2.3/1.9	-	-	-	8.2
Winter (Dec.1–Mar.31)	76/11	43.7	20.1–69.0	0.3/0.3	**39.9**	13.0–70.8	0.3/0.4	13.7	2.6–32.0	0.5/0.6	-	-	-	2.7

Table 6. Quantifying the effect of resequencing on proportions of beluga from each population and unknown (UNK) harvested in Nunavik and Belcher Islands managements units. Note that the proportions of Eastern Hudson Bay (EHB) population presented in this table are not reliable due to the low number of reference individuals in the Western Hudson Bay (WHB) population (n = 41, see methods for more details) or low sample size per management unit (using only samples in common to FWI and MLI databases). DIFF are the absolute difference between EHB proportions from simulations with FWI samples until 2019 and same or different reference samples for MLI samples until 2019, respectively.

Management units		FWI samples until 2019 (%)			MLI samples until 2019 (%)			
	N	WHB	**EHB**	UNK	WHB	**EHB**	UNK	**DIFF (%)**
Hudson Strait								
Spring	621	81.6	**13.3**	5.2	78.2	**12.6**	9.2	**0.7**
Fall	359	71.7	**25.5**	2.8	64.8	**30.2**	5.0	**4.7**
Ungava Bay								
Spring	96	90.2	**3.6**	6.3	83.5	**10.2**	6.3	**6.6**
Northeastern Hudson Bay								
Fall	22	50.9	**44.6**	4.6	47.2	**48.3**	4.6	**3.7**
Sanikiluaq								
Spring	181	55.3	**23.1**	21.6	51.4	**26.5**	22.1	**3.4**
Fall	31	86.2	**10.6**	3.2	85.8	**11.0**	3.2	**0.4**
Winter	48	59.6	**38.3**	2.1	20.5	**50.3**	29.2	**12.0**

Table 7. Genetic mixture analysis using the long haplotypes and new reference groups for harvested belugas from the Hudson Strait at different periods. September-October represents harvested proportions during the usual hunt closure period. Ns: number of individual samples; Nv: number of different hunt dates (events); P: proportion; WHB: Western Hudson Bay, EHB: Eastern Hudson Bay, JAM: James Bay, CSB: Cumberland Sound, UNK: Unknown; CI: confidence interval based on variance among hunting events; CV: coefficients of variation based on individual samples (CVs) / hunting events (CVv). ND: not determined (sample or event size < 10).

Period	Ns/Nv	WHB population (%)			BEL-EHB stock (%)			JAM population (%)			CSB population (%)			UNK P (%)
		P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	P	95% CI	CVs/CVv	
May	6/6	ND	-	-	**ND**	-	-	ND	-	-	ND	-	-	ND
Jun.	577/230	71.3	64.977.3	0.0/0.0	**12.4**	7.9–17.7	0.2/0.2	4.8	2.0–8.8	0.4/0.4	8.6	4.7–13.5	0.2/0.3	2.9
Jul.	223/114	84.7	77.2–90.9	0.0/0.0	**11.0**	5.6–18.0	0.3/0.3	0.0	-	-	1.6	0.0–6.7	1.0/1.1	2.7
Aug.	18/14	75.8	46.8–95.3	0.2/0.2	**13.7**	0.0–57.4	0.8/1.2	4.7	0.0–33.2	1.9/1.9	0.3	0.0–0.6	0.5/0.6	5.6
Sept.	26/7	ND	-	-	**ND**	-	-	ND	-	-	ND	-	-	ND
Oct.	223/104	49.5	37.5–61.6	0.1/0.1	**47.3**	34.7–60.1	0.1/0.1	0.0	-	-	0.0	-	-	3.1
Nov.	263/91	45.9	32.3–59.8	0.1/0.2	**45.1**	33.0–57.6	0.1/0.1	0.0	-	-	4.4	1.1–9.7	0.5/0.5	4.6
Nov. 1–10	167/62	41.2	27.8–55.2	0.2/0.2	**51.5**	39.0–63.9	0.1/0.1	0.0	-	-	4.4	0.5–12.2	0.6/0.7	3.0
Nov. 11–20	96/29	50.1	22.5–77.6	0.2/0.3	**33.9**	13.9–57.6	0.2/0.3	4.5	0.5–12.5	1.0/0.7	4.3	0.5–12.1	0.8/0.7	7.3
Nov. 21–30	49/13	71.9	47.9–90.6	0.1/0.2	**10.4**	0.9–29.5	0.5/0.7	0.0	-	-	7.5	0–35	1.0/1.3	10.2

SUPPLEMENTARY MATERIAL

Table S1

Metadata for each beluga from this study (N = 2861)

Table S2

Sequence library of short control region in the mtDNA of belugas from the Hudson Bay-Strait Complex

Table S3

Sequence library of long control region in the mtDNA of belugas from the Hudson Bay-Strait Complex

Table S4

Long haplotype frequencies per summering area

All tables are available at this link: Reexamining populations of beluga in the Hudson Bay-Strait Complex and assessing the impact on harvests in Nunavik and Sanikiluaq management units

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Recovery Potential Assessment for Beluga (*Delphinapterus leucas)* Stocks in Nunavik (Northern Quebec)

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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

In 2020, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the eastern Hudson Bay (EHB) and Ungava Bay (UB) beluga designatable units (DUs) as Threatened and Endangered, respectively. These two DUs are currently under ministerial review for listing under the *Species at Risk Act* (SARA). DFO Science has been tasked to undertake a Recovery Potential Assessment (RPA) for these two DUs to help inform the listing decision and, if the listing is confirmed, the future development of recovery documents. Since the last beluga DU review by COSEWIC in 2016, a distinct genetic population has been identified in the Belcher Islands (BEL), within the EHB DU's geographic summer distribution area. Therefore, this RPA is not specific to the EHB genetic population alone, but rather to the joint BEL-EHB stock. Beluga aggregations are observed during summer in the estuaries and along the coast of the eastern Hudson Bay arc. In the fall, beluga from this area undertake a northward seasonal migration along the Nunavik coast to reach wintering areas in Hudson Strait and along the Labrador coast. While UB beluga were historically abundant in southern Ungava Bay, no large beluga aggregation has been seen during surveys conducted over the past 40 years. However, continued sightings and occasional harvests either suggest that the Ungava Bay DU persists at a very low level, or that neighbouring DUs frequent Ungava Bay. Most recent data indicates a continuous decline in BEL-EHB beluga since the 1970s, with an abundance estimate of 2,900-3,200 beluga in 2021. Management of subsistence beluga harvest is the main challenge for BEL-EHB and UB beluga survival and recovery. Other threats from human activities in the habitat of BEL-EHB and UB beluga include anthropogenic noise, industrial development, vessel traffic, chemical pollution, commercial fisheries, and climate change. A long-term (i.e., over > 100 years) distribution objective would be to recover the historical distribution of beluga in eastern Hudson Bay estuaries and within southern Ungava Bay and its estuaries.Three recovery abundance objectives are proposed for BEL-EHB beluga: 1) attain an abundance equal to or exceeding the 2015 abundance estimate in ten years, 2) attain an abundance equal to or exceeding the Precautionary Reference Level (PRL = 5,300 individuals) in 86 years, and 3) attain an abundance corresponding to the demographic growth given no harvest from this stock. The current harvest levels are incompatible with any of these recovery targets. Two recovery targets for abundance are proposed for UB beluga: 1) maintain population size at or above the 2022 abundance estimate, and 2) attain a population size corresponding to the demographic growth given no harvest from this DU. Perpetuating current harvest levels for UB beluga would lead to population decline and extirpation of any remaining stock in this area within 4 to 21 years. The Potential Biological Removal for BEL-EHB and UB beluga was estimated at 5 and 0 whales per year, respectively based on 2022 abundance estimates. Projections indicate that it is feasible for the BEL-EHB stock to reach the PRL in 86 year with an annual harvest level of 20 beluga.

CONTEXT

In 2016, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has identified eight recognized designatable units (DUs) of beluga in Canada, including the Eastern Hudson Bay (EHB) and the Ungava Bay (UB), populations. In 2020, COSEWIC assessed the EHB DU as Threatened and the UB DU as Endangered. These two DUs are currently under ministerial review for listing under the *Species at Risk Act* (SARA). In support of listing recommendations for EHB and UB beluga populations, DFO Science has been asked to undertake a Recovery Potential Assessment (RPA) for these two DUs.

Since the last COSEWIC beluga DU review, a distinct genetic population has been identified in the Belcher Islands (BEL), within the EHB DU's geographic summer distribution area. Accordingly, this RPA is not specific to the EHB genetic population alone, but rather to the joint BEL-EHB stock, and hereafter referred to as BEL-EHB beluga to better reflect the composite nature of the beluga aggregations occurring in this area during summer (see Caution section below for details).

The information presented as part of the current report has been reviewed during the February 20-24, 2023 National marine mammal peer review committee meeting (Appendix A), and updates and/or consolidates any existing advice regarding both EHB and UB beluga. The current RPA may be used to inform both scientific and socio-economic aspects of the listing decision, the development of a recovery strategy and action plan, or the actions undertaken by DFO following SARA listing.

CAUTION

Since the last COSEWIC beluga designatable unit (DU) review, a genetic re-analysis of beluga samples by DFO has identified a distinct population in the Belcher Islands (BEL), i.e., within the geographic summer distribution area of the EHB DU (Parent et al. 2023; COSEWIC 2016). Aerial surveys in eastern Hudson Bay showed that there was a continuous distribution of beluga from the coast between Kuujjuarapik and Inukjuak, which extends as far offshore as the Belcher Islands (Smith and Hammill 1986; Kingsley 2000; Gosselin et al. 2002, 2009, 2013; St-Pierre et al. 2024). In addition, most beluga equipped with satellite transmitters in estuaries of the eastern Hudson Bay performed repeated inshore-offshore movements extending out to the Belcher Islands during summer (Bailleul et al. 2012a). Therefore, there is likely a spatial overlap between the BEL and EHB genetic population distributions, and beluga summering in this area are considered together throughout this report, and referred to as the BEL-EHB management stock (DFO 2022). The conclusions from this report should be interpreted with caution as the potential for recovery and the recovery targets are not specific to the EHB genetic population alone, but rather based on the abundance and distribution of the joint BEL-EHB stock.

In addition, there is uncertainty as to whether the Ungava Bay beluga DU still exists or whether is has been extirpated. Beluga in this DU were defined by a summer aggregation centered near the Marralik River estuary, with concentrations at other rivers in southern Ungava Bay (COSEWIC 2016). However, COSEWIC (2004) defines the Ungava Bay area as the range for this DU, and it is generally recognized that beluga from other DUs occur in Ungava Bay from spring to fall, but not in summer (Lewis et al. 2009; Cuerrier et al. 2012; Cardinal 2013). Consequently, aerial surveys conducted in summer over the full extent of Ungava Bay provide an abundance estimate for the entirety of the bay (Sauvé et al. 2023; Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). Although beluga were detected during the 2022 summer survey of Ungava Bay, none were observed in the historical aggregation areas in the south of the bay (Sauvé et al. 2023). Therefore, there is uncertainty as to whether beluga sighted during the 2022 survey represent beluga from the UB DU itself or animals from other stocks that interrupted their summer migration the central Ungava Bay area. Nevertheless, a small number of beluga continue to be sighted and harvested in estuaries in southern Ungava Bay (e.g., Durkalec et al. 2020). The present assessment of the potential for recovery for the UB DU is based on the most recent, 2022 survey, which covered the entirety of Ungava Bay. For consistency with the surveyed area, we considered harvest levels occurring throughout Ungava Bay when estimating threats and potential biological removals.

INTRODUCTION

The beluga (*Delphinapterus leucas)* has a nearly circumpolar distribution in Arctic and subarctic waters (NAMMCO 2018). Only one species is recognized worldwide, with no recognized subspecies. A significant proportion of the species' global range is distributed in Canadian waters. Populations are defined based on summering aggregations (Richard 2010; COSEWIC 2016; NAMMCO 2018), informed by lines of evidence underlining that beluga show strong intra- and inter-annual site fidelity based on behavioural (Caron and Smith 1990), as well as telemetry (Bailleul et al. 2012a), genetic (Brown Gladden et al. 1999; de March and Postma 2003; Postma et al. 2012; Turgeon et al. 2012; Colbeck et al. 2013; Parent et al. 2023), isotopic and trace element (Rioux et al. 2012) studies.

There are eight recognized DUs of beluga in Canada, namely the Eastern Beaufort Sea (EBS), Eastern High Arctic – Baffin Bay (EHA-BB), Cumberland Sound (CS), Ungava Bay (UB), Western Hudson Bay (WHB), Eastern Hudson Bay (EHB), St. Lawrence Estuary (SLE), and James Bay (JB) populations (Figure 2). Among all eight recognized beluga DUs, the CS, EHB and UB DUs are currently under ministerial review for listing, while the SLE DU is listed under the *Species at Risk Act* (SARA).

The COSEWIC first assessed the EHB and UB beluga DUs in 1988, affording them a status of Threatened and Endangered, respectively (Reeves and Mitchell 1988). The status of UB beluga has remained Endangered throughout COSEWIC's reassessments (COSEWIC 2004, 2020a). EHB beluga were reclassified as Endangered in 2004 based on a declining demographic trend and overharvesting, but their status was revised to Threatened in 2020 after stabilisation of the demographic trend and harvest removals (COSEWIC, 2004, 2020a).

After the COSEWIC assesses an aquatic species as Threatened, Endangered, or Extirpated, DFO undertakes a number of actions required to support implementation of the SARA. Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice is typically developed through a RPA that is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes, including recovery planning.

In 2005, DFO conducted a RPA for EHB and UB beluga conjointly with the CS and SLE beluga (DFO 2005). Since then, various research projects have been undertaken by DFO Science to increase the understanding of EHB and UB beluga populations. The advice generated via the present process updates and/or consolidates any existing advice regarding both the BEL-EHB and UB beluga stocks.

ASSESSMENT

SPECIES INFORMATION

Element 1*: Summarize the biology of EHB and UB Beluga.*

***Element 2**: Evaluate the recent species trajectory for abundance, distribution and number of populations.*

***Element 3**: Estimate the current or recent life-history parameters for EHB and UB Beluga*

Biology

The beluga is a medium-sized, toothed whale inhabiting Arctic and sub-Arctic waters. Along with the narwhal, it is one of two cetacean species of the *Monodontidae* family, and the only member of the *Delphinapterus* genus. They have a round head adorned with a melon which they use for echolocation. They lack a dorsal fin, which is probably an adaptation to life in partially ice-covered waters, and have an unfused cervical vertebrae which allows flexibility in the neck. Beluga calves are born dark grey or brown in colour and measure around 1.5 m at birth (Lesage et al. 2014; COSEWIC 2020a). They gradually transition to white between 10-20 years of age (COSEWIC 2020a). Mature individuals are white in colour and are sexually dimorphic, with a size ranging between 2.6 and 4.5 m, and adult female lengths nearing 80% the length of adult males (Lesage et al. 2014; COSEWIC 2020a). Size at sexual maturity may vary among populations. Beluga sampled in Hudson Bay were of relatively small size at maturity compared to other regions (see Lesage et al. 2014 for review), with estimated asymptotic length for mature males and females of 3.5 and 3.3 meters, respectively (Doidge 1990a). Whether this observed smaller size represents a phenotypic trait of Hudson Bay beluga populations or results from the long history of heavy exploitation that might have depleted older, bigger individuals from the area is unknown.

Gregarious in nature, belugas can form large aggregations (>300 individuals) throughout their habitat, and both closely related and unrelated individuals may group together (O’Corry-Crowe et al. 2020). They have a large repertoire of acoustic calls, such as clicks, burst pulses, whistles, and combined signals. Belugas mostly vocalize in the 0.1 to 12 kHz frequency range (Erbe et al. 2016), although they produce sounds up to 160 kHz (Southall et al. 2007). Their peak hearing frequency is situated between 0.5 and 130 kHz (Erbe et al. 2016). Vocalizations are used for communication, navigation, and foraging.

Beluga are generalists, with a diet which includes small pelagic, demersal, and riverine fish species, as well as invertebrates such as shrimps, squids, and sea worms (e.g., Doidge et al. 2002; Marcoux et al. 2012; Kelley et al. 2010; Quakenbush et al. 2015; Breton-Honeyman et al. 2016; Lesage et al. 2020). Beluga can dive to depths of hundreds of metres to forage, with dives generally lasting 8-15 minutes (Heide-Jørgensen et al. 1998; Kingsley et al. 2001; Martin et al. 2001).

Additional information on beluga biology can be found in the latest COSEWIC assessment and status report (COSEWIC 2020a).

Life history

Age at physical maturity was estimated at 15 and 10 years of age for females and males, respectively, using length-at-age curves from Doidge (1990a) and assuming deposition of one growth layer group (GLG) per year in teeth dentine (Table 1). Beluga longevity is unknown and likely underestimated given that old individuals systematically suffer from tooth wear, some losing their teeth altogether. Although the maximum age of sampled individuals mostly ranges between 45-60 years of age (Lesage et al. 2014; Hobbs et al. 2015; Ellis et al. 2018), the oldest free ranging beluga sampled was 89 years old(Ferguson et al. 2020). Generation time is defined as the average age of the parents of the current cohort (i.e., newborns), and reflects the turnover rate of breeding individuals in a population (Taylor al. 2007). Beluga generation time is estimated at 28.6 years (Lowry et al. 2017), although there are caveats associated with that estimate, and a generation time closer to 20-23 years may be more accurate (COSEWIC 2020a). Throughout this document, we use the 28.6 year generation time retained by COSEWIC (2020a) for consistency and because the difference between this and other suggested values did not affect the conclusions of this RPA for BEL-EHB and UB beluga.

On average, females give birth to one calf every three years (Vladykov 1944; Doidge 1990a; Suydam 2009), with a gestation period of 12.8 to 15 months (COSEWIC 2014; Matthews and Ferguson 2015). Therefore, approximately one-third of the sexually mature females are expected to become pregnant each year (Mosnier et al. 2015). Body size has been identified as a driver of reproductive activity in Hudson Bay beluga females (Ferguson et al. 2021). Perinatal mortality of the calf may result in decreased calving intervals as females may become available for mating one year earlier (Doidge 1990b; Mosnier et al. 2015). Lactation may continue for up to three years (Doidge 1990b; Matthews and Ferguson 2015), partially overlapping with the next gestation period. Ingestion of solid food starts during the calf's first to second year (Matthews and Ferguson 2015). The timing of mating and calving varies among populations, but mating generally occurs in late winter and spring, while calving takes place during summer. Beluga from eastern Hudson Bay are thought to mate in offshore areas in early May, with calving in late May of the following year (Doidge 1990b). There is no available information specific to Ungava Bay beluga. The beluga is one of the rare species with females showing signs of menopause (post-reproductive lifespan in females; Ellis et al. 2018). However, there is variability in age at sexual senescence, since pregnant females aged 60-70 years have been reported (Burns and Seaman 1986). Because of tooth wear in older beluga, age at senescence is difficult to assess.

Age-specific mortality rates differ among beluga populations and over time depending on the relative occurrence of the different causes of natural mortality (e.g., dystocia and peripartum complications, cancers, contaminants, predation) affecting the population. Beluga mortality rates were estimated based on individuals harvested on the eastern coast of Hudson Bay at 31% for young calves (age 0-1 year), and varied between 12-21% and 2-10% for beluga aged 2-9 years and ≥ 10 years, respectively (Doidge 1990b). There is no data available for UB beluga. However, Hammill and Lesage (2019) estimated similar trends in SLE and Alaska beluga: 14-29% for young calves (0-1 year), 2-7% for old calves/juveniles (1-8 years), 3-6% for young adults (9-44 years), and 8-17% for older adults (≥ 45 years). A recent model, which estimated median (± SE) mortality rates during 1980-2021 in SLE beluga, suggested lower mortality rates for most age classes: 49 ± 3% for young calves (0-1 year), 3 ± 1% in yearlings (1-2 years), 0.9 ± 0.1% in juveniles (4-7 years), and 0.8 ± 0.1% in young adults (8-11 years) (Tinker et al. 2024). The Hoenig's (1983) mean regression equation for teleosts and marine mammals, which is based on maximum age for populations and assumes a constant mortality rate after early life history stages, provided a mortality estimate ranging between 5.1-10.0% for a maximal age ranging between 45 and 89 years (Table 1).

Cultural significance

Beluga are deeply anchored in the Inuit culture and identity as a reliable source of nutritive food for families and communities (Inuit Tapiriit Kanatami and Inuit Circumpolar Council 2012; Lemire et al. 2015). The hunting, butchering, and sharing of beluga represent social and cultural practices that allow the perpetuation of Inuit knowledge, skills, and social bounds (Tyrrell 2007, 2008; Breton-Honeyman et al. 2021). Therefore, beluga are extremely important as a top predator in their ecosystem, and to the culture and lives of Nunavik (Northern Quebec) Inuit.

Number of populations, distribution and abundance

Sub-units of a species are defined as ‘populations’, ‘stocks’, and ‘DUs’ among other terms, and there is considerable debate as to how to differentiate these (Stewart 2008). See Appendix B for the definitions of species sub-unit terms, and how they apply to BEL-EHB and UB beluga.

Twenty-two putative stocks of beluga are recognized worldwide by the International Whaling Commission (IWC), totalling more than 150,000 animals, two-thirds of which are found in Canadian waters (NAMMCO 2018; Figure 3). Eight recognized DUs of beluga occur in Canada (Figure 2; COSEWIC 2016). There is a certain level of range overlap between the WHB, EHB, and UB DUs in Hudson Strait and between the WHB, EHB and JB DUs in the Belcher Islands region in eastern Hudson Bay. The newly identified BEL population also overlaps in its summer range with beluga from the WHB, EHB, and JB populations (Parent et al. 2023). The BEL population was genetically identified after the most recent definition of beluga DUs by COSEWIC (Parent et al. 2023; COSEWIC 2016), therefore, there is a mismatch between the current DU definitions and our understanding of population structure in the eastern Hudson Bay area. Moreover, there might be some interbreeding among animals from different DUs on shared wintering grounds.

BEL-EHB beluga summer in the estuaries of the eastern Hudson Bay arc, and can be seen up to 60 km west of the Belcher Islands (Figure 4; Bailleuil et al. 2012b). Historically, the largest aggregations were observed in July and August in Richmond Gulf, Little and Great Whale rivers, and the Nastapoka River (Smith and Hammill 1986; Caron and Smith 1990). Commercial over-harvesting decimated the beluga summering in Great Whale River which left Little Whale and the Nastapoka rivers as the main aggregation areas (Reeves and Mitchell 1987a). Although occasional sightings are still reported in the Nastapoka River estuary, no beluga have been observed there during aerial surveys since 2004, suggesting that it is no longer an important beluga summering area along the eastern coast of Hudson Bay (Gosselin et al. 2017; COSEWIC 2020a; St-Pierre et al. 2024). Consequently, the Little Whale River estuary appears to be the only remaining area in the eastern Hudson Bay Arc where significant numbers of animals occur (Figure 4). In the fall, beluga from the eastern Hudson Bay coast undertake a seasonal migration along the Nunavik coast and may sometimes travel in Ungava Bay to reach wintering areas in Hudson Strait and along the Labrador coast (Lewis et al. 2009; Bailleul et al. 2012a). The most recent population model abundance estimate for the BEL-EHB stock is 2,900 animals (95% CI= 1,500-4,200; Hammill et al. 2023).

UB beluga were historically abundant in southern Ungava Bay, mostly aggregating in the Koksoak, Leaf, Whale, Marralik (Mucalic), and George rivers, as well as in Hopes Advance Bay (near the community of Aupaluk) from mid-July to mid-August (Figure 1; Reeves and Mitchell 1987b). However, no large beluga aggregation has been seen during surveys conducted in the Ungava Bay area since the 1980’s (Boulva 1981; Finley et al. 1982; Smith and Hammill 1986; Hammill et al. 2004; Gosselin et al. 2009; Sauvé et al. 2023). Continued sightings and the occasional harvest of animals suggest that the Ungava Bay DU either persists at a very low level, or that neighbouring DUs frequent Ungava Bay (DFO 2005; Durkalec et al. 2020). Information on distribution and seasonal movements are fragmentary for this population. While assessments by COSEWIC present the Ungava Bay as the area of extent of the UB DU, traditional knowledge suggests some animals may leave the bay and overwinter in Hudson Strait and off the Labrador coast. It is not clear if these reported movements were from UB beluga and/or from animals from other stocks (e.g., BEL-EHB and WHB) known to be migrating through Ungava Bay (Lewis et al. 2009; Bailleul et al. 2012a; Cuerrier et al. 2012; Breton-Honeyman et al. 2013; COSEWIC 2016; Durkalec et al. 2020).

Summer samples collected since 1994 (n = 113) from northern Ungava Bay indicate no genetic structure suggestive of an isolated matrilineage in this area based on mitochondrial DNA haplotypes (Parent et al. 2023). There is limited possibility to collect genetic samples from historical aggregation sites in southern Ungava Bay during summer, which limits our ability to examine the genetic identity or define the characteristics of beluga summering in the area. An Inuit-led research project initiated in 2019 yielded four samples from a limited hunt in the Marralik (Mucalic) River and three biopsies, providing tissues which can be used to start building a sample library to address stock identity.

Recent Trajectory

Historically, BEL-EHB beluga were thought to number around 12,500 animals in the 1800s. Commercial whaling during the eighteenth, nineteenth, and early twentieth centuries resulted in a sharp decline in abundance (DFO 2005; Lawson et al. 2006; Hammill et al. 2017a), and continued high subsistence harvests have limited the recovery, with climate change and habitat modification being additional underlying factors. In 2001, a stock assessment estimated that if harvests were not reduced, the BEL-EHB stock would go extinct within two to three decades (Bourdages et al. 2002). A series of severe management measures to which a relatively high compliance was observed (Lesage et al. 2001a) slowed the population decline. Population models fitted to the aerial survey abundance estimates, and taking into account reported harvests, indicated that the population had declined from 6,600 animals in 1974 to a minimum of 3,100 in 2001. A reduction in harvest levels resulted in an increase to 3,400 (95% CI=2,200-5,000) in 2015 (Hammill et al. 2017a), which provided support for revising the DU status from Endangered to Threatened in 2020 (COSEWIC 2020a; Figure 5a). Since 2015, reported catches have exceeded recommended harvest levels. An assessment in 2022 that fitted the model to the updated survey time series, including the most recent survey flown in 2021, indicated that the population had probably been declining, albeit a very slow rate (approx. 1% per year) between 2001-2015. Since 2015, the rate of population decline had accelerated (approx. 3% per year), leading to a decline in abundance from 3,700-3,900 in 2015 to 2,900-3,200 in 2021, depending on model assumptions (Hammill et al. 2023; Figure 5b). This estimate reflects the combined abundance for the BEL-EHB stock, as defined by the most recent genetic analysis (Parent et al. 2023).

Beluga summering in Ungava Bay were estimated to have numbered over 1,900 whales in the late 1800s, i.e., prior to the active commercial whaling that occurred from 1867 to 1911, which severely depleted the DU (DFO 2005). Continued subsistence harvest during summer until the mid 1980s (mean annual takes 1974-1985: 83, CV= 19%; Smith 1998) likely contributed to further reductions in abundance (DFO 2005; Boulva 1981; Finley et al. 1982). Beginning in 1986, the Marralik (Mucalic) estuary was closed to hunting and quotas were implemented for Ungava Bay beluga (Lesage et al. 2001a). The Marralik estuary remained closed until a limited harvest of three beluga was allowed in 2021 and 2022. A series of four systematic visual surveys conducted between 1985 and 2008, and covering nearshore and offshore areas of Ungava Bay failed to detect beluga on transects, and yielded very low numbers of observations in nearshore areas (maximum daily count range: 0-36 beluga; Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). Given the absence of beluga sightings on transects flown during these four consecutive surveys, Doniol-Valcroze and Hammill (2011) estimated a maximal population size of 32 (95% CI: 0-94) UB beluga. The last survey conducted in the summer of 2022 yielded an estimated abundance of 68 (95% CI: 23-202) individuals based on three sightings (for a total of four beluga; Sauvé et al. 2023). The 2022 abundance estimate is not significantly different from the previous zero-count derived estimate, suggesting little change in abundance over the last four decades. This is in agreement with the hunter's perception that there has been a lack of increase in beluga numbers in the southern UB estuaries (Durkalec et al. 2020).

HABITAT

> ***Element 4**: Describe the habitat properties that EHB and UB Beluga need for successful completion of all life-history stages.*

Beluga are highly mobile, tolerate a broad range of environmental conditions, and occupy a vast habitat spanning 221,000 and 51,000 km^2 for the BEL-EHB and UB DUs, respectively (COSEWIC 2020a). These factors led COSEWIC (2020a) to suggest that it may be more appropriate to refer to beluga habitat *preferences* rather than habitat requirements. Habitat preferences vary seasonally and between the sexes (Barber et al. 2001).

In summer, beluga generally occupy coastal and offshore waters within their summering distribution, but aggregate in large numbers in estuaries and river mouths (Sergeant 1973; Sergeant and Brodie 1975; Smith et al. 1985; Smith and Hammill 1986; Smith and Martin 1994; NAMMCO 2018). As discussed in the Distribution section above, Little Whale River estuary is currently the main aggregation in eastern Hudson Bay based on surveys conducted since 2004, but aggregations have been reported in the Richmond Gulf, the Little Whale River and the Nastapoka River during previous surveys (Smith and Hammill 1986; Gosselin et al. 2017; COSEWIC 2020a; St-Pierre et al. 2024). Beluga aggregation behaviour in estuarine habitat is incompletely understood, but estuaries are believed to serve multiple biological functions, including foraging on concentrations of anadromous fish, moulting, rearing of calves and predation avoidance (Frost and Lowry 1990; St. Aubin et al. 1990; Watts et al. 1991; Richard et al. 2001; Loseto et al. 2006; Smith et al. 2017). Females with young calves are seen in higher numbers in estuaries than large males, which are more likely to be observed offshore (Hauser et al. 2017; Loseto et al. 2006; Barber et al. 2001; Smith et al. 1994;). This spatial segregation of male and females in summering grounds raised the idea that estuaries might play an important role as calf-rearing grounds, notably by providing shelter from large-sized predators (most notably killer whales; Loseto et al. 2006; Smith et al. 2017).

In summer, BEL-EHB and UB beluga feed on various fish species notably capelin, salmonids, sculpin, Arctic cod, whitefish, and crustaceans (Kelley et al. 2010; Breton-Honeyman et al. 2016). To what relative extent estuaries and offshore waters contribute to beluga diet is for the most part undetermined: although traditional ecological knowledge (TEK), field observations, and isotopic evidence show that beluga feed on estuarine species (Kelley et al. 2010; Breton-Honeyman et al. 2016; Durkalec et al. 2020), most stomach contents from beluga harvested in the summer in estuaries were empty (Caron 1987; Kelley et al. 2010). However, beluga are reported to regurgitate their stomach content during the chase associated with harvesting (Vladykov 1944; Byers and Roberts 1995; Norton and Harwood 2001), indicating that food is ingested in summering grounds but that the reliability of dietary analyses based on stomach contents from harvested individuals is limited. Beluga tagged along the eastern Hudson Bay coast undertook frequent inshore to offshore movements during the summer, which are thought to represent foraging trips influenced by tidally-driven prey availability (Ezer et al. 2008; Bailleul et al. 2012a). A variety of factors are thought to influence beluga presence in estuaries, including winds and waves (Scharffenberg et al. 2020), bathymetry (Hornby et al. 2016), seabed composition (Whalen et al. 2020), currents and upwellings (Williams et al. 2006; Hauser et al. 2015), tides (Simard et al. 2014), and anthropogenic disturbances (Halliday et al. 2020). In the fall, females start making more frequent trips offshore (Barber et al. 2001), and increase their diving activity during the weeks preceding migration (Heide-Jørgensen et al. 1998; Bailleul et al. 2012a).

In late summer or early fall, most beluga populations migrate, generally in groups of related individuals (Colbeck et al. 2013), to various wintering sites that may be shared by several DUs. Wintering sites include offshore open water or loose pack ice close to sea ice edges (Jonkel 1969; Finley and Renaud 1980; McDonald et al. 1997; Lewis et al. 2009; Heide-Jørgensen et al. 2010). In the spring, beluga often follow the floe edge along their migration routes towards summering areas (Cardinal 2013). The pattern of seasonal migration varies among beluga populations and suggested environmental factors that could be directing these migrations include the distribution of prey species, climate indicators of ecosystem productivity, the risks of ice-entrapment and predation (Bailleul et al. 2012b; Hauser 2016). Summer movement of beluga tagged on the eastern Hudson Bay coast and the initiation of their fall migration has been linked to sea-surface temperature (Bailleul et al. 2012b). These satellite-tagged beluga were associated with a sea-surface temperature of around 3°C in both summer and winter (Bailleul et al. 2012a, 2012b). During their seasonal migration, tagged beluga remained close to the coastline, presumably to benefit from currents prevailing along the east side of Hudson Bay (Saucier et al. 2004; Bailleul et al. 2012a). Beluga from the eastern Hudson Bay area over-winter in partially ice-covered, open water (e.g., polynya) or deeper warmer water areas in offshore waters of eastern Hudson Strait, Ungava Bay and on the continental shelf along Labrador (Bailleul et al. 2012a; Durkalec et al. 2020; Babb et al. 2021).

Seasonal migration of UB beluga is not as well documented but the summer use of estuaries is recognized and they also require partially ice-covered, open water and deeper warmer open water areas in winter. Satellite telemetry and genetic information show that animals from different DUs, including EHB and WHB are present in Ungava Bay, Hudson Strait, and the Labrador Sea in winter. There is uncertainty on the potential extent of any seasonal migration of UB beluga (COSEWIC 2016; Cuerrier et al. 2012).

Little is known about foraging activities in wintering grounds: fish species that might be of interest to beluga in Hudson Strait and on the continental shelf of Labrador Sea include capelin, Arctic cod, Greenland halibut and American sand lance (Stewart and Lockhart 2004). Beluga are thought to forage extensively in their wintering habitats as they tend to be fatter at the end of the winter and thinner in the fall (Breton-Honeyman et al. 2016). Moreover, a greater proportion of beluga daily activity is spent diving 1-2 months prior to the fall migration and at wintering grounds compared to during the migration (Bailleul et al. 2012a).

Studies of beluga from other Canadian DUs and Alaska suggested that habitat selection is driven by bathymetry, ice cover, sea-surface temperature and turbidity (Barber et al. 2001; Hauser et al. 2017, 2018; Noel et al. 2022). However, habitat preferences are likely to differ among beluga populations. While seasonal satellite telemetry and summer systematic aerial survey data exist to document the distribution of BEL-EHB beluga, information on the distribution for UB beluga is not sufficient to develop habitat selection or preference models.

One important aspect of beluga habitat use and migration routes is that beluga exhibit strong philopatry to natal locations (Caron and Smith 1990; Smith et al. 1994; Turgeon et al. 2012; O’Corry-Crowe et al. 2018). Knowledge of summering grounds and migratory routes are considered to be transmitted culturally from older individuals to juveniles (Palsbøll et al. 2002; O’Corry-Crowe et al. 2020), and from mothers to their offspring (Brown Gladden et al. 1997; O’Corry-Crowe et al. 1997, 2018; Turgeon et al. 2012; Colbeck et al. 2013), resulting in genetic structures among beluga populations defined, at least partly, by their summering location.

Sources of uncertainty

- Migration patterns of BEL-EHB beluga were derived from 32 beluga tagged in the Nastapoka and Little Whale rivers in the summers of 1993 to 2004 (Bailleul et al. 2012a).

Our understanding of BEL-EHB beluga is therefore inferred from animals tagged at two aggregation sites along the eastern Hudson Bay coast, while no telemetry data is available from the Belcher Islands or for UB beluga. Moreover, tag battery life was insufficient to document the spring migration for tracked individuals. Migration phenology was derived from shoreline Inuit observations, which have a restricted spatial extent (Lewis et al. 2009). Further studies of beluga movement and distribution within, to, and from their summer and winter habitat would improve our understanding of habitat functions.

- Further studies examining BEL-EHB and UB beluga diving behaviour would help identify important foraging grounds, both in summering and wintering habitats.
- There is uncertainty related to habitat-specific carrying capacity limits (K) for the different habitats used by BEL-EHB and UB beluga. Pre-commercial whaling abundance can only be inferred from the quantities of oil recorded and the trade in skins, and there is a gap of > 100 years in harvest reports from the eastern Hudson Bay coast (Hammill et al. 2017b). It is therefore difficult to estimate catches over time, and thus K at the time of commercial exploitation of the stocks. Moreover, there have been changes in ecosystem conditions since the late 1800s, suggesting that an historic estimate of K might not be valid under current conditions (Hammill et al. 2017b). Although the BEL-EHB population model used for beluga provides a proxy of overall, population-specific K (see Recovery Target section), it does not provide any insight into which habitats used by beluga have the most limiting effect on population dynamics. Studies examining the bioenergetics of Nunavik beluga, compounded with habitat-specific prey availability studies, would improve our understanding of beluga habitat functions, and their relationship with fitness and population dynamics.

HABITAT SPATIAL EXTENT: NOT RELEVANT

***Element 5**: Provide information on the spatial extent of the areas in EHB and UB Beluga's distribution that are likely to have these habitat properties.*

Beluga matrilineages consistently return to the same estuaries in summer (Turgeon et al. 2012). This is considered to constrain the beluga's behavioural plasticity to environmental change and anthropogenic disturbance (Laidre et al. 2008; Smith et al. 2017). As such, areas where beluga used to aggregate in high numbers which were subsequently depleted by over exploitation have not been recolonized (e.g., Great Whale River in the eastern Hudson Bay arc, and the Marralik (Mucalic) Estuary in southern Ungava Bay). Beluga continue to occupy the Nelson and Churchill estuaries, where water flow has been modified by hydroelectricity development (Reeves and Mitchell 1987b, 1987c, 1989; Hammill et al. 2004; Smith et al. 2017), and they were observed consistently returning to the Nastapoka estuary within an average of 7.7 days following hunting or motor boat disturbance (Caron and Smith 1990). In eastern Hudson Bay, the Nastapoka River used to be an important aggregation area until the early 2000s, but no large aggregations has been observed during aerial surveys conducted over the last two decades (Gosselin et al. 2017; COSEWIC 2020a; St-Pierre et al. 2024). Whether this change in beluga distribution is due to undocumented local environmental changes altering the suitability of the habitat for beluga or to local extirpation due to unreported removals is unknown. A better understanding of the factors that led beluga to stop aggregating in the Nastapoka River could help the projection of important habitat use in other estuaries. Given current BEL-EHB and UB beluga demographic trends, the probability of beluga colonizing new estuaries in the next ten years is very low.

SPATIAL CONSTRAINTS: NOT RELEVANT

***Element 6**: Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.*

Beluga move freely, inhabiting a wide vertical distribution in the water column as well as a broad geographical distribution in the Arctic and sub-Arctic waters. During winter, sea ice creates a spatial constraint to beluga distribution, movement, and habitat use since most of their summering habitat is covered. Changes in the timing of freeze-up and breakup, in sea ice coverage, as well as in icebreaker activity are expected to increase beluga wintering habitat availability and connectivity. Therefore, spatial constraints to beluga movements, if any, may weaken due to climate change and anthropogenic activity.

CONCEPT OF RESIDENCE: NOT RELEVANT

> ***Element 7:*** *Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence.*

SARA defines “residence” as “a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating” (SARA s.2(1)). The concept of residence is not applicable to marine mammals, including beluga.

THREATS AND LIMITING FACTORS

> ***Element 8:*** *Assess and prioritize the threats to the survival and recovery of EHB and UB beluga.*
>
> ***Element 9:*** *Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities*
>
> ***Element 10:*** *Assess any natural factors that will limit the survival and recovery of EHB and UB beluga.*
>
> ***Element 11:*** *Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species.*

THREATS SUMMARY

Important population declines in both BEL-EHB and UB stocks are attributable to intensive commercial hunting in the mid-19th and early 20th centuries. Since then, continued high levels of subsistence harvesting have contributed to further declines (DFO 2005). Management of subsistence beluga harvest remains the main challenge for BEL-EHB and UB beluga recovery, where short and long term harvest rights and long term conservation objectives must be balanced.

Threats from current human activities in the habitat of beluga include subsistence harvest, anthropogenic noise, potential industrial development, vessel traffic, chemical pollution, and commercial fisheries in Hudson Strait and Labrador Sea (Table 2). Climate change is also considered a threat to beluga through diverse effects on the ecosystem. Threats identified for BEL-EHB and UB beluga also affect other Canadian DUs, with some variation on the level of impact depending on respective distribution ranges. In Nunavik, whale carcasses are rarely retrieved from shores. Data from necropsies are thus unavailable for both BEL-EHB and UB beluga, limiting any quantification of the impact the threats detailed below pose to beluga recovery, except for subsistence harvest.

THREATS DESCRIPTION

Subsistence harvest – Beluga are an important source of nutrients (Lemire et al. 2015), are essential to Inuit food security and constitute an integral part of the Inuit culture (Alayco et al. 2007; Inuit Tapiriit Kanatami and Inuit Circumpolar Council 2012). Between the mid-19th and early 20th centuries, intensive non-Inuit commercial beluga exploitation substantially reduced some Canadian populations, notably those in Cumberland Sound, Ungava Bay, and eastern Hudson Bay. Beluga from the eastern Hudson Bay coast were mainly harvested between 1854 and 1877, with more than 8,000 individuals harvested between 1854 and 1863 (Reeves and Mitchell 1987a). Whaling in Ungava Bay occurred between the 1860's and early 1900's, but no total number of catches has been reported for that area (Reeves and Mitchell 1987b). By the 1960s and 1970s, all large-scale commercial beluga hunting had ceased (Sergeant and Brodie 1975; Kemper 1980; Reeves and Mitchell 1989).

Although local knowledge attributes the continued decline of BEL-EHB and UB beluga to increased vessel traffic (Johannes et al. 2000), this hypothesis is not supported by the available information. In areas such as Little Whale River, the Churchill River estuary (Manitoba), and the Mackenzie River estuary (Northwest territory) where vessel traffic, oil and gas exploration, and/or commercial whale watching take place, abundant concentrations of beluga are still seen (Norton et al. 1986; Hammill et al. 2004). In contrast, summering areas where beluga were seemingly extirpated have not been recolonized by large aggregations (Reeves and Mitchell 1987a, 1987b, 1989; Hammill et al. 2004). Severe local population reductions can therefore have long-lasting effects on beluga distribution (Wade et al. 2012).

The depletion of BEL-EHB and UB beluga due to excessive commercial exploitation and their failure to recover as a result of high subsistence harvest levels led DFO to establish management plans in the mid-1980s. Measures included a combination of quotas, and seasonal and area closures for subsistence beluga harvest. The Whale, Marralik (Mucalic), Tuctuc, and Tunulic river estuaries (all part of the Marralik (Mucalic) Estuary, Ungava Bay) were completely closed to harvesting in 1986, while seasonal closures were implemented in the Nastapoka and Little Whale River estuaries (eastern Hudson Bay) in 1990 and 1995, respectively. While the management of beluga was initially the sole responsibility of DFO, since the signature of the *Nunavik Inuit Land Claim Agreement* (NILCA) in 2006, beluga harvests in the Nunavik Marine Region waters have been co-managed by the Nunavik Marine Region Wildlife Board (NMRWB), DFO, and the Eeyou Marine Region Wildlife Board in areas where the land claims overlap (NILCA 2007). Since 2014, plans incorporate a flexible total allowable take (TAT) which uses available information on beluga migration timing and seasonal relative abundance of BEL-EHB beluga compared to WHB beluga to determine the number of beluga allocated for subsistence harvest in different Nunavik regions.

Management plans are renewed every three to five years and the current plan covers the 2021-2026 period (NMRWB and DFO 2021). The present management plan conservation objective is to maintain the BEL-EHB stock at or above the 2015 abundance estimate of 3,400 animals and that the probability of a decline due to harvesting must not exceed 50% (Hammill et al. 2017a, 2021). Management measures to meet this objective include combinations of harvest limits in the south-eastern Hudson Bay coastal area and seasonal closures in Hudson Strait and Ungava Bay (NMRWB and EMRWB 2020). The Marralik (Mucalic), Nastapoka and Little Whale River estuaries are still closed to hunting, but harvest may be authorised under certain circumstances. For example, the harvest of a low number of beluga in the Marralik (Mucalic) estuary has been approved for cultural purposes since 2021 (2 belugas taken in 2021 and in 2022). The killing of calves and of adults accompanied by calves is forbidden.

Management efforts to limit harvest of the BEL-EHB stock slowed the population declines to 1% or less between 2004 and 2014, but the rate of decline increased to > 3% annually since then (Hammill et al. 2023). These declines in abundance are not unexpected since harvests have consistently exceeded the recommended TAT levels (Figure 6), and previous assessments under-estimated the proportions of BEL-EHB beluga in Nunavik landings (DFO 2020; Hammill et al. 2023).

Anthropogenic noise – Anthropogenic noise is one of the most important threats to marine mammals worldwide since it can disturb normal behaviour, mask communications, interfere with feeding and diving patterns, and ultimately lead to hearing damage (Weilgart 2007). Due to their broad hearing frequencies, a variety of anthropogenic noise sources may disturb beluga. Beluga have been reported fleeing estuaries for up to 48h following acute sound disturbances (Reeves and Mitchell 1987a; Caron and Smith 1990). In addition, changes in vocal behaviour have been described, including reduction in calling frequency, suggesting predation avoidance mechanisms, and increases in the rate of repeated calls, similar to warning signals (Finley et al. 1990; Lesage et al. 1999; Halliday et al. 2019). In high circulation areas, notably the St. Lawrence river and Cook Inlet, vessel noise can mask beluga vocalization in the soundscape up to 94% of the time and impair mother-calf communication (Gervaise et al. 2012; Castellote et al. 2018; Vergara et al. 2021). Nevertheless, beluga are seen in high circulation areas such as Churchill (WHB DU – Manitoba), the St. Lawrence estuary (SLE DU – Québec), Longyearbyen (Svalbard beluga – Norway), Anadyr (Anadyr beluga – Russia) and Anchorage (Cook Inlet beluga – Alaska, United States). Yet, at least three of the five beluga stocks listed above are of concern (NAMMCO 2018), and anthropogenic noise is recognized as an important contributing factor to their decline (COSEWIC 2014; Castellote et al. 2018). Inuit consider that anthropogenic noise may have been an important contributing factor to the drastic reduction in population size for BEL-EHB and UB beluga (Doidge et al. 2002). Similarly, Inuit in Cumberland Sound consider that beluga are thinner than in the past due to increased energy expenditure devoted to boat traffic avoidance (Kilabuk 1998).

The main sources of anthropogenic noise that may affect BEL-EHB and UB beluga are from icebreakers, shipping vessels, sonars and seismic surveys in their wintering habitat, and recreational boats and aircraft in their summering habitats (Finley et al. 1990; Cosens and Dueck 1993; Lesage et al. 1999; Weilgart 2007; Moore et al. 2012; Halliday et al. 2017). Among these, large vessels (shipping vessels and icebreakers) are the most prominent sources of anthropogenic noise. Most large vessels circulate through Labrador Sea and Hudson Strait, although some enter Hudson and Ungava bays mainly to deliver goods to communities and for ore shipping. The increasing vessel traffic into and through the Northwest passage may change the soundscape in the eastern end of BEL-EHB and UB wintering distribution. Noise from vessels can last for hours due to ships' relatively slow travel speed (Castellote et al. 2018) and can be heard up to 80 km from the source underwater (Finley et al. 1990; Halliday et al. 2017). Other important sources of very loud underwater anthropogenic noise within BEL-EHB and UB habitat is seismic exploration, which is widespread in high latitudes. Since the western portion of the Hudson Bay, Hudson Strait, Ungava Bay and Labrador Sea are major hydrocarbons basins (Reeves et al. 2014), some seismic surveys have been completed throughout the Hudson Bay complex, including eastern Hudson Bay (Lavoie et al. 2019; Figure 7). Seismic airguns can generate up to 70 dB in noise at low frequency bands, and may still be heard at higher frequency bands past 48 kHz (Kyhn et al. 2019). Beluga usually tend to remain 20-30 km away from operating seismic survey vessels (Miller et al. 2005). Sound emitted from aircraft and recreational boats is of lower impact to beluga: emission duration is generally limited to a few seconds to minutes, and the number of events, even in high circulation areas, is considerably lower than shipping noise and hydrocarbon-related activities (Castellote et al. 2018). Nevertheless, controlled experiments in the St. Lawrence Seaway suggested that the vocal communication of beluga was altered both by low-frequency noise produced by a ferry moving along a predictable path and by high-frequency noises from a small outboard motorboat moving erratically (Lesage et al. 1999). Similarly, Inuit hunters report that beluga respond to the noise of small hunting vessels and snowmobiles (Kilabuk 1998). Despite these considerations, it is difficult to evaluate the relative impact of anthropogenic noise disturbance on BEL-EHB and UB beluga.

Industrial development – Industries that are a cause for concern in areas inhabited by BEL-EHB and UB beluga include offshore oil and gas development, port development related to mining, and the construction of hydroelectric dams. Industrial development can pose a threat to beluga via different mechanisms. It can cause acute and chronic underwater anthropogenic noise through seismic surveys, drilling, ship traffic, and construction of infrastructure such as pipelines and ports.

Industrial development also introduces the risk of toxic spills from maritime transport and gas exploitation, which can harm beluga through direct contamination, or through contamination of their prey (Meador et al. 1995; Wilson et al. 2005). Large oil spills can lead to recruitment failures of fish populations (Nahrgang et al. 2010; Laurel et al. 2019), potentially reducing prey availability for beluga. Moreover, hydrocarbons can persist in the environment for decades and be released by future dredging activities (Bagby et al. 2017). Spills are relatively rare in Canada (Marty and Potter 2014), and spill risk is particularly low in the Arctic given the limited vessel traffic in the area (Marty et al. 2016). Nevertheless, single spills vary largely in their severity depending on the substance involved, the volume, the spatial extent, the location, and the timing. Since the Hudson Bay complex is an inland sea, spills can remain enclosed for extended periods of time, increasing the severity of their impacts on wildlife (Tao and Myers 2021). Additionally, there are uncertainties related to the efficiency of the response in case of a spill in remote Arctic areas (AMAP 2007).

One project of concern identified in the last COSEWIC assessment was the construction of a port to support the operations of an iron mine projected for 2019-2021 near Aupaluk, southwest Ungava Bay. This project was not initiated, and the environmental assessment was terminated without being completed by Oceanic Iron Ore Corporation in 2022 (Impact Assessment Agency of Canada 2022). Nevertheless, the rich iron reserves in the soil of western Ungava Bay may lead to future interest in exploitation of the area (Oceanic Iron Ore Corp. 2012). The Raglan Mine is a nickel mining complex located ≈100 south of Deception Bay, between the Nunavik communities of Salluit and Kangiqsujuaq and has been operating since 1997. The ore produced is trucked to Deception Bay, were a 152 m icebreaking bulk carrier ensures shipping to Quebec City. The icebreaking activity and shipping lanes overlap with BEL-EHB migration routes and both BEL-EHB and UB wintering habitat.

Another project of industrial development of concern is the Mary River Iron Mine North of Baffin Island (DFO 2014b, 2019; Gavrilchuk and Lesage 2014) because the migration routes of BEL-EHB beluga (as well as those of other DUs which are not the focus of the present RPA) overlap with the shipping lanes associated with the port of Milne and the projected port at Steensby.

Hydroelectric dams modify water flow, salinity, sedimentation rates and turbidity, alter pelagic communities in favour of lake species, especially near reservoirs, and increase mercury levels in the environment for up to 15 years (Lawrence et al. 1992; Hayeur 2000). Resulting modifications to estuarine physical and biotic conditions represent alterations to beluga summering habitat, which may have consequences for their behaviour and/or fitness. For example, in the Nelson River estuary, WHB beluga aggregate further from the estuary when dam water discharges are higher (Smith et al. 2017). Local people in Waskaganish, QC, also report that beluga no longer swim upriver to feed and are observed in fewer numbers since the diversion of the Rupert River to support the Eastmain and La Grande Complex projects (Blackned 2019). More drastically, SLE beluga, which once occupied Manicouagan banks in the summer, never recolonized the area after the construction of dams up Manicouagan river (COSEWIC 2014), but over hunting may also have contributed to their extirpation of the area.

The development of the James Bay hydroelectric complex and the La Grande system induced changes in the Hudson Bay freshwater balance through the construction of reservoirs which retain water in the spring and release it in the winter. River inflow into Hudson Bay shifted from spring and summer, when most of river runoff, precipitation, and sea ice melt contributed to freshwater entering Hudson Bay, to winter, when river runoff used to be low as the land remained frozen and the formation of sea ice withdraws freshwater from the surface of the ocean (Eastwood et al. 2020). This freshwater input in the winter was noticed by Inuit in the Belcher Islands area, where polynyas representing eider duck wintering habitat experienced rapid freezing (Eastwood et al. 2020). These changes in ice coverage and dynamics may impact a portion of BEL-EHB beluga, since a fraction of the BEL population may overwinter in the Belcher Islands (Parent et al. 2023).

Most of the hydroelectric development in Nunavik occurred in the La Grande complex in James Bay (Hydro-Québec) and Churchill and Nelson Rivers in Hudson Bay (Manitoba Hydro). The Innavik Hydro project is currently building a run-of-river power plant on the Innuksuac River to supply the community of Inukjuak with hydroelectricity. The damn and turbines are being installed upriver and are not expected to directly affect beluga, although minor fish habitat loss and mortality (Pituvik Landholding Corporation 2010) may result in some indirect effects through changes in prey availability. Starting in 1970, Hydro-Québec planned another major hydroelectric development in the Great Whale River basin, which would have altered both Great Whale River and Little Whale River estuaries (Hayeur 2000). The project was abandoned in 1994, but discussions on revival of the project have been underway with the provincial government since 2022 (Bell and Stewart 2022). Hydro-Québec also assessed the hydroelectric potential of rivers from the Marralik (Mucalic) Estuary, but no hydroelectric development project was undertaken (Hayeur 2000). Any future hydroelectric development in Nunavik is likely to have significant impacts on BEL-EHB and/or UB beluga.

Chemical pollution – Beluga are apex predators with large lipid reserves, which make them highly vulnerable to persistent organic pollutants (POPs) which bioaccumulate in their tissues. High concentrations of POPs have been correlated to immunosuppression and endocrine malfunction in beluga (Letcher et al. 2010). Males tend to accumulate higher levels of POPs compared to females, a difference that can be attributed to elimination through pregnancy and lactation (Addison and Brodie 1987; Stern et al. 2005) and/or differential diets between males and females (Lesage et al. 2001b; Nozères 2006).

Nunavik is considered a pristine environment due to the low human and industrial occupation (14 communities along the coast of Hudson and Ungava Bay with c.a. 14,000 residents). Consequently, most pollutants arrive from the south via oceanic and atmospheric transport (Lohmann et al. 2007). Burdens of contaminants, organohalogens, perfluorinated compounds, mercury and other heavy metals are considerably lower in Canadian arctic and subarctic beluga populations than in SLE beluga (Muir et al. 1990; Ray et al. 1991; McKinney et al. 2006). While contaminants are thought to play a role in the non-recovery of SLE beluga (DFO 2005; COSEWIC 2014), their current impact on BEL-EHB and UB beluga is likely minor, yet difficult to assess. With the global ban of several POPs in 2004 (UNEP 2019), the concentration of POPs in arctic wildlife tissues is on a downward trend (Rigét et al. 2019). Nevertheless, because of its effects on contaminant cycling, sedimentation and processing, climate change may reintroduce some contaminants into the arctic food web (Noël et al. 2018).

Commercial fisheries – Beluga are not considered susceptible to entanglement in fishing gear due to their particularly acute echolocation abilities and their ability to swim backwards (NAMMCO 2018). Yet, entanglements account for 1% of deaths for SLE beluga (Lair et al. 2016), and netting is a traditional Inuit beluga harvest technique that is still practised. There is no existing entanglement or by-catch record for BEL-EHB and/or UB beluga. Beluga caught in fishing gear in areas where subsistence hunting occurs are likely reported as harvest rather than by-catch (NAMMCO 2018).

The other mechanism by which commercial fisheries might affect beluga is through competition for their prey. No important commercial fisheries are currently exploited in the summer range of BEL-EHB and UB beluga. There is a commercial shrimp fishery in Hudson and Davis Straits, and in the northern Labrador Sea. A bottom trawl Greenland halibut fishery is conducted in the Labrador Sea (Coté et al. 2019; Storey and Eibner 2021). The Greenland halibut fishery occurs in the Northwest Atlantic Fisheries Organization (NAFO) Subarea 0, which includes Baffin Bay (Division 0A) and Davis Strait (Division 0B; DFO 2014c; Figure 8). Fisheries for Greenland Halibut and shrimp were identified as a significant concern for narwhal (NAMMCO 2018), which lead to the closing of an area that overlaps the winter foraging range of narwhals in NAFO Division 0A (DFO 2007, 2014c; Figure 8). Beluga telemetry data suggested a main winter residency area at the southern junction between Hudson Strait and Labrador Sea (Bailleul et al. 2012b). Although tagged beluga remained close to the coast in that area, fisheries in the south-western portion of NAFO Division 0B may overlap with beluga winter foraging grounds. Since beluga also prey on Greenland Halibut and shrimp during the winter (Watt et al. 2016), there may be competition with fisheries in this area. However, information on beluga energetic requirements and foraging patterns in their wintering habitat is currently too sparse to evaluate the extent to which these fisheries may affect beluga. Bycatch of forage fish species by the shrimp fishery may be another source of competition for prey between beluga and fisheries (NMRWB 2019).

With climate change, productivity in Arctic regions is expected to increase, leading to the potential development of new or more intensive fisheries. However, current projections suggest that the enhanced productivity in the Canadian arctic ecosystem is unlikely to sustain profitable fisheries like those exploited in subarctic areas (Dunbar 1970; Slagstad et al. 2015; Tai et al. 2019). Further research on beluga foraging behaviour in wintering habitats and the extent of competitive pressure posed by fisheries is needed to better characterise the associated threat to BEL-EHB and UB beluga recovery.

Vessel traffic – The passage of large vessels, recreational boats, and aircraft can affect beluga. Such physical disturbances can increase stress, force beluga to flee a given area for extended periods of time (up to 48h; Caron and Smith 1990), and modulate their vocalization rates (Lesage et al. 1999; Halliday et al. 2019). This can, in turn, negatively affect the rearing of young, especially if the disturbance occurs in estuaries, result in increased energy expenditure, and interfere with beluga's ability to forage. Vessel traffic also increases collision risks. Strikes caused by small, high speed vessels can severely injure beluga which may reduce their fitness or be lethal. In the St. Lawrence estuary, where more than 8,000 vessels navigate the waterway every year, vessel strikes account for 2% of deaths in SLE beluga (Lair et al. 2016). Across BEL-EHB and UB beluga distribution, most small vessel traffic occurs along the coasts, surrounding Inuit communities. There is no available data on vessel strike-induced mortalities for BEL-EHB and UB beluga, but the relatively low traffic level suggests it likely minimal. Vessel traffic in Nunavik is most prominent during the open-water season (May through October). BEL-EHB and UB beluga are therefore most susceptible to vessel strikes in their summering habitat or during their migration.

Other effects of increased vessel traffic in Hudson Strait are related to the use of icebreakers. The passage of icebreakers creates artificial open-water channels which beluga can follow and get trapped in once ice re-forms. The noise generated by icebreakers may also delay fall migration through avoidance of the Hudson Strait area, resulting in whales being trapped in the ice before they can reach wintering grounds (Nacke 2017).

Climate change – Climate warming of the Arctic is two to three times faster than the rest of the globe (Holland and Bitz 2003), and Nunavik is particularly vulnerable to its effect, notably in the Hudson Bay area, which is warming two times faster than the rest of polar regions (Brand et al. 2014).

Among the first noticeable changes are the lengthening of the ice-free season and the increase in sea surface temperatures. Changes in beluga migration phenology in response to changes in the timing of autumn freeze-up and spring break-up differ across populations. In some populations, beluga delay their fall migrations, and initiate their spring migrations to match ice dynamics (Bailleul et al. 2012b; Hauser et al. 2017). In the case of beluga from the eastern Hudson Bay coast, observations between 1995 and 2010 indicated fall migration has been delayed by 18 days per decade, while spring migration has been occurring 8 days earlier every decade (Hammill 2013).

Changes in ice regimes also generate unpredictable conditions, possibly increasing the risk of ice entrapments. Ice entrapments occur when rapid shifts in wind direction and drops in temperature rapidly close breathing holes in the pack ice, leading to mass drowning or inability to escape predation by polar bears. Ice entrapments can lead to mass casualties of several hundreds of individuals. In 1955, more than 3,000 belugas died in Disko Bay, Greenland, due to an ice entrapment (Golodnoff 1956). In small populations such as BEL-EHB and UB beluga, the effect of mass mortalities associated with ice entrapment could be disproportionate since it could reduce the population to an abundance from which recovery would no longer be possible (Hobbs et al. 2015). Furthermore, because related beluga tend to travel together (Colbeck et al. 2013; O'Corry-Crowe et al. 2018), entire lineages could be lost in a single event. Yet, the reduction in sea ice may also decrease the risk of ice entrapments depending on the area. In Disko Bay, where sea ice coverage has decreased significantly over the last decades, there has been no large-scale ice entrapment of beluga since 1990 (Heide-Jørgensen et al. 2010).

Another change caused by climate change is the shift in species composition. Hudson Bay forage fish assemblages, where lipid-rich Arctic cod (*Boreogadus saida*) was once dominant, is shifting in favour of boreal taxa, notably sand lance (*Ammodytes hexapterus*) and capelin (*Mallotus villatus)* (Ponton et al. 1993; Watt et al. 2016; Schembri 2022). Changes in the distribution of predators are also expected, and killer whales are being sighted with increasing frequency in Hudson Strait, Ungava Bay, and Hudson Bay (Higdon and Ferguson 2009; Ferguson et al. 2010). The loss of sea ice coverage due to climate change may result in beluga being more accessible to killer whales. Killer whales and polar bears are the most prominent predators of beluga (Ferguson et al. 2012), and increased predation rates on small populations may lead to extirpation if abundance falls below a certain threshold (Hobbs et al. 2015).

Other impacts of climate change that may indirectly affect beluga include landslides and permafrost thaw, which may increase in frequency and intensity (Owczarek et al. 2020). For example, in 2021, an important landslide occurred up Great Whale River, with 45 million cubic meters of sediments spilled in the river. Two smaller landslides also occurred in Little Whale River in the fall of 2022. Such events may alter beluga in and surrounding estuaries by increasing turbidity, reducing oxygen levels for fish, and reducing river flow (Geertsema et al. 2009). Similarly, permafrost thaw, which is predicted to accelerate (Dagenais et al. 2020; Smith et al. 2022), is expected to change hydrologic flows (Connon et al. 2014; Walvoord and Kurylyk

2016) and could lead to the release of a wide variety of contaminants into the water (Miner et al. 2021), with consequences on physical and chemical characteristics of estuarine habitats, and thus potentially beluga health and fitness.

THREATS TO CO-OCCURING SPECIES

Other marine mammals found in the Nunavik Marine Region are also impacted by most of the threats listed above (Huntington 2009). If threats to BEL-EHB and UB DUs were abated, it would thus benefit multiple species, including some listed as of special concern by COSEWIC, notably the ringed seal, polar bear, bowhead whale, narwhal, and killer whale. Similarly, a reduction in the risk of spills and the implementation of mitigation measures for anthropogenic noise and pollution could benefit the whole ecosystem. Subsistence harvest pressure varies substantially among species and is managed differentially.

LIMITING FACTORS

Disease – Beluga in high latitudes are considerably less affected by infectious diseases than beluga living in other areas, for example SLE beluga (Martineau et al. 1999; Mikaelian et al. 1999; Lair et al. 2014). Nonetheless, climate change is expected to alter wildlife disease dynamics, including exposure and transmission, through changes in host-pathogen-environment interactions (Burek et al. 2008). The warming climate has been associated with a worldwide increase of diseases in marine species (Kuiken et al. 2006). Therefore, epidemiological monitoring in Arctic and subarctic beluga populations, integrated with demographic data and the relationship with environmental factors is needed to understand the effects of climate change on beluga health. Such baseline data could act as an early warning system to foresee potential consequences for Threatened and Endangered populations.

Allee effect – The Allee effect, also known as depensation in the field of fisheries sciences, is defined as positive density dependence (i.e., per capita population growth is slowed at very small population sizes; Allee and Bowen 1932). The mechanisms involved include reduced reproduction due to the inability to find a mate, inbreeding depression, and behavioural changes such as reduced foraging success or protection from predators (Wade 2018). A decline in population growth rates at low levels can increase the risk of extinction of small populations, or prevent their recovery despite relief from anthropogenic threats (Dennis 1989; Liermann and Hilborn 2001). The absence of recovery in severely depleted cetacean populations in spite of it being several decades since the cessation of commercial whaling suggests that Allee effects might play a role in the population dynamics of marine mammals (Clapham et al. 2008). There are substantial uncertainties related to the UB beluga population trend. The population size might have been lower than the 2022 abundance estimate and recovering over the last decades. Alternatively, the UB beluga population may be stagnating despite over three decades since the closure of the southern Ungava Bay and the Marralik (Mucalic) Estuary to hunting, as a result of reduced productivity in this very small population. Contrasting reproductive rates among beluga populations of various statuses, and monitoring temporal trends in reproductive rates within populations would be useful to explore the role of potential Allee effects in the dynamics of beluga populations, as well as their significance for the achievability of recovery targets.

RECOVERY TARGETS

Caution: All recovery target abundance numbers provided in the following sections of the document are subject to change as new survey and harvest data become available to input into the population model. The recovery objectives used prevail over the population sizes shown in

Tables 3 and 4, regardless of whether model demographic trends and estimates change in future BEL-EHB and UB beluga stock assessments. In addition, recovery targets identified in this section are not specific to EHB beluga but to the joint BEL-EHB stock.

Element 12: *Propose candidate abundance and distribution target(s) for recovery.*

The EHB DU was assessed as Threatened in 2020 according to COSEWIC's criteria A1: 'Decline in total number of mature individuals' based on the approximately 50% decrease in population size between 1974 and 2015. The causes of decline were deemed understood and ceased (Hammill et al. 2017a; COSEWIC 2020a). However, the most recent survey and modelling data suggest that the BEL-EHB stock is still declining (Hammill et al. 2023, St-Pierre et al. 2024). Therefore, we propose three possible objectives (recovery targets) for the BEL-EHB stock (see Table 3 for corresponding population size benchmarks):

1. Attain a population size at or exceeding the 2015 abundance estimate in ten years. It should be noted that this objective is similar to the conservation objective of the current 2021-2026 beluga management plan.
2. Attain a population size which meets or exceeds the Precautionary Reference Level (PRL; defined as 48% of the carrying capacity) in 86 years (3 generations). This is based on the DFO-Maximum Sustainable Yield framework (DFO 2006).
3. Attain a population size corresponding to the estimated maximal demographic growth given no harvest from this stock.

Under SARA, population and distribution recovery objectives are set at the best achievable condition for a species (SARA 2021). In this context, objective 3) represents the best achievable condition for BEL-EHB beluga. However, beluga management plans aim at balancing harvesting rights with conservation objectives as identified within the land-claim agreements. The current conservation objective identified in the 2021-2026 management plan is to maintain the population at or above an abundance of 3,400 animals and that the probability of a decline due to harvesting must not exceed 50% (Hammill et al. 2017a, 2021). This is considered a high risk management approach because it fails to establish any buffer for implementation errors and possible model bias, likely under-estimates parameter uncertainty, and does not consider possible recovery of the stock. In contrast, precautionary approach frameworks aim at managing threats of serious irreversible harm to stocks where there is scientific uncertainty by accounting for the risk of unknown errors in model parameters (Doniol-Valcroze et al. 2013; Hammill and Stenson 2013; Hammill et al. 2017b). Objective 2) above aims for the stock status to attain the Healthy Zone under the precautionary approach framework (DFO 2006), and thus represents an intermediate recovery target integrating Inuit rights and sustainability of harvests.

In addition to a targeted abundance and a timeframe to reach that abundance, recovery targets should identify a probability that the targeted population size is attained. The current 2021-2026 management plan identified 50% as the acceptable probability of meeting the conservation objective. This management approach is highly risky, as is equivalent to accepting a 50% chance of failure to maintain the population at its current, low level. Alternatively, management objectives aiming for a 80% or 95% probability of maintaining or reaching the target population size would provide good, or very good chances of reaching the recovery target, respectively (e.g., Hammill and Stenson 2003, 2007, 2010, 2013; Stenson et al. 2012).

Another aspect of the BEL-EHB recovery objectives include the stock distribution within its summering habitat. Given the philopatry to summering sites displayed by individual beluga, and the potential desertion or extirpation from a formally major beluga aggregation area along the coast of eastern Hudson Bay (c.a., the Nastapoka Estuary) over the last two decades, there would be interest in avoiding further loss from the current BEL-EHB beluga summering distribution. Additionally, a long-term objective (i.e., over > 100 years) would be to recover the historical distribution of beluga in eastern Hudson Bay estuaries previously frequented during the summer, including Richmond Gulf and the Nastapoka River.

The Ungava Bay population was assessed as Endangered in 2020 based on criteria A2: 'Decline in total number of mature individuals', with a decline > 50% over the last three generations, and criteria D1: 'Very small or restricted population. Total number of mature individuals < 250'. Although the last assessment suggests a population size of 68 whales in total in the Ungava Bay area, uncertainty remains whether these individuals are part of a remanent UB DU or migrants from other units. Therefore, the possibility that the UB DU may be extinct cannot be discarded. Because there is no carrying capacity (K) estimate available for UB beluga, it is not possible to compute a PRL for this DU (see Allowable Harm Assessment section). Thus, we propose two possible recovery targets for the UB beluga, assuming the DU still exists at very low levels (see Table 4 for corresponding population size benchmarks):

1. Maintain the population size at or above the 2022 abundance estimate. This represents the survival objective for this DU.
2. Attain a population size corresponding to the estimated maximal demographic growth given no harvest from this DU.

The main summering areas for UB beluga (south of Ungava Bay and the Marralik (Mucalic) Estuary) have been closed to hunting since 1986 to protect this small population. However, harvesting in UB has continued and, given the very small size of any remaining DU, any removals or unusual mortality event would substantially limit recovery. In addition, there is substantial uncertainty related to the UB demographic trend and its drivers. In this context, the survival target (objective 1) may be the most achievable recovery target for this DU. Alternatively, objective 2) aims for population growth under a no mortality, and no density-dependence assumptions (i.e., no Allee effect affecting population dynamics). Although aiming for population growth for UB beluga would be highly recommended, a better understanding of population distribution, abundance, and dynamics within this DU would be required to assess the feasibility of this recovery target.

A distribution objective for UB beluga could be to recover the historical distribution of the population within southern Ungava Bay and its estuaries. This includes the Koksoak, Leaf, Whale, Marralik (Mucalic), and George rivers, as well as Hopes Advance Bay. This objective can only be considered on the long term (i.e., > 100 years).

Sources of uncertainty

- Although recovery targets for UB beluga are presented in the document, research efforts are necessary to establish whether the UB DU still exists or is extinct.
- The population models (see Element 13 for description) used to determine maximal growth objectives assumes that the only source of density-independent mortality for beluga whales is harvest. Under the current harvest levels, this assumption is considered a valid simplification of beluga population dynamics, where population size would stabilize around the carrying capacity in the absence of harvests. However, other factors, such as disease epidemics, ice entrapments or environmental events may also be responsible for beluga mortality, which are not captured in the maximal growth rate abundance numbers. In addition, if UB beluga productivity were affected by an Allee effect, the stock would not grow at its maximal rate of 4%, and therefore projections from the exponential growth function would not apply. Thus, the corresponding recovery targets may be overly optimistic.

- Any remanent of the UB beluga DU is highly vulnerable to stochastic demographic and environmental events given its highly limited size. Therefore, unpredictable causes may lead to extirpation of this DU even in the absence of harvest.
- There has been compelling evidence that beluga display strong philopatry to their natal site, and tend not to recolonize suitable habitat that was previously used as aggregation areas once they are abandoned or the local population is extirpated (Reeves and Mitchell 1987b, 1987c, 1989; Hammill et al. 2004). However, high population density can lead to increased dispersal through intraspecific competition (Lambin et al. 2001). It is therefore conceivable that beluga may recolonize suitable habitats if populations substantially increase to a point where densities approach local carrying capacities. Beluga population sizes at which such density-dependent dispersal may arise in eastern Hudson Bay and Ungava Bay, and likewise the timeframe within which this may occur, are unknown because it has not yet been observed.

Element 13: *Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current EHB and UB beluga population dynamics parameters.*

Population model structure – All BEL-EHB demographic trajectories described in the present document were generated using the stochastic stock-production population model described in Hammill et al. (2023). Briefly, Bayesian methods are used to fit a state-space model that considers survey abundance data to be the outcome of two stochastic processes: a state process and an observation process (De Valpine and Hastings 2002). The state process describes the underlying population dynamics and the temporal series for the true stock using the formulae:

$$\mathrm{N_t} = \mathrm{N_{t-1}} \cdot (1 + (\lambda_{max} - 1) \cdot \left[1 - (\mathrm{N_{t-1}}/\mathrm{K})^{\theta}\right]) \cdot \varepsilon_{\mathrm{p_t}} - \mathrm{R_t} \qquad \text{(Equation 1)}$$

$$\text{with } \varepsilon_{\mathrm{p_t}} \sim \mathrm{logN}\left(0, \tau_{\mathrm{p}}\right) \qquad \text{(Equation 2)}$$

where N is the abundance at time t or t-1, λ_{max} is the maximum rate of increase, K is the environmental carrying capacity, theta (θ) defines the shape of the density-dependent function, and $\varepsilon_{p_t}$is the process error. Removals (R_t) were calculated by adjusting reported catches (C_t) of whales for struck and loss (SL, i.e., the proportion of animals that were wounded or killed but not recovered), as well as non-reported catches:

$$\mathrm{R_t} = \mathrm{C_t} \cdot (1 + \mathrm{SL}) \qquad \text{(Equation 3)}$$

The observation process describes the relationship between the true population size (N_t) and the survey estimates (S_t) where

$$\mathrm{S_t} \sim \Gamma(\alpha, \beta) \qquad \text{(Equation 4)}$$

$$\text{with } \alpha = \mathrm{N_t} \cdot \beta \qquad \text{(Equation 5)}$$

$$\text{and } \beta = \mathrm{N_t} \cdot \varepsilon_{\mathrm{S_t}} \qquad \text{(Equation 6)}$$

And ε_{S_t} corresponds to the precision of the survey estimate.

Model parametrization – The BEL-EHB abundance estimates from the eight surveys conducted between 1985 and 2021 (St-Pierre et al. 2024) were used to fit the model. The runs used the same model and fitting as outlined in Hammill et al. (2023), with the exception that the reported harvests were updated to include harvesting reported to 27 November 2022 (see Appendix B).

Model output – Perpetuating current harvest levels (110 for BEL-EHB beluga; including landings from Nunavut and Nunavik, and derived from BEL-EHB proportions from most recent genetic data; Hammill et al. 2023) would result in BEL-EHB abundances having a 50% probability of being ≥ 2,300 in ten years, and most (> 97%) projections predicting extinction within 33 years (Figure 9). Therefore, the current population dynamic parameters, most notably harvest levels, are incompatible with any of the recovery targets, and have high probabilities of resulting in BEL-EHB beluga extinction within the next two generations.

Exponential growth function – The 2022 survey provided the first abundance estimate for the UB beluga distribution area, despite being the fifth of a series of systematic surveys covering Ungava Bay since 1985 (Sauvé et al. 2023). No beluga were detected on transect lines in any of the four previous surveys, yielding no abundance estimate, although a small number of animals were seen off transect (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin et al. 2009). Therefore, no abundance time series was available to fit a population model for UB beluga. In addition, since the Marralik (Mucalic) Estuary has been closed to hunting since 1986, there has been no reported harvest in the area over the last decades, except for those resulting from the estuary hunt plans in 2021 and 2022 (2 landings each year). Finally, negative population-dependence is unlikely to affect the UB demographic growth at its current size. Therefore, an exponential growth function with an intercept corresponding to the 2022 survey estimate and a 4% growth rate was fitted to make projections for the UB beluga population size under different harvest levels. Harvests were subtracted from the total population following annual growth, and a struck and loss of 27% (median estimated by the population model for BEL-EHB beluga) was applied since no struck and loss data from Ungava Bay was available.

Estimating current UB harvest levels is challenging due to the lack of genetic data available to derive season-specific proportions of UB beluga harvested in Ungava Bay. Because Ungava Bay is frequented by beluga from other, larger DUs during migration, only beluga harvested in summer in Ungava Bay were considered taken from the UB DU. There is uncertainty relative to the timing of the end of the period during which migrants from other DUs leave Ungava Bay in the spring. Therefore, three alternative periods were used to estimate UB beluga harvest levels: 2022 harvests taken by the communities of Aupaluk, Tasiujaq, Kuujjuaq, and Kangiqsualujuaq between 1) August and September (harvest = 4), 2) Mid-July and September (harvest = 10), and 3) July and September (harvest = 22). Perpetuating any of these harvest levels for UB beluga would result in a population decline leading to extirpation of any remaining stock within 4 to 21 years. Therefore, both the growth and survival recovery objectives are unachievable under current harvest levels (Figure 10).

Sources of uncertainty other than those identified in Element 12

- Aerial survey estimates for beluga are known to be highly variable. The BEL-EHB 2021 aerial survey abundance estimate was very low, yet estimated to be more precise than other surveys of this DU (St-Pierre et al. 2024). Given the relatively few surveys that have been completed for this stock, our understanding of current trends is sensitive to changes in the last survey estimate used in the model.
- There is uncertainty relative to the estimation of the number of BEL-EHB beluga harvested annually. BEL-EHB and WHB annual takes are considered to represent a proportion of the total number of beluga landed in Nunavik and Sanikiluaq. These proportions are area- and season-specific, and introduced as priors informed by genetic studies into the population model (Annex A; Hammill et al. 2023; Parent et al. 2023). Recent genetic data indicated that BEL-EHB animals represent a greater proportion of total landings than initially thought (Parent et al. 2023; see Element 15). The TATs and management measures established in

the current beluga management plan (NMRWB and EMRWB 2020) rely on previous, less conservative EHB proportions of total landings. In this document, revised, more conservative proportions are used. Nevertheless, both previous and revised proportions result in beluga removals exceeding the Science advice (DFO 2022).

- Field observations of animals struck and killed but not recovered or reported is an important source of uncertainty in the BEL-EHB population model. Any nonreporting or underreporting of takes has a high impact on model fitting and derived predictions for the population trend. In addition, the median struck and lost level estimated from the BEL-EHB model (27%) was used in the UB beluga demographic projection because no estimate was available for the Ungava Bay harvest efforts. Given the small size of the UB beluga DU, under- or overestimations of the struck and lost level applied to UB beluga harvests are likely to have substantial consequences for the UB beluga demographic projections.
- The UB beluga demographic projection was based on an exponential growth function assuming a constant 4% growth rate, corresponding to the default maximum natural growth rate for cetaceans (Wade 1998). Considering that the stock is depleted, UB beluga could be expected to exhibit a rate of increase close to their intrinsic maximum, which is not well known for beluga specifically. Alternatively, it is possible that UB beluga are subject to an Allee effect, where population growth is negatively influenced by density at very low population sizes. The projections from the 4% growth curve should therefore be interpreted as maximal population sizes.

Element 15: *Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.*

Under current harvest levels, the probability of reaching any of the recovery objectives for BEL-EHB or UB beluga is null. Decreasing anthropogenic mortality (i.e., harvest) would increase chances of recovery for BEL-EHB and UB beluga (Figure 11).

There has been substantial changes in the BEL-EHB population model predictions since the COSEWIC evaluation (COSEWIC 2020a). The most recent assessment indicates that the BEL-EHB stock abundance is not stable as previously thought (Hammill et al. 2017a, 2021), but has been declining at a rate of 3% per year since 2015 (Hammill et al. 2023). This decline is due to high levels of harvests that have consistently exceeded sustainable levels and an under-estimation of the proportion of BEL-EHB animals in the harvest (Hammill et al. 2023). The latter results from a re-analysis of the genetic information that determined that the stock could be further subdivided into an EHB and a separate Belcher Island (BEL) components. In previous analyses using short haplotypes, many of the beluga from the newly identified Belcher Island component had been grouped with WHB animals (Parent et al. 2023). This has important consequences for model parametrization and projections, since a proportion of landings from Sanikiluaq (Belcher Islands) that were previously deemed non-EHB beluga, are now considered as BEL-EHB animals when calculating their proportion in the total Nunavik and Sanikiluaq landings.

Using these updated proportions, no harvest level can provide a 50% probability that the BEL-EHB stock will be > 3,700 in 2026 (current management objective for the beluga management plan; NMRWB and EMRWB 2020). In contrast, the probabilities of BEL-EHB stock abundance being ≥ 3,700 whales in ten years (recovery target 1 identified above) or in one, two, or three generation times given different annual harvest levels are presented in Figure 12.

Probabilities that the BEL-EHB beluga stock would be above the LRL and PRL (recovery target 2) listed above) are presented in the Allowable Harm Assessment section. The probability of attaining a growing population of 3,900 BEL-EHB whales in ten years or 10,200 whales in 86 years is 50% under no harvesting pressure and is unachievable under harvest levels ≥ 1 (by definition of this maximal growth recovery objective).

In the population model used, productivity is modulated via a density-dependent function and a maximum rate of population growth (Hammill et al. 2023). Although the maximum rate of population increase is not known, most studies have suggested a median estimate around 4%, with a range of 2–8% (Alvarez-Flores and Heide-Jørgensen 2004; Hobbs et al. 2006; Lowry et al. 2008; Doniol-Valcroze et al. 2012, 2013). The prior distribution used for λ_{max} in the current model is a Beta distribution with a range of 0.02 to 0.06 (Appendix C), while the median model estimate for λ_{max} was 0.035 (2.5%-97.5% quantiles = 0.021-0.055). It appears unrealistic that this number would increase, and the current model already accounts for density dependence on productivity. Therefore, no simulations of increased productivity were attempted.

Regarding UB beluga, the exponential growth function suggest that at a harvest level of 2 annual takes, the population would remain stable, while any higher harvest level would result in rapid population decline.

Sources of uncertainty

Sources of uncertainty identified in Elements 12 and 13 apply.

SUPPLY OF SUITABLE HABITAT: NOT RELEVANT

Element 14: *Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.*

Due to philopatry to natal sites and cultural and vertical transmission of migration routes, BEL-EHB and UB beluga distribution is considered restricted to the summering and wintering grounds they occupy. Their recovery is not limited by the supply of suitable habitat.

SCENARIOS FOR MITIGATION OF THREATS AND ALTERNATIVES TO ACTIVITIES

Beluga are non-commercially exploited by Inuit from Nunavik and Nunavut. Inuit have harvesting rights under land claim agreements (NILCA and NLCA), and therefore do not require permits to harvest beluga. At present, the main hunting method is the use of a rifle (Breton-Honeyman et al. 2021), although traditional methods are allowed, including harpooning first and netting. There are no hunting fleets, but rather small private motorboats that are used by groups of hunters (Breton-Honeyman et al. 2021). The main hunting locations include the coastal waters off the 14 Nunavik communities and the waters off Belcher Islands, but hunting camps are also set at more remote locations, including Long Island (southeast Hudson Bay) and Marralik (Mucalic) River.

Most Nunavik Marine Region waters are currently managed without a total allowable take (TAT), except within the Eastern Hudson Bay Arc Region where a TAT is shared among communities (Figure 13) to protect BEL-EHB beluga (NMRWB and EMRWB 2020). The Nastapoka, Little Whale River and Marralik (Mucalic) Estuaries are closed to harvesting, and other seasonal closures are in place to protect BEL-EHB beluga during their seasonal migrations (*Marine Mammal Regulations* SOR/93-56, 2018). There is no TAT in Sanikiluaq (Nunavut), but the municipality implements voluntary closures from July 15 to September 30 annually to protect BEL-EHB beluga (DFO 2016). Harvesters are required to report all beluga harvested to DFO and/or Uumajuit Wardens. Nunavik hunters report a struck and lost rate of 5.7% (NMRWB and

EMRWB 2020), but the population model's median estimate for BEL-EHB is 27.3%. This model estimate also includes non-reporting.

> ***Element 16:*** *Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).*
>
> ***Element 17:*** *Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).*

Table 5 proposes mitigation measures that would likely decrease mortality and/or stressors of BEL-EHB and UB beluga. It is difficult to directly increase productivity of beluga populations, as it is dependent on environmental conditions influencing prey availability and carrying capacity. Productivity can likely be indirectly influenced by reducing anthropogenic threats to reproductively mature females and calves. Likewise, there is very little available data on BEL-EHB and UB natural mortality, and harvesting is considered the most important source of mortality for both stocks. Under current conditions, precautionary management of subsistence harvests represents the most likely measure for increasing BEL-EHB, and possibly UB, beluga survival.

The primary threat to BEL-EHB and UB beluga is overharvesting. Under the amended provisions of the *Fisheries Act* (2019), there is renewed emphasis on the sustainability of fisheries through the development of a management framework based on the Precautionary Approach. Under the DFO-MSY approach, the BEL-EHB stock lies in what is considered the Cautious zone, below the PRL but slightly above the LRL (Figure 14). Harvest strategies should focus on rebuilding the BEL-EHB stock within a certain timeframe. This is important both from a conservation perspective, but also to meet the needs of a growing population of hunters in Nunavik. One of the recovery objectives identified in this RPA for the BEL-EHB stock is recovery above the PRL within three generations (86 years), and harvest levels that could achieve this objective are presented in the Allowable Harm Assessment section of this document. In addition, given the known strong philopatry to summering sites expressed by beluga, management of harvests at the estuary level would represent a precautionary approach to avoid depleting family groups of beluga who may be vulnerable to single, large harvest events.

In contrast, the UB population is in the critical zone, under the LRL which is considered a lower limit below which significant harm can occur to the stock, significantly jeopardizing its recovery (Stenson et al. 2012; Doniol-Valcroze et al. 2013; Hammill et al. 2017b). It is unknown whether the non-recovery of UB beluga despite four decades of harvest closure in their main summering habitat is due to the small size of the population altering productivity via Allee effects, to non-reported continued harvests, or to the fact that this population may be extinct, and that animals observed in southern Ungava Bay and its estuaries in the summer may be migrants from other populations. Growth curves indicate that any harvest on remaining UB beluga would be unsustainable and pose serious threats to the survival of any residual population.

The impacts of other threats on BEL-EHB and UB beluga survival and recovery are difficult to assess, mostly due to the restricted data available on migration routes and timing, distribution in wintering grounds, season-specific diet and energetic requirements, and the physiological and fitness effects of the different stressors. A better understanding of spatiotemporal overlap of beluga migration and winter distribution with fisheries efforts, vessel traffic, and seismic exploration is required to estimate the reduction in mortality and increase in productivity expected by proposed mitigation measures or alternatives. Additionally, the implementation of a marine mammal carcass reporting and sampling program in Nunavik could provide valuable data on natural and anthropogenic causes of beluga mortality other than hunting.

> ***Element 19:*** *Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17.*
>
> ***Element 20:*** *Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19.*

The current Nunavik beluga population model is a surplus production model, characterized by no age structure, and no explicit mortality or reproductive rates. The maximum rate of increase parameter (λ_{max}) integrates total births and mortalities and is fitted for the entire time series. It is, therefore, difficult to predict what impact on population dynamics individual mitigation measures would have. However, the one cause of mortality that is explicitly included in the model is removals through harvesting. Any reduction in harvest levels represent mortalities that are avoided. How this reduction in anthropogenic mortality interacts with density-dependent effects depends on the relative population size and carrying capacity. Figures 15 and 16 show the projected population trends with varying harvest levels for the BEL-EHB and UB stocks, respectively.

> ***Element 21:*** *Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.*

The parameter values estimated by the model are presented in Table 6. One aspect that the current model does not account for is unusual mortality events (UME) due, for example, to ice entrapments or disease epidemics, that are likely to affect overall abundance and, if repeated over time, may impact the overall productivity estimate. We simulated occasional UME in the BEL-EHB stock where 60 whales are harvested per year to explore potential impacts on population dynamics (Figure 17). While events causing additional mortality of 10 whales every 20 years had little impact on population dynamics, events removing an additional 50 beluga every 20 years resulted in delayed population growth. This demonstrates that stochastic, punctual events causing the mortality of several tens of beluga should be accounted for when modelling population dynamics.

A recently developed progesterone titration method allows the calculation of female pregnancy rates from beluga blubber samples (Renaud et al. 2023). Moreover, genetic sexing of historic beluga samples from harvest suggest sex biases in removals (Parent and Sauvé, DFO, unpublished data). Sex-skewed harvest can have numerous effects on mammal population dynamics, including impaired fecundity in low reproductive potential species (e.g. Ginsberg and Milner-Gulland 1994; Langvatn and Loison 1999; McLoughlin et al. 2005; Taylor et al. 2008). Therefore, incorporating information on age-specific reproductive rates and age- and sex-specific harvest levels into a sex- and age-structured demographic model could represent a way to integrate the effects of environmental variability and harvest biases into beluga population dynamics.

> ***Element 18:*** *If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values.*

Habitat supply is unlikely to limit BEL-EHB and UB beluga to achieve recovery targets.

ALLOWABLE HARM ASSESSMENT

Element 22: *Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.*

Currently, the Government of Canada does not have a standardized, quantitative definition of Allowable Harm. In contrast, the U.S. Government adopted the potential biological removal (PBR) level as a tool for quantifying the maximum annual number of animals that may be removed in addition to natural mortality while still allowing the target population to reach or maintain its optimum sustainable population size within 100 years (Wade 1998). The PBR therefore has an implicit management objective, which is to identify harvest levels that have a 95% probability of the population being above the Maximum Net Productivity Level, defined as 50% of the carrying capacity over a period of 100 years (Wade 1998). The PBR is calculated as:

$$PBR = 0.5\,R_{max}\ \times RF\ \times N_{min} \qquad \text{(Equation 7)}$$

Where R_{max} is the maximum rate of population increase (by default set to 4% for cetaceans), *FR* is a recovery factor ranging between 0.1 and 1, and N_{min} is the estimated population size using the 20th percentile of the assumed log-normal distribution around the abundance estimate (Wade 1998). N_{min} is calculated using the equation:

$$N_{min} = \frac{N_{est}}{\exp\,(z\sqrt{\ln\,(1+CV(N_{est})^2)})} \qquad \text{(Equation 8)}$$

where N_{est} is the point estimate of the most recent population size, *z* is the standard normal variate (0.824 for the 20th percentile), and *CV(N)* is the coefficient of variation for N_{est}.

The median BEL-EHB abundance estimate for 2022 was 2,833 (CV = 22.73%), resulting in an N_{min} of 2,355. For UB, we calculated N_{min} using the most recent survey abundance estimate of 68 (CV = 61.85%; Sauvé et al. 2023), the estimate N_{min} was 43.

Recovery factor values < 1 allocate a proportion of the expected net production to demographic growth, while accounting for uncertainties hindering population recovery (National Marine Mammals Service 2016). Default values of 0.1 and 0.5 are recommended for Endangered and Threatened DUs, respectively (Barlow et al. 1995; Wade 1998). Nevertheless, Canadian criteria suggest a RF of 0.1 for small, declining populations or populations with unknown trends(DFO 2018) . We thus used a RF of 0.1 for both populations.

Using these parameters, the PBR for BEL-EHB was 4.71 whales per year, while the PBR for UB was 0.085 whales per year. These PBR values represent an estimate of total removals from the population, thus including harvests, struck and loss, non-reported harvest, and other sources of human-induced mortality such as bycatch and vessel strikes. The TAT should therefore be lower than the PBR to account for sources of human-induced mortality other than harvesting.

In the case of BEL-EHB beluga, a certain level of information on abundance, trend and population dynamics is available. Therefore, a precautionary approach framework, which is more structured and leads to the calculation of different harvest levels which would still meet management objectives, can be applied to this DU (Hammill et al. 2017b). International agreements have identified the MSY as a management objective. Estimating MSY requires information on ecosystem carrying capacity (*K*) and the shape of the density dependent relationship. For some species, historic catch data have been used to infer pre-commercial hunt population sizes, which is assumed to be an estimate of *K*. In the case of BEL-EHB beluga, there is important uncertainty in historical catch. Moreover, there has been a change in ecosystem conditions in the Hudson-James Bay complex, including a shortening of the ice-covered season and the construction of hydro-electric dams that modified waterflow within the Bay (Tsuji et al. 2009; Galbraith and Larouche 2011; Hammill and Stenson 2013). This suggests that *K* might have varied since the late 1800s, and that other proxies of K under current conditions should be used (Hammill and Stenson 2007).

The model fitted to the 1985-2021 aerial survey data and including the 1974-2022 catch data produced an estimate of *K* for the period of the modelling (Table 6) that could act as a proxy in setting the PRL and LRL under the MSY approach (Hammill et al. 2017b). Assuming that maximum productivity occurs at 60% of *K*, the PRL and LRL are set at 48% and 24% of this *K* estimate, respectively (Hammill et al. 2017b). This results in a BEL-EHB beluga PRL and LRL of 5,300 and 2,700 whales, respectively. The median current population estimated from the population model was 2,800 whales. The probability that the 2022 population is above the PRL is zero, while the probability that it is above the LRL is 60%. The DU, therefore, lies in the cautious zone, below the PRL but above the LRL. Thus, under the precautionary approach framework, BEL-EHB beluga harvest strategies should focus on rebuilding the stock above the PRL within a certain time frame, which represents recovery objective 2) identified in Element 13. A recommended management objective is to maintain a 95% probability that the population is above the LRL and 80% probability that the population is above the PRL (Hammill and Stenson 2003, 2007, 2010, 2013; Stenson et al. 2012). The probabilities that the BEL-EHB stock increases above the LRL and PRL in 10 years, and in one, two, and three generation times considering different harvest levels are presented in Figures 18 and 19.

Projections, therefore, suggest that attaining a BEL-EHB stock size above the PRL in one generation is relatively unlikely (<70% probability under no annual harvest), while attaining the PRL in three generations is feasible with reasonable probability (e.g., 80%) with annual harvest levels of 20 beluga. Annual harvest levels ranging between 20-30 beluga are compatible with a 90-95% probability that the population remains over the LRL over the next two to three generations.

Sources of uncertainty

- Because the relative sizes of the EHB and BEL populations are unknown, it is currently not possible to derive population-specific allowable harm levels within the BEL-EHB stock. Nevertheless, total allowable harm reported in this section may exceed the yet undetermined EHB- or BEL-specific allowable harm levels if harvests differentially target the EHB and BEL populations. Exceeding the population-specific allowable harm levels could lead to extirpation of matrilineages occurring on the eastern Hudson Bay coast or around the Belcher Islands. Avoiding harvesting several beluga from a same group and distributing harvest efforts across the BEL-EHB distribution range are practices that could contribute to avoiding differential targeting of the BEL and EHB populations. In addition, assessing the relative population sizes of BEL and EHB beluga would allow calculation of population-specific allowable harm levels.

RESEARCH RECOMMENDATIONS

Different aspects of beluga distribution, behaviour and population dynamics for which additional information is required to better characterize the level of impact of the different threats and provide a more meaningful Allowable Harm assessment have been highlighted throughout this document. The three main aspects which are of particular importance are: 1) whether the UB DU still persists or is extinct, 2) the strong influence of the 2021 BEL-EHB abundance estimate on demographic model trends and projections, and 3) the scarcity of information on BEL-EHB and UB beluga feeding behaviour and winter distribution.

To address the question of the persistence of the UB beluga DU, beluga tissue samples from the summer distribution area must be collected and contrasted with that of other populations.

The lack of samples from this area is attributable to the absence of harvest in the south of Ungava Bay and the Marralik (Mucalic) Estuary since 1986, before genetic sampling was instigated. Biopsies, which provide samples from live animals, would represent a potential way of increasing sampling in that area without promoting removals on this very small, if not extinct population. Environmental DNA (eDNA) also represents a non-invasive sampling method, however only mitochondrial DNA can be analysed from eDNA samples due to nuclear DNA degradation. Recent analyses suggest nuclear DNA is more promising for identifying beluga populations than mitochondrial DNA (Geneviève Parent, DFO, personal communication). Caution is however warranted, as the absence of a genetically-distinct population in Ungava Bay in summer would not represent unequivocal evidence that the DU is extinct. Many beluga DUs in Canada are defined based on philopatry to summering grounds. Therefore, collecting behavioural (e.g., telemetry) data on beluga summering in southern Ungava Bay to document movements and characterize the summer distribution of these animals may be necessary to determine if beluga frequenting the area are summer residents or migrating individuals.

The addition of the low and unusually precise 2021 survey estimate into the time series used to fit the BEL-EHB demographic model changed the estimated population trend and projections. The extent to which the 2021 abundance estimate exerts a disproportional effect on the population model is unknown, but derived model estimates and projection raise concern as to the DU's status. Beluga aerial survey-derived abundance estimates from a same area are highly variable, which is thought to result from the small size of surveyed populations, coupled with the non-random or contagious distribution of individuals that spend most of their time under the surface (Kingsley and Gauthier 2002; Gosselin et al. 2007; Gosselin et al. 2014). Conducting repeated surveys allows to capture the variability associated with the contagious distribution of beluga (e.g., Gosselin et al. 2007). Repeating aerial surveys to obtain other recent BEL-EHB stock abundance estimates to input into the population model would therefore provide a better understanding of current population trends and may reduce uncertainty associated with individual survey estimates. Moreover, incorporating sex- and age-specific data related to harvest and reproductive as well as environmental factors into a stochastic, rather than deterministic population model would better capture aspects of beluga population dynamics that are unaccounted for with the model currently used.

Over the last decades, telemetry devices have improved drastically in terms of battery life and data storage. The deployment of modern satellite telemetry tags which could collect dive data from beluga on the eastern Hudson Bay coast and from the Belcher Islands would provide unprecedented information on Nunavik beluga foraging behaviour, as well as information on movements to and within wintering grounds. This, compounded with detailed information on fishing effort, shipping traffic, seismic exploration and environmental variables, would allow a better assessment of the level to which the different threats may affect BEL-EHB beluga recovery, and would allow the development of habitat selection models.

Finally, TEK has provided extremely valuable information on beluga diet, distribution, condition, and the timing of migration which has been presented in this RPA. Additional efforts are needed among hunters, researchers, and managers so that Inuit knowledge and values that have been gained over countless generations are passed on and integrated into meaningful collaborations contributing to our understanding of beluga biology, behaviour, and demographic trends.

CONCLUSIONS

Beluga have general life-history traits that result in a low intrinsic rate of population increase and relatively long generation time. In addition, they display strong philopatry to their summering areas and culturally transmitted migration routes. These characteristics makes their populations highly susceptible to harvesting pressure, the main threat identified for both the BEL-EHB and UB stocks.

There are important uncertainties relative to the threat assessment, estimated probabilities of reaching the different recovery targets identified, and to the current population trends for both BEL-EHB and UB beluga. Nonetheless, most recent data indicates a continuous decline in BEL-EHB beluga since the 1970s, interspersed with periods where the decline has slowed or the population briefly stabilised. The population size of UB beluga remains very small, assuming the DU is not extinct. Management objectives should, therefore, target the recovery of both stocks, not only from a conservation perspectives, but also to ensure the continuation of the socio-culturally important beluga harvesting practices along the coasts of Nunavik. Collaborative research efforts and community engagement are critical to increase our understanding of the interactions between beluga behaviour and population dynamics, its changing ecosystem, and human activities including, but not limited to, harvesting.

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REFERENCES CITED

Addison, R. F., and Brodie, P. F. 1987. Transfer of Organochlorine Residues from Blubber through the Circulatory System to Milk in the Lactating Grey Seal *Halichoerus grypus*. Can. J. Fish. Aquat. Sci. 44, 782–786. doi: 10.1139/f87-095.

Alayco, S., Bergeron, M., and Michaud, M. D. 2007. Inuit elders and their traditional knowledge: beluga hunting and sustainable practices. Report from group interviews held between March 8 and 15, 2006.

Allee, W. C., and Bowen, E. S. 1932. Studies in animal aggregations: Mass protection against colloidal silver among goldfishes. J. Exp. Zool. 61, 185–207. doi: 10.1002/jez.1400610202.

Alvarez-Flores, C. M., and Heide-Jørgensen, M. P. 2004. A risk assessment of the sustainability of the harvest of beluga (*Delphinapterus leucas* (Pallas 1776)) in West Greenland. ICES J. Mar. Sci. 61, 274–286. doi:10.1016/j.icesjms.2003.12.004.

AMAP. 2007. Arctic Oil and Gas 2007. Arctic Monitoring and Assessment Programme (AMAP) Oslo, Norway, xiii + 40.

Babb, D. G., Kirillov, S., Galley, R. J., Straneo, F., Ehn, J. K., Howell, S. E. L., Brady, M., Ridenour, N. A., and Barbere, D. G. 2021. Sea Ice Dynamics in Hudson Strait and Its Impact on Winter Shipping Operations. J. Geophys. Res. Oceans 126, 23. doi: 10.1029/2021JC018024.

Bagby, S. C., Reddy, C. M., Aeppli, C., Fisher, G. B., and Valentine, D. L. 2017. Persistence and biodegradation of oil at the ocean floor following Deepwater Horizon. Proc. Natl. Acad. Sci. 114, E9-E18. doi: 10.1073/pnas.1610110114.

Bailleul, F., Lesage, V., Power, M., Doidge, D. W., and Hammill, M. O. 2012a. Differences in diving and movement patterns of two groups of beluga whales in a changing Arctic environment reveal discrete populations. Endanger. Species Res. 17, 27–41. doi: 10.3354/esr00420.

Bailleul, F., Lesage, V., Power, M., Doidge, D. W., and Hammill, M. O. 2012b. Migration phenology of beluga whales in a changing Arctic. Clim. Res. 53, 169–178. doi: 10.3354/cr01104.

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, 305–316. doi: 10.14430/arctic790.

Barlow, J., Swartz, S. L., Eagle, T. C., and Wade, P. R. 1995. U.S. Marine Mammal Stock Assessments: Guidelines for Preparation, Background, and a Summary of the 1995 Assessments. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-OPR-6, 73 p.

Bell, S., and Stewart, D. 2022. Talk of new dams in Quebec election has some Indigenous leaders surprised, others on guard. CBC News September 14, 2022.

Blackned, G. 2019. Letter from Gordon Blackned, Chairperson, Eeyou Marine Region Wildlife Board, Waskaganish, QC, 19 August 2019, to Hal Whitehead, Co-chair, COSEWIC Marine Mammal Subcommittee.

Boulva, J. 1981. Catch statistics of beluga (*Delphinapterus leucas*) in northern Quebec: 1974 to 1976, final; 1977 to 1978, preliminary. Rep. Int. Whal. Comm. 31, 531–538.

Bourdages, H., Lesage, V., Hammill, M. O., and de March, B. 2002. Impact of harvesting on population trends of beluga in eastern Hudson Bay. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/36. i + 45.

Brand, U., Came, R. E., Affek, H., Azmy, K., Mooi, R., and Layton, K. 2014. Climate-forced change in Hudson Bay seawater composition and temperature, Arctic Canada. Chem. Geol. 388, 78–86. doi: 10.1016/j.chemgeo.2014.08.028.

Breton-Honeyman, K., Furgal, C. M., and Hammill, M. O. 2013. Nunavimmiut knowledge of belugas. Preliminary report. Environmental and Life Sciences Program, Trent University, Peterborough, ON.

Breton-Honeyman, K., Hammill, M. O., Furgal, C. M., and Hickie, B. 2016. Inuit Knowledge of beluga whale (*Delphinapterus leucas*) foraging ecology in Nunavik (Arctic Quebec), Canada. Can. J. Zool. 94, 713–726. doi: 10.1139/cjz-2015-0259.

Breton-Honeyman, K., Huntington, H. P., Basterfield, M., Campbell, K., Dicker, J., Gray, T., et al. 2021. Beluga whale stewardship and collaborative research practices among Indigenous peoples in the Arctic. Polar Res. 40, 18. doi: 10.33265/polar.v40.5522.

Brown Gladden, J. G., Ferguson, M. M., and Clayton, J. W. 1997. Matriarchal genetic population structure of North American beluga whales *Delphinapterus leucas* (Cetacea: Monodontidae). Mol. Ecol. 6, 1033–1046. doi: 10.1046/j.1365-294X.1997.00275.x.

Brown Gladden, J. G., Ferguson, M. M., Friesen, M. K., and Clayton, J. W. 1999. Population structure of North American beluga whales (*Delphinapterus leucas*) based on nuclear DNA microsatellite variation and contrasted with the population structure revealed by mitochondrial DNA variation. Mol. Ecol. 8, 347–363. doi: 10.1046/j.1365-294X.1998.00559.x.

Burek, K. A., Gulland, F. M. D., and O'Hara, T. M. 2008. Effects of climate change on arctic marine mammal health. Ecol. Appl. 18, S126–S134. doi: 10.1890/06-0553.1.

Burns, J. J., and Seaman, G. A. 1986. Investigations of belukha whales in coastal waters of western and northern Alaska. II. Biology and ecology. US Department of Commerce, NOAA, OCSEAP Final Report 56, 221–357.

Byers, T., and Roberts, L. W. 1995. Harpoons and Ulus: Collective Wisdom and Traditions of Inuvialuit Regarding the Beluga ("qilalugaq") in the Mackenzie River Estuary. Byers Environmental Studies, 152.

Cardinal, N. 2013. Aboriginal Traditional Knowledge Designatable Units Report prepared for the ATK Subcommittee of COSEWIC on Beluga Whale *Delphinapterus leucas* in Canada. Unpublished report, not for public distribution. Committee on the Status of Endangered Wildlife in Canada. 59.

Caron, L. M. J. 1987. Status, site fidelity, and behavior of a hunted herd of white whales (*Delphinapterus leucas*) in the Nastapoka estuary, eastern Hudson Bay. M. Sc. thesis, McGill University, xvi + 135.

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. Can. Bull. Fish. Aquat. Sci. 224, 69–79.

Castellote, M., Thayre, B., Mahoney, M., Mondragon, J., Lammers, M. O., and Small, R. J. 2018. Anthropogenic Noise and the Endangered Cook Inlet Beluga Whale, *Delphinapterus leucas*: Acoustic Considerations for Management. Mar. Fish. Rev. 80, 63–88. doi: 10.7755/MFR.80.3.3.

Clapham, P. J., Aguilar, A., and Hatch, L. T. 2008. Determining spatial and temporal scales for management: lessons from whaling. Mar. Mamm. Sci. 24, 183–201. doi: 10.1111/j.1748-7692.2007.00175.x.

Colbeck, G. J., Duchesne, P., Postma, L. D., Lesage, V., Hammill, M. O., and Turgeon, J. 2013. Groups of related belugas (*Delphinapterus leucas*) travel together during their seasonal migrations in and around Hudson Bay. Proc. R. Soc. B: Biol. Sci. 280. doi: 10.1098/rspb.2012.2552.

Connon, R. F., Quinton, W. L., Craig, J. R., and Hayashi, M. 2014. Changing hydrologic connectivity due to permafrost thaw in the lower Liard River valley, NWT, Canada. Hydrol. Process. 28, 4163–4178. doi: 10.1002/hyp.10206.

Cosens, S. E., and Dueck, L. P. 1993. Icebreaker noise in Lancaster Sound, N.W.T., Canada: Implications for marine mammal behavior. Mar. Mamm. Sci. 9, 285–300. doi: 10.1111/j.1748-7692.1993.tb00456.x.

COSEWIC. 2004. Assessment and update status report on the beluga whale *Delphinapterus leucas*. Committee on the Status of Endangered Wildlife in Canada, ix + 70 pp.

COSEWIC. 2014. COSEWIC assessment and status report on the Beluga Whale *Delphinapterus leucas*, St. Lawrence Estuary population, in Canada. Committee on the Status of Endangered Wildlife in Canada, xii + 64.

COSEWIC. 2016. Special Report Designatable Units for Beluga Whales (*Delphinapterus leucas*) in Canada. Committee on the Status of Endangered Wildlife in Canada, 73 p.

COSEWIC. 2020a. COSEWIC assessment and status report on the Beluga Whale *Delphinapterus leucas*, Eastern High Arctic - Baffin Bay population, Cumberland Sound population, Ungava Bay population, Western Hudson Bay population, Eastern Hudson Bay population and James Bay populationn in Canada. Committee on the Status of Endangered Wildlife in Canada, xxxv + 84.

COSEWIC. 2020b. COSEWIC guidelines for recognizing designatable units. (Accessed 2023-05-11).

Coté, D., Heggland, K., Roul, S., Robertson, G., Fifield, D., Wareham, V., Colbourne, E., Maillet, G., Devine, B., Pilgrim, L., Pretty, C., Le Corre, N., Lawson, J.W., Fuentes-Yaco, C. and Mercier, A. 2019. Overview of the biophysical and ecological components of the Labrador Sea Frontier Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/067. v + 59 p.

Cuerrier, A., and the Elders of Kangiqsualujjuaq. 2012. The zoological knowledge of the Inuit of Kangiqsualujjuaq, Nunavik. Westmount, QC: Nunavik Publications, 132.

Dagenais, S., Molson, J., Lemieux, J.-M., Fortier, R., and Therrien, R. 2020. Coupled cryo-hydrogeological modelling of permafrost dynamics near Umiujaq (Nunavik, Canada). Hydrogeol. J. 28, 887–904. doi: 10.1007/s10040-020-02111-3.

de March, B. G. E., and Postma, L. D. 2003. Molecular genetic stock discrimination of Belugas (*Delphinapterus leucas*) hunted in eastern Hudson Bay, northern Quebec, Hudson Strait, and Sanikiluaq (Belcher Islands), Canada, and comparisons to adjacent populations. Arctic 56, 111–124. doi: 10.14430/arctic607.

De Valpine, P., and Hastings, A. 2002. Fitting population models incorporating process noise and observation error. Ecol. Monogr. 72, 57–76. doi: 10.1890/0012-9615(2002)072[0057:FPMIPN]2.0.CO;2.

Dennis, B. 1989. Allee effects: Population Growth, Critical Density, and the Chance of Extinction. Nat. Resour. Model. 3, 481–538. doi: 10.1111/j.1939-7445.1989.tb00119.x.

DFO. 2005. Recovery potential assessment of Cumberland Sound, Ungava Bay and St. Lawrence beluga populations (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/036, 14.

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

DFO. 2007. Development of a closed area in NAFO 0A to protect narwhal over-wintering grounds, including deep-sea corals. DFO Can. Sci. Advis. Sec. Sci. Resp. 2007/002.

DFO. 2014a. Guidance on Assessing Threats, Ecological Risk and Ecological Impacts for Species at Risk. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (Erratum: June 2016)

DFO. 2014b. Science review of the final environmental impact statement addendum for the early revenue phase of Baffinland's Mary River Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2013/024.

DFO. 2014c. Fishery management plan: Greenland halibut (*Reinhardtius hippoglossoides)* — Northwest Atlantic Fisheries Organization subarea 0 — Effective 2014.

DFO. 2016. Update to the proportion of eastern Hudson Bay beluga harvested and implications for harvest allocations in Nunavik. DFO Can. Sci. Advis. Sec. Sci. Resp. 2016/043.

DFO. 2018. Harvest advice for eastern and western Hudson Bay Beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/008. (Erratum : September 2020)

DFO. 2019. Science Review of the Phase 2 Adddendum to the Final Environmental Impact Statement for the Baffinland Mary River Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2019/015.

DFO. 2020. 2020 Harvest Advice for Eastern Hudson Bay Beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/031.

DFO. 2022. Harvest advice for Eastern Hudson Bay and James Bay beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/024.

Doidge. D. W. 1990a. Age-length and length-weigth comparisons in the beluga, *Delphinapterus leucas*, p.59-68 *In*: Simth, T.G., St-Aubin, D. J. and Geraci, J. R. (eds). Advances in research on the beluga whale, *delphinapterus leucas*. Bull. Fish. Aquat. Sci. 224.

Doidge, D. W. 1990b. Age and state based analysis of the population dynamics of beluga whales, *Delphinapterus leucas*, with particular reference to the northern Quebec population. PhD Dissertation. *McGill University*, 190 p.

Doidge, D. W., Adams, W., and Burgy, C. 2002. *Traditional Ecological Knowledge of beluga whales in Nunavik: Interviews from Puvirnituq, Umiujaq and Kuujjuaraapik*. Report 12-419 of the Nunavik Research Centre submitted to Environment Canada's Habitat Stewardship Program for Species at Risk. Project PH-2001-2-20022. Makivik Corporation. Kuulluaq, ac. 10 p + Appendix of 9 maps.

Doniol-Valcroze, T., and Hammill, M. O. 2011. Information on abundance and harvest of Ungava Bay beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/126, iv + 12.

Doniol-Valcroze, T., Hammill, M. O., and Lesage, V. 2012. Information on abundance and harvest of eastern Hudson Bay beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/119. iv + 17.

Doniol-Valcroze, T., Gosselin, J.-F., and Hammill, M. O. 2013. Population modeling and harvest advice under the precautionary approach for eastern Hudson Bay beluga (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2012/168. iii + 31.

Dunbar, M. J. 1970. On the Fishery Potential of the Sea Waters of the Canadian North. Arctic 23, 150–174. doi: 10.14430/arctic3169.

Durkalec, A., Basterfield, M., Jean-Gagnon, F., Kasudluak, P., and Breton-Honeyman, K. 2020. Inuit Knowledge of Beluga of Southern Ungava Bay and the Marralik (Mucalic) and Ungunniavik (Whale) River Estuaries. Nunavik Marine Region Wildlife Board (NMRWB) Final report, 56.

Eastwood, R. A., Macdonald, R. W., Ehn, J. K., Heath, J., Arragutainaq, L., Myers, P. G., Barber, D. G., and Kuzyk, Z. A. 2020. Role of River Runoff and Sea Ice Brine Rejection in Controlling Stratification Throughout Winter in Southeast Hudson Bay. Estuaries Coasts 43, 756–786. doi: 10.1007/s12237-020-00698-0.

Ellis, S., Franks, D. W., Nattrass, S., Currie, T. E., Cant, M. A., Giles, D., Balcomb, K. C., and Croft, D. P. 2018. Analyses of ovarian activity reveal repeated evolution of post-reproductive lifespans in toothed whales. Sci. Rep. 8, 1–10. doi: 10.1038/s41598-018-31047-8.

Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K., and Dooling, R. 2016. Communication masking in marine mammals: A review and research strategy. Mar. Pollut. Bull. 103, 15–38. doi: 10.1016/j.marpolbul.2015.12.007.

Ezer, T., Hobbs, R. C., and Oey, L.-Y. 2008. On the movement of beluga whales in Cook Inlet, Alaska: Simulations of tidal and environmental impacts using a hydrodynamic inundation model. Oceanogr. 21, 15–23.

Ferguson, S. H., Higdon, J. W., and Chmelnitsky, E. G. 2010. “The Rise of Killer Whales as a Major Arctic Predator,” in A Little Less Arctic: Top Predators in the World’s Largest Northern Inland Sea, Hudson Bay, eds. S. H. Ferguson, L. L. Loseto, and M. L. Mallory (Dordrecht: Springer Netherlands), 117–136. doi: 10.1007/978-90-481-9121-5_6.

Ferguson, S. H., Higdon, J. W., and Westdal, K. H. 2012. Prey items and predation behavior of killer whales (*Orcinus orca*) in Nunavut, Canada based on Inuit hunter interviews. Aquat. Biosyst. 8, 1–16. doi: 10.1186/2046-9063-8-3.

Ferguson, S. H., Willing, C., Kelley, T. C., Boguski, D. A., Yurkowski, D. J., and Watt, C. A. 2020. Reproductive parameters for female beluga whales (*Delphinapterus leucas*) of Baffin Bay and Hudson Bay, Canada. Arctic 73, 405–420.

Ferguson, S. H., Yurkowski, D. J., Hudson, J. M., Edkins, T., Willing, C., and Watt, C. A. 2021. Larger body size leads to greater female beluga whale ovarian reproductive activity at the southern periphery of their range. Ecol. Evol. 11, 17314–17322. doi: 10.1002/ece3.8367.

Finley, K. J., and Renaud, W. E. 1980. Marine mammals inhabiting the Baffin Bay North Water in winter. Arctic 33, 724–738.

Finley, K. J., Miller, G. W., Allard, M., Davis, R. A., and Evans, C. R. 1982. The belugas (*Delphinapterus leucas*) of northern Quebec: distribution, abundance, stock identity, catch history and management. Can. Tech. Rep. Fish. Aquat. Sci. 1123, vi + 57.

Finley, K. J., Miller, G. W., Davis, R. A., and Greene, C. R. 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high Arctic. *Canadian Bulletin of Fisheries and Aquatic Sciences* 224, 97–117.

Fisheries Act. 2019. An Act to amend the Fisheries Act and other Acts in consequence. S.C. 2019, c. 14.

Frost, K. J., and Lowry, L. F. 1990. “Distribution, abundance, and movements of beluga whales, *Delphinapterus leucas*, in coastal waters of western Alaska,” in *Advances in research on the beluga whale, Delphinapterus leucas*. Bull. Fish. Aquat. Sci. 224., eds. T. G. Smith, D. J. St. Aubin, and J. R. Geraci, 39–57.

Galbraith, P. S., and Larouche, P. 2011. Sea-surface temperature in Hudson Bay and Hudson Strait in relation to air temperature and ice cover breakup, 1985–2009. J. Mar. Syst. 87, 66–78. doi: 10.1016/j.jmarsys.2011.03.002.

Gavrilchuk, K., and Lesage, V. 2014. Large-scale marine development projects (mineral, oil and gas, infrastructure) proposed for Canada’s North. Can. Tech. Rep. Fish. Aquat. Sci. 3069, viii + 84.

Geertsema, M., Highland, L., and Vaugeouis, L. 2009. Environmental Impact of Landslides in Sassa, K., Canuti, P. (eds) Landslides – Disaster Risk Reduction (Berlin, Heidelberg: Springer Berlin Heidelberg), 589–607. doi: 10.1007/978-3-540-69970-5_31.

Gervaise, C., Simard, Y., Roy, N., Kinda, B., and Ménard, N. 2012. Shipping noise in whale habitat: Characteristics, sources, budget, and impact on belugas in Saguenay–St. Lawrence Marine Park hub. J. Acoust. Soc. Am. 132, 76–89. doi: 10.1121/1.4728190.

Ginsberg, J. R., and Milner-Gulland, E. J. 1994. Sex-Biased Harvesting and Population Dynamics in Ungulates: Implications for Conservation and Sustainable Use. Conserv. Biol. 8, 157–166. doi: 10.1046/j.1523-1739.1994.08010157.x.

Golodnoff, M. 1956. Den store savssat (The big savssat). Grønland 7, 269–280.

Gosselin, J.-F., Lesage, V., Hammill, M. O., and Bourdages, H. 2002. Abundance indices of beluga in James Bay, eastern Hudson Bay and Ungava Bay in summer 2001. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/042, 27 p.

Gosselin, J.-F., Hammill, M. O., and Lesage, V. 2007. Comparison of photographic and visual abundance indices of belugas in the St. Lawrence Estuary in 2003 and 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2007/025, ii + 27.

Gosselin, J.-F., Lesage, V., and Hammill, M. O. 2009. Abundance indices of beluga in James Bay, eastern Hudson Bay and Ungava Bay in 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/006. iv + 25.

Gosselin, J.-F., Doniol-Valcroze, T., and Hammill, M. O. 2013. Abundance estimate of beluga in eastern Hudson Bay and James Bay, summer 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/016. vii + 20.

Gosselin, J.-F., Hammill, M. O., and Mosnier, A. 2014. Summer abundance indices of St. Lawrence Estuary beluga (*Delphinapterus leucas*) from a photographic survey in 2009 and 28 line transect surveys from 2001 to 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/021, iv + 51.

Gosselin, J.-F., Hammill, M. O., and Mosnier, A. 2017. Indices of abundance for beluga (*Delphinapterus leucas*) in James Bay and eastern Hudson Bay in summer 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/067, iv + 25.

Halliday, W. D., Insley, S. J., Hilliard, R. C., de Jong, T., and Pine, M. K. 2017. Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. Mar. Pollut. Bull. 123, 73–82. doi: 10.1016/j.marpolbul.2017.09.027.

Halliday, W. D., Scharffenberg, K. C., Macphee, S., Hilliard, R. C., Mouy, X., Whalen, D., Loseto, L. L., and Insley, S. J. 2019. Beluga vocalizations decrease in response to vessel traffic in the Mackenzie River Estuary. Arctic 72, 337–346. doi: 10.14430/arctic69294.

Halliday, W. D., Scharffenberg, K., Whalen, D., MacPhee, S. A., Loseto, L. L., and Insley, S. J. 2020. The summer soundscape of a shallow-water estuary used by beluga whales in the western Canadian Arctic. Arct. Sci. 6, 361–383. doi: 10.1139/as-2019-0022.

Hammill, M. O. 2013. "Effects of Climate Warming on Arctic Marine Mammals in Hudson Bay: Living on the Edge?," in Responses of Arctic Marine Ecosystems to Climate Change, eds. F. J. Mueter, D. M. S. Dickson, H. P. Huntington, J. R. Irvine, E. A. Logerwell, S. A. MacLean, *et al.* (Alaska Sea Grant: University of Alaska Fairbanks). doi: 10.4027/ramecc.2013.02.

Hammill, M.O., and Lesage, V. 2019. Conservation value to assisting live-stranded neonates and entrapped juvenile beluga (*Delphinapterus leucas*) from the St. Lawrence Estuary population. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/065. iii + 20 p.

Hammill, M. O., and Stenson, G. B. 2003. Application of the Precautionary Approach and Conservation Reference Point to the Management of Atlantic Seals: A Discussion Paper. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/067, iii + 17.

Hammill, M. O., and Stenson, G. B. 2007. Application of the precautionary approach and conservation reference points to management of Atlantic seals. ICES J. Mar. Sci. 64, 702–706. doi: 10.1093/icesjms/fsm037.

Hammill, M. O., and Stenson, G. B. 2010. A preliminary evaluation of the performance of the Canadian management approach for harp seals using simulation studies. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/093, iv + 47.

Hammill, M. O., and Stenson, G. B. 2013. A Discussion of the Precautionary Approach and its Application to Atlantic Seals. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/030, v + 25.

Hammill, M. O., Lesage, V., Gosselin, J.-F., Bourdages, H., de March, B. G. E., and Kingsley, M. C. S. 2004. Evidence for a Decline in Northern Quebec (Nunavik) Belugas. Arctic 57, 183–195.

Hammill, M. O., Mosnier, A., Gosselin, J.-F., Matthews, C. J. D., Marcoux, M., and Ferguson, S. H. 2017a. Management Approaches , Abundance Indices and Total Allowable Harvest levels of Belugas in Hudson Bay. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/062, iv + 43.

Hammill, M. O., Stenson, G. B., and Doniol-Valcroze, T. 2017b. A management framework for Nunavik beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/060, v + 34.

Hammill, M. O., Mosnier, A., and Bordeleau, X. 2021. An update of impacts of harvesting on the abundance of Nunavik beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/003, iv + 21.

Hammill, M. O., St-Pierre, A. P., Mosnier, A., and Parent, G. J. 2023. Total abundance and harvest impacts on Eastern Hudson Bay and James Bay beluga 2015–2022. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/066. iv + 50 p.

Hauser, D. D. W. 2016. Beluga whale distribution, migration, and behavior in a changing Pacific Arctic. PhD Dissertation, University of Washington, xv + 206.

Hauser, D. D. W., Laidre, K. L., Parker-Stetter, S. L., Horne, J. K., Suydam, R. S., and Richard, P. R. 2015. Regional diving behavior of Pacific Arctic beluga whales *Delphinapterus leucas* and possible associations with prey. Mar. Ecol. Prog. Ser. 541, 245–264. doi: 10.3354/meps11530.

Hauser, D. D. W., Laidre, K. L., Stern, H. L., Moore, S. E., Suydam, R. S., and Richard, P. R. 2017. Habitat selection by two beluga whale populations in the Chukchi and Beaufort seas. *PLoS ONE* 12, 1–19. doi: 10.1371/journal.pone.0172755.

Hauser, D. D. W., Laidre, K. L., Stern, H. L., Suydam, R. S., and Richard, P. R. 2018. Indirect effects of sea ice loss on summer-fall habitat and behaviour for sympatric populations of an Arctic marine predator. Divers. Distrib. 24, 791–799. doi: 10.1111/ddi.12722.

Hayeur, G. 2000. Synthèse des connaissances environnementales acquises en milieu nordique de 1970 à 2000. Montréal, Hydro-Québec. 110 p.

Heide-Jørgensen, M. P., Richard, P. R., and Rosing-Asvid, A. 1998. Dive patterns of belugas (*Delphinapterus leucas*) in waters near eastern Devon Island. Arctic 51, 17–26. doi: 10.14430/arctic1041.

Heide-Jørgensen, M. P., Laidre, K. L., Borchers, D. L., Marques, T. A., Stern, H. L., and Simon, M. 2010. The effect of sea-ice loss on beluga whales (*Delphinapterus leucas*) in West Greenland. Polar Res. 29, 198–208. doi: 10.1111/j.1751-8369.2009.00142.x.

Higdon, J. W., and Ferguson, S. H. 2009. Loss of Arctic sea ice causing punctuated change in sightings of killer whales (*Orcinus orca*) over the past century. Ecol. Appl. 19, 1365–1375. doi: 10.1890/07-1941.1.

Hobbs, R. C., Shelden, K. E. W., Vos, D. J., Goetz, K. T., and Rugh, D. J. 2006. Status review and extinction assessment of Cook Inlet belugas (*Delphinapterus leucas*). AFSC Processed Rep. 2006-16, 74.

Hobbs, R. C., Wade, P. R., and Shelden, K. E. W. 2015. Viability of a small, geographically-isolated population of beluga whales, *Delphinapterus leucas*: Effects of hunting, predation, and mortality events in Cook Inlet, Alaska. Mar. Fish. Rev. 77, 59–88. doi: 10.7755/MFR.77.2.4.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 81, 898–903.

Holland, M. M., and Bitz, C. M. 2003. Polar amplification of climate change in coupled models. Clim. Dyn. 21, 221–232. doi: 10.1007/s00382-003-0332-6.

Hornby, C. A., Hoover, C., Iacozza, J., Barber, D. G., and Loseto, L. L. 2016. Spring conditions and habitat use of beluga whales (*Delphinapterus leucas*) during arrival to the Mackenzie River Estuary. Polar Biol. 39, 2319–2334. doi: 10.1007/s00300-016-1899-9.

Huntington, H. P. 2009. A preliminary assessment of threats to arctic marine mammals and their conservation in the coming decades. Mar. Policy 33, 77–82. doi: 10.1016/j.marpol.2008.04.003.

Impact Assessment Agency of Canada. 2022. Hopes Advance Iron Mining Project. Canadian Impact Assessment Registry.

Inuit Tapiriit Kanatami, and Inuit Circumpolar Council. 2012. Inuit and the Right to Food. Submission to the United Nations Special Rapporteur on the Right to Food for the Official Country Mission to Canada, 1–14.

Johannes, R. E., Freeman, M. M. R., and Hamilton, R. J. 2000. Ignore fishers' knowledge and miss the boat. Fish Fish. 1, 257–271. doi: 10.1111/j.1467-2979.2000.00019.x.

Jonkel, C. J. 1969. White Whales Wintering in James Bay. J. Fish. Board Can. 26, 2205–2207.

Kelley, T. C., Loseto, L. L., Stewart, R. E. A., Yurkowski, M., and Ferguson, S. H. 2010. "Importance of Eating Capelin: Unique Dietary Habits of Hudson Bay Beluga," in A Little Less Arctic: Top Predators in the World's Largest Northern Inland Sea, Hudson Bay (Dordrecht: Springer Netherlands), 53–70. doi: 10.1007/978-90-481-9121-5_3.

Kemper, J. B. 1980. History and use of narwhal and beluga by Inuit in the Canadian eastern Arctic including changes in hunting methods and regulations. Indian and Northern Affairs, 32.

Kilabuk, P. 1998. A Study of Inuit Knowledge of the Southeast Baffin Beluga. Nunavut Wildlife Management Board Final Report, 74.

Kingsley, M. C. S. 2000. Numbers and distribution of beluga whales, *Delphinapterus leucas*, in James Bay, eastern Hudson Bay, and Ungava Bay in Canada during the summer of 1993. Fish. Bull. 98, 736–747.

Kingsley, M. C. S., and Gauthier, I. 2002. Visibility of St Lawrence belugas to aerial photography, estimated by direct observation. NAMMCO Sci. Publ. 4, 259–270.

Kingsley, M. C. S., Gosselin, S., and Sleno, G. A. 2001. Movements and Dive Behaviour of Belugas in Northern Quebec. Arctic 54, 262–275.

Kuiken, T., Kennedy, S., Barrett, T., Van de Bildt, M. W. G., Borgsteede, F. H., Brew, S. D., *et al.* 2006. The 2000 Canine Distemper Epidemic in Caspian Seals (*Phoca caspica*): Pathology and Analysis of Contributory Factors. Vet. Pathol. 43, 321–338. doi: 10.1354/vp.43-3-321.

Kyhn, L. A., Wisniewska, D. M., Beedholm, K., Tougaard, J., Simon, M., Mosbech, A., and Madsen, P. T. 2019. Basin-wide contributions to the underwater soundscape by multiple seismic surveys with implications for marine mammals in Baffin Bay, Greenland. Mar. Pollut. Bull. 138, 474–490. doi: 10.1016/j.marpolbul.2018.11.038.

Laidre, K. L., Stirling, I., Lowry, L. F., Wiig, Ø., Heide-Jørgensen, M. P., and Ferguson, S. H. 2008. Quantifying the sensitivity of arctic marine mammals to climate-induced habitat change. Ecol. Appl. 18, S97–S125. doi: 10.1890/06-0546.1.

Lair, S., Martineau, D., and Measures, L. N. 2014. Causes of mortality in St. Lawrence Estuary beluga (*Delphinapterus leuca*) from 1983 to 2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/119. iv + 37.

Lair, S., Measures, L. N., and Martineau, D. 2016. Pathologic Findings and Trends in Mortality in the Beluga (*Delphinapterus leucas*) Population of the St Lawrence Estuary , Quebec , Canada, From 1983 to 2012. Vet. Pathol. 53, 22–36. doi: 10.1177/0300985815604726.

Lambin, X., Aars, J., and Piertnet, S. B. 2001. Dispersal, intraspecific competition, kin competition and kin facilitation: A review of the empirical evidence. *In*: Clobert, J., Danchin, E., Dhondt, A. A., et al. (eds). Dispersal. Oxford University Press, New York, 261–72.

Langvatn, R., and Loison, A. 1999. Consequences of harvesting on age structure, sex ratio and population dynamics of red deer *Cervus elaphus* in central Norway. Wildl. Biol. 5, 213–223. doi: 10.2981/wlb.1999.026.

Laurel, B. J., Copeman, L. A., Iseri, P., Spencer, M. L., Hutchinson, G., Nordtug, T., *et al.* 2019. Embryonic Crude Oil Exposure Impairs Growth and Lipid Allocation in a Keystone Arctic Forage Fish. iScience 19, 1101–1113. doi: 10.1016/j.isci.2019.08.051.

Lavoie, D., Pinet, N., Zhang, S., Reyes, J., Jiang, C., Ardakani, O. H., *et al.* 2019. Hudson Bay, Hudson Strait, Moose Rive , and Foxe basins : synthesis of the research activities under the Geomapping for Energy and Minerals (GEM) programs 2008-2018. Geological Survey of Canada Open File, 76. doi: 10.4095/314653.

Lawrence, M. J., Paterson, M., Baker, R. F., and Schmidt, R. 1992. Report on the workshop examining the potential effects of hydroelectric development on Beluga of the Nelson River Estuary, Winnipeg, Manitoba, November 6 and 7, 1990. DFO Can. Tech. Rep. Fish. Aquat. Sci. 1838, iv+39.

Lawson, J., Hammill, M. O., and Stenson, G. B. 2006. Characteristics for recovery: Beluga whale. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/075, 20.

Lemire, M., Kwan, M., Laouan-Sidi, A. E., Muckle, G., Pirkle, C., Ayotte, P., and Dewailly. 2015. Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec. Sci. Total Environ. 509–510, 248–259. doi: 10.1016/j.scitotenv.2014.07.102.

Lesage, V., Barrette, C., Kingsley, M. C. S., and Sjare, B. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Mar. Mamm. Sci. 15, 65–84. doi: 10.1111/j.1748-7692.1999.tb00782.x.

Lesage, V., Doidge, D. W., and Fibich, R. 2001a. Harvest statistics for beluga whales in Nunavik, 1974-2000. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/022, 35.

Lesage, V., Hammill, M. O., and Kovacs, K. M. 2001b. Marine mammals and the community structure of the Estuary and Gulf of St Lawrence, Canada: evidence from stable isotope analysis. Mar. Ecol. Prog. Ser. 210, 203–221. doi: 10.3354/meps210203.

Lesage, V., Measures, L. N., Mosnier, A., Lair, S., and Michaud, R. 2014. Mortality patterns in St . Lawrence Estuary beluga (*Delphinapterus leucas*), inferred from the carcass recovery data, 1983-2012. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/118, iv + 23.

Lesage, V., Lair, S., Turgeon, S., and Béland, P. 2020. Diet of St. Lawrence Estuary Beluga (*Delphinapterus leucas*) in a changing ecosystem. Can. Field-Nat. 134, 21. 10.22621/cfn.v134i1.2421.

Letcher, R. J., Bustnes, J. O., Dietz, R., Jenssen, B. M., Jørgensen, E. H., Sonne, C., Verreault, J., Vijayan, M. M., and Gabrielsen, G. W. 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Sci. Total Environ. 408, 2995–3043. doi: 10.1016/j.scitotenv.2009.10.038.

Lewis, A. E., Hammill, M. O., Power, M., Doidge, D. W., and Lesage, V. 2009. Movement and aggregation of eastern Hudson Bay beluga whales (*Delphinapterus leucas*): A comparison of patterns found through satellite telemetry and Nunavik Traditional Ecological Knowledge. Arctic 62, 13–24. doi: 10.14430/arctic109.

Liermann, M., and Hilborn, R. 2001. Depensation: evidence, models and implications. Fish Fish. 2, 33–58.

Lohmann, R., Breivik, K., Dachs, J., and Muir, D. 2007. Global fate of POPs: Current and future research directions. Environ. Pollut. 150, 150–165. doi: 10.1016/j.envpol.2007.06.051.

Loseto, L. L., Richard, P., Stern, G., Orr, J., and Ferguson, S. H. 2006. Segregation of Beaufort Sea beluga whales during the open-water season. Can. J. Zool. 84, 1743–1751. doi: 10.1139/Z06-160.

Lowry, L. F., Frost, K. J., Zerbini, A., DeMaster, D., and Reeves, R. R. 2008. Trend in aerial counts of beluga 1 or white whales (*Delphinapterus leucas*) in Bristol Bay, Alaska, 1993-2005. J. Cetacean Resour. Manage. 10, 201–207.

Lowry, L., Reeves, R., and Laidre, K. 2017. *Delphinapterus leucas*. The IUCN Red List of Threatened Species 2017: e.T6335A50352346.

Marcoux, M., McMeans, B. C., Fisk, A. T., and Ferguson, S. H. 2012. Composition and temporal variation in the diet of beluga whales, derived from stable isotopes. Mar. Ecol. Prog. Ser. 471, 283–291. doi: 10.3354/meps10029.

Marine Mammal Regulations SOR/93-56. 2018. Fisheries Act.

Martin, A. R., Hall, P. A., and Richard, P. R. 2001. Dive Behaviour of Belugas (*Delphinapterus leucas*) in the Shallow Waters of Western Hudson Bay. Arctic 54, 276–283.

Martineau, D., Lair, S., De Guise, S., P. Liscomb, T., and Beland, P. 1999. Cancer in beluga whales from the St Lawrence Estuary, Quebec, Canada: A potential biomarker of environmental contamination. J. Cetacean Res. Manage. 1, 249–265. doi: 10.47536/jcrm.v1i1.252.

Marty, J., and Potter, S. 2014. Risk assessment for marine spills in canadian waters, phase 1: Oil spills south of the 60th parallel. Proceedings of the 37th AMOP Technical Seminar on Environmental Contamination and Response, 537–552.

Marty, J., Nicoll, A., Potter, S., Wallace, M., and Lumire, C. 2016. Evaluation of the risk of oil spills in Canadian arctic waters. 39th AMOP Technical Seminar on Environmental Contamination and Response.

Matthews, C. J. D., and Ferguson, S. H. 2015. Weaning age variation in beluga whales (*Delphinapterus leucas*). J. Mammal. 96, 425–437.

McAlpine, D. F., Kingsley, M. C. S., and Daoust, P.-Y. 1999. A lactating record-age St. Lawrence beluga (*Delphinapterus leucas*). Mar. Mamm. Sci. 15, 854–859. doi: 10.1111/j.1748-7692.1999.tb00848.x.

McDonald, M., Arragutainaq, L., and Novalinga, Z. 1997. Voices from the Bay: Traditional Ecological Knowledge of Inuit and Cree in the Hudson Bay Bioregion. Ottawa: Canadian Arctic Resources Committee and Environmental Committee of the Municipality of Sanikiluaq. xiii + 98 p., maps. doi: 10.14430/arctic1156.

McKinney, M. A., De Guise, S., Martineau, D., Béland, P., Lebeuf, M., and Letcher, R. J. 2006. Organohalogen contaminants and metabolites in beluga whale (*Delphinapterus leucas*) liver from two canadian populations. Environ. Toxicol. Chem. 25, 1246. doi: 10.1897/05-284R.1.

McLoughlin, P. D., Taylor, M. K., and Messier, F. 2005. Conservation Risks of Male-Selective Harvest for Mammals with Low Reproductive Potential. J. Wildl. Manage. 69, 1592–1600.

Meador, J. P., Stein, J. E., Reichert, W. L., and Varanasi, U. 1995. Bioaccumulation of Polycyclic Aromatic Hydrocarbons by Marine Organisms. Rev. Environ. Contam. Toxicol. 143, 79–165. doi: 10.1007/978-1-4612-2542-3_4.

Mikaelian, I., Tremblay, M.-P., Montpetit, C., Tessaro, S. V., Cho, H. J., House, C., Measures, L., and Martineau, D. 1999. Seroprevalence of selected viral infections in a population of beluga whales (*Delphinapterus leucas*) in Canada. Vet. Rec. 144, 50–51. doi: 10.1136/vr.144.2.50.

Miller, G. W., Moulton, V. D., Davis, R. A., Holst, M., Millman, P., MacGillivray, A., and Hannay, D. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. Offshore oil and gas environmental effects monitoring/Approaches and technologies. Battelle Press, Columbus, OH, 511–542.

Miner, K. R., D'Andrilli, J., Mackelprang, R., Edwards, A., Malaska, M. J., Waldrop, M. P., and Miller, C. E.. 2021. Emergent biogeochemical risks from Arctic permafrost degradation. Nat. Clim. Change 11, 809–819. doi: 10.1038/s41558-021-01162-y.

Moore, S. E., Reeves, R. R., Southall, B. L., Ragen, T. J., Suydam, R. S., and Clark, C. W. 2012. A new framework for assessing the effects of anthropogenic sound on marine mammals in a rapidly changing Arctic. BioScience 62, 289–295. doi: 10.1525/bio.2012.62.3.10.

Mosnier, A., Doniol-Valcroze, T., Gosselin, J.-F., Lesage, V., Measures, L. N., and Hammill, M. O. 2015. Insights into processes of population decline using an integrated population model: the case of the St. Lawrence Estuary beluga (*Delphinapterus leucas*). Ecol. Model. 314, 15–31.

Muir, D. C. G., Ford, C. A., Stewart, R. E. A., Smith, T. G., Addison, R. F., Zinck, M. E., and Béland, P. 1990. Organochlorine contaminants in belugas, *Delphinapterus leucas*, from Canadian waters. Can. Bull. Fish. Aquat. Sci. 224, 165–190.

Nacke, M. 2017. Shipping through sea ice: impacts on marine habitats and best practices. WWF-Canada.

Nahrgang, J., Camus, L., Gonzalez, P., Jönsson, M., Christiansen, J. S., and Hop, H. 2010. Biomarker responses in polar cod (*Boreogadus saida*) exposed to dietary crude oil. Aquat. Toxicol. 96, 77–83. doi: 10.1016/j.aquatox.2009.09.018.

NAMMCO. 2018. Global Review of Monodontids. North Atlantic Marine Mammal Commision Report, Hillerød, Denmark, 277.

National Marine Mammals Service. 2016. Guidelines for Assessing Marine Mammal Stocks. Reports Pursuant to Section 117 of the Marine Mammal Protection Act, 23.

NILCA. 2007. Nunavik Inuit Land Claim Agreement Act.

NMRWB. 2019. Nunavik Marine Region Wildlife Board comments on draft status report, prepared by Kaitlin Breton-Honeyman, Director of Wildlife Management, NMRWB.

NMRWB, and DFO. 2021. Beluga Management System - Regional Rules in the Nunavik Marine Region.

NMRWB, and EMRWB. 2020. Reasons for Final Decisions in relation to the Resolutions for the establishment of a Total Allowable Take for Beluga in the Eastern Hudson Bay Arc Region and Associated Non-Quota Limitations for Beluga in the Nunavik Marine Region (2020-2026).

Noel, A., Iacozza, J., Devred, E., Marcoux, M., Hornby, C., and Loseto, L. L. 2022. Environmental drivers of beluga whale distribution in a changing climate: a case study of summering aggregations in the Mackenzie Estuary and Tarium Niryutait Marine Protected Area. Arct. Sci. 8, 1305-1319. doi: 10.1139/as-2022-0003.

Noël, M., Loseto, L. L., and Stern, G. 2018. Legacy contaminants in the Eastern Beaufort Sea beluga whales (*Delphinapterus leucas*): Are temporal trends reflecting regulations? Arct. Sci. 4, 373–387. doi: 10.1139/as-2017-0049.

Norton, P., and Harwood, L. A. 2001. Report of the second workshop on Beaufort Sea beluga, April 22-24, 1996, Inuvik, NT., Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2578, vi + 28.

Norton, P., Birchard, E. C., and Harwood, L. A. 1986. Distribution, abundance and behaviour of white whales in the Mackenzie Estuary. Environmental Studies Revolving Funds Report 036, 73.

Nozères, C. A. 2006. Régime alimentaire du béluga, *Delphinapterus leucas*, tel que révélé par l'analyse des acides gras du lard. M. Sc. Thesis, Université Laval, 207.

O'Corry-Crowe, G. M., Suydam, R. S., Rosenberg, A., Frost, K. J., and Dizon, A. E. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. Mol. Ecol. 6, 955–970. doi: 10.1046/j.1365-294X.1997.00267.x.

O'Corry-Crowe, G. M., Suydam, R. S., Quakenbush, L. T., Potgieter, B., Harwood, L. A., Litovka, D., Ferrer, T., Citta, J., Burkanov, V., Frost, K., and Mahoney, B. 2018. Migratory culture, population structure and stock identity in North Pacific beluga whales (*Delphinapterus leucas*). PLoS ONE 13, 1–32. doi: 10.1371/journal.pone.0194201.

O'Corry-Crowe, G., Suydam, R. S., Quakenbush, L. T., Smith, T. G., Lydersen, C., Kovacs, K. M., Orr, J., Harwood, L., Litovka, D., and Ferrer, T. 2020. Group structure and kinship in beluga whale societies. Sci. Rep. 10, 11462. doi: 10.1038/s41598-020-67314-w.

Oceanic Iron Ore Corp. 2012. Technical report on the mineral resource estimate update Hopes Advance Bay iron deposits Unfava Bay Region, Québec Canada, 280.

Owczarek, P., Opała-Owczarek, M., Boudreau, S., Lajeunesse, P., and Stachnik, Ł. 2020. Re-activation of landslide in sub-Arctic areas due to extreme rainfall and discharge events (the mouth of the Great Whale River, Nunavik, Canada). Sci. Total Environ. 744, 140991. doi: 10.1016/j.scitotenv.2020.140991.

Palsbøll, P. J., Heide-Jørgensen, M. P., and Bérubé, M. 2002. Analysis of mitochondrial control region nucleotide sequences from Baffin Bay beluga, (*Delphinapterus leucas*): detecting pods or sub-populations? NAMMCO Sci. Publ. 4, 39. doi: 10.7557/3.2836.

Parent, G.J, Mosnier, A., Montana, L., Cortial, G., St-Pierre, A.P., Bordeleau, X., Lesage, V., Watt, C., Postma, L., and Hammill, M.O. 2023. Re-examining populations of beluga in the Hudson Bay-Strait Complex and assessing the impact on harvests in Nunavik and Sanikiluaq management units. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/004. iv + 31 p.

Pituvik Landholding Corporation. 2010. Project Background.

Ponton, D., Gagné, J. A., and Fortier, L. 1993. Production and dispersion of freshwater, anadromous, and marine fish larvae in and around a river plume in subarctic Hudson Bay, Canada. Polar Biol. 13, 321-331. doi: 10.1007/BF00238359.

Postma, L. D., Petersen, S. D., Turgeon, J., Hammill, M. O., Lesage, V., and Doniol-Valcroze, T. 2012. Beluga whales in James Bay: a separate entity from eastern Hudson Bay belugas? DFO Can. Sci. Advis. Sec. Res. Doc. 2012/074, ii + 23.

Quakenbush, L. T., Suydam, R. S., Bryan, A. L., Lowry, L. F., Frost, K. J., and Mahoney, B. A. 2015. Diet of beluga whales, *Delphinapterus leucas*, in Alaska from stomach contents, March-November. Mar. Fish. Rev. 77, 70–84. doi: 10.7755/MFR.77.1.7.

Ray, S., Dunn, B. ., Payne, J. ., Fancey, L., Helbig, R., and Béland, P. 1991. Aromatic DNA-carcinogen adducts in beluga whales from the Canadian Arctic and Gulf of St Lawrence. Mar. Pollut. Bull. 22, 392–396. doi: 10.1016/0025-326X(91)90342-P.

Reeves, R. R., and Mitchell, E. D. 1987a. History of White Whale (*Delphinapterus leucas*): Exploitation in Eastern Hudson Bay and James Bay. Can. Spec. Publ. Fish. Aquat. Sci. 95, 45.

Reeves, R. R., and Mitchell, E. D. 1987b. Catch history, former abundance, and distribution of white whales in Hudson Strait and Ungava Bay. Can. Field-Nat. 114, 1–65.

Reeves, R. R., and Mitchell, E. D. 1987c. Distribution and Migration, Exploitation, and Former Abundance of White Whales (*Delphinapterus leucas*) in Baffin Bay and Adjacent Waters. Can. Spec. Publ. Fish. Aquat. Sci. 99, 34.

Reeves, R. R., and Mitchell, E. D. 1988. COSEWIC status report on the beluga whale *Delphinapterus leucas* (Eastern Hudson Bay population) in Canada. Ottawa, 60.

Reeves, R. R., and Mitchell, E. D. 1989. Status of white whales, *Delphinapterus leucas*, in Ungava Bay and eastern Hudson Bay. Can. Field-Nat. 1032, 220–239.

Reeves, R. R., Ewins, P. J., Agbayani, S., Heide-Jørgensen, M. P., Kovacs, K. M., Lydersen, C., Suydam, R., Elliot, W., Polet, G., van Dijk, Y., and Blijleven, R. 2014. Distribution of endemic cetaceans in relation to hydrocarbon development and commercial shipping in a warming Arctic. Mar. Policy 44, 375–389. doi: 10.1016/j.marpol.2013.10.005.

Renaud, L.-A, Bordeleau, X., Kellar, N. M., Michaud, R., Morin, Y., Lair, S., Therien, A., and Lesage, V. 2023. Estimating pregnancy rate from blubber progesterone levels of a blindly biopsied beluga population poses methodological, analytical and statistical challenges. Conserv. Physiol. Vol. 11, 1, coad075.

Richard, P.R. 2010. Stock definition of belugas and narwhals in Nunavut. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/022. iv + 14.

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, 223-236. doi: 10.14430/arctic783.

Rigét, F., Bignert, A., Braune, B., Dam, M., Dietz, R., Evans, M., *et al.* 2019. Temporal trends of persistent organic pollutants in Arctic marine and freshwater biota. Sci. Total Environ. 649, 99–110. doi: 10.1016/j.scitotenv.2018.08.268.

Rioux, È., Lesage, V., Postma, L. D., Pelletier, É., Turgeon, J., Stewart, R. E. A., Stern, G., and Hammill, M.O. 2012. Use of stable isotopes and trace elements to determine harvest composition and wintering assemblages of belugas at a contemporary ecological scale. Endanger. Species Res. 18, 179–191. doi: 10.3354/esr00445.

Royce, W. F. 1972. Introduction to fisheries sciences. Academic Press. 351 p.

SARA. 2021. Species at risk policy on recovery and survival: final version 2021.

Saucier, F. J., Senneville, S., Prinsenberg, S., Roy, F., Smith, G., Gachon, P., Caya, D., and Laprise, R. 2004. Modelling the sea ice-ocean seasonal cycle in Hudson Bay, Foxe Basin and Hudson Strait, Canada. Clim. Dyn. 23, 303–326. doi: 10.1007/s00382-004-0445-6.

Sauvé, C., St-Pierre, A.P., Hammill, M.O., Gosselin, J.-F. 2023. Abundance estimate for beluga (*Delphinapterus leucas*) in the Ungava Bay area in summer 2022. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/055. iv + 26 p.

Scharffenberg, K. C., Whalen, D., MacPhee, S. A., Marcoux, M., Iacozza, J., Davoren, G., and Loseto, L. L. 2020. Oceanographic, ecological, and socio-economic impacts of an unusual summer storm in the Mackenzie Estuary. Arct. Sci. 6, 62–76. doi: 10.1139/as-2018-0029.

Schembri, S. 2022. Biodiversité, distribution et biomasse du zooplancton et de l'ichtyoplancton dans le système de la baie d'Hudson, Ph. D. Thesis, Univeristé Laval, xvii + 201.

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.

Sergeant, D. E., and Brodie, P. F. 1975. Identity, Abundance, and Present Status of Populations of White Whales, *Delphinapterus leucas*, in North America. J. Fish. Res. Board Can. 32, 1047–1054. doi: 10.1139/f75-123.

Simard, Y., Loseto, L. 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. Tech. Rep. Fish. Aquat. Sci. 3068, vi + 49.

Slagstad, D., Wassmann, P. F. J., and Ellingsen, I. 2015. Physical constrains and productivity in the future Arctic Ocean. Front. Mar. Sci. 2. doi: 10.3389/fmars.2015.00085.

Smith, A. J., Higdon, J. W., Richard, P. R., Orr, J. R., Bernhardt, W., and Ferguson, S. H. 2017. Beluga whale summer habitat associations in the Nelson River estuary , western Hudson Bay, Canada. PLoS ONE 12, 1–19.

Smith, S. L., O'Neill, H. B., Isaksen, K., Noetzli, J., and Romanovsky, V. E. 2022. The changing thermal state of permafrost. Nat. Rev. Earth Environ. 3, 10–23. doi: 10.1038/s43017-021-00240-1.

Smith, T. G. 1998. Seasonal movements and migrations of belugas, Delphinapterus leucas, along the Nunavik coastlines: Evidence from harvest statistics, game reports, local knowledge and scientific studies. Unpublished report prepared for the Department of Fisheries and Oceans Canada.

Smith, T. G., and Hammill, M. O. 1986. Population estimates of white whales in James Bay, eastern Hudson Bay and Ungava Bay. Can. J. Fish. Aquat. Sci. 43, 1982–1987.

Smith, T. G., and Martin, A. R. 1994. Distribution and Movements of Belugas, *Delphinapterus leucas*, in the Canadian High Arctic. Can. J. Fish. Aquat. Sci. 51, 1653–1663.

Smith, T. G., Hammill, M. O., Burrage, D. J., and Sleno, G. A. 1985. Distribution and abundance of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, in the Canadian High Arctic. Can. J. Fish. Aquat. Sci. 42, 676–684.

Smith, T. G., Hammill, M. O., and Martin, A. R. 1994. Herd composition and behaviour of white whales (*Delphinapterus leucas*) in two Canadian arctic estuaries. Medd. Grønl., Biosci. 39, 175–184.

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene, C. R. J., Kastak, D., Ketten, D. R., Miller, J. H., Nachtigall, P. E., Richardson, J. W., Thomas, J. A., and Tyack, P. L. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquat. Mamm. 33, 411–509.

St-Pierre, A. P., Gosselin, J.-F., Mosnier, A., and Hammill, M. O. 2024. Abundance estimates for beluga (*Delphinapterus leucas*) in James Bay and the Belcher Islands-eastern Hudson Bay area in summer 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/040. iv + 38 p.

St. Aubin, D. J., Smith, T. G., and Geraci, J. R. 1990. Seasonal epidermal molt in beluga whales, Delphinapterus leucas. Can. J. Zool. 68, 359–367.

Stenson, G. B., Hammill, M. O., Ferguson, S. H., Stewart, R. E. A., and Doniol-Valcroze, T. 2012. Applying the Precautionary Approach to Marine Mammal Harvests in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/107, ii + 15.

Stern, G., Macdonald, C. R., Armstrong, D., Dunn, B., Fuchs, C., Harwood, L., Muir, D. C. G., and Rosenberg, B. 2005. Spatial trends and factors affecting variation of organochlorine contaminants levels in Canadian Arctic beluga (*Delphinapterus leucas*). Sci. Total Environ. 351–352, 344–368. doi: 10.1016/j.scitotenv.2004.10.033.

Stewart, D. B., and Lockhart, W. L. 2004. Summary of the Hudson Bay Marine Ecosystem Overview. Prepared by Arctic Biological Consultants, Winnipeg, for Canada Department of Fisheries and Oceans, Winnipeg, MB. Draft vi + 66.

Stewart, R. E. A. 2008. Redefining walrus stocks in Canada. Arctic 61, 292–308.

Storey, K., and Eibner, M. 2021. Reinvesting fishery profits for economic and social development: A case study of the northern coalition. Report prepared for the Harris Centre of Regional Policy and Development, Memorial University, St. John's, Newfoundland and Labrador, 76.

Suydam, R. S. 2009. Age, growth, reproduction, and movements of beluga whales (*Delphinapterus leucas*) from the eastern Chukchi Sea. Ph. D. Thesis, University of washington, xi + 152.

Tai, T. C., Steiner, N. S., Hoover, C., Cheung, W. W. L., and Sumaila, U. R. 2019. Evaluating present and future potential of arctic fisheries in Canada. Mar. Policy 108, 103637. doi: 10.1016/j.marpol.2019.103637.

Tao, R., and Myers, P. G. 2021. Modelling the advection of pollutants in the Hudson Bay complex. J. Mar. Syst. 214, 13. doi: 10.1016/j.jmarsys.2020.103474.

Taylor, B.L., Chivers, S.J., Larese, J. and Perrin, W.F. 2007. Generation length and percent mature estimates for IUCN assessments of cetaceans. US National Marine Fisheries Service, Southwest Fisheries Science Center, Administrative Report LJ-07-01.

Taylor, M. K., McLoughlin, P. D., and Messier, F. 2008. Sex-selective harvesting of polar bears *Ursus maritimus*. Wildl. Biol. 14, 52–60. doi: 10.2981/0909-6396(2008)14[52:SHOPBU]2.0.CO;2.

Tinker, M. T., Mosnier, A., St-Pierre, A. P., Lair, S., Michaud, R., and Lesage, V. 2024. An Integrated Population Model for St. Lawrence Estuary Belugas (*Delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Res. Doc. 2023/047.

Tsuji, L. J. S., Gomez, N., Mitrovica, J. X., and Kendall, R. 2009. Post-Glacial Isostatic Adjustment and Global Warming in Subarctic Canada: Implications for Islands of the James Bay Region. Arctic 62, 458-467. doi: 10.14430/arctic176.

Turgeon, J., Duchesne, P., Colbeck, G. J., Postma, L. D., and Hammill, M. O. 2012. Spatiotemporal segregation among summer stocks of beluga (*Delphinapterus leucas*) despite nuclear gene flow: Implication for the endangered belugas in Eastern Hudson Bay (Canada). Conserv. Genet. 13, 419–433. doi: 10.1007/s10592-011-0294-x.

Tyrrell, M. 2007. Sentient beings and wildlife resources: Inuit, beluga whales and management regimes in the Canadian arctic. Hum. Ecol. 35, 575–586. doi: 10.1007/s10745-006-9105-2.

Tyrrell, M. 2008. Nunavik Inuit Perspectives on Beluga Whale Management in the Canadian Arctic. Hum. Organ. 67, 322–334. doi: 10.17730/humo.67.3.47826252k0623352.

UNEP. 2019. Stockholm Convention on persistent organic pollutants (POPS) - Texts and Annexes. Secretariat of the Stockholm Convention (SSC), 79.

Vergara, V., Wood, J., Lesage, V., Ames, A., Mikus, M.-A., and Michaud, R. 2021. Can you hear me? Impacts of underwater noise on communication space of adult, sub-adult and calf contact calls of endangered St. Lawrence belugas (*Delphinapterus leucas*). Polar Res. 40. doi: 10.33265/polar.v40.5521.

Vladykov, V. D. 1944. Etudes sur les mammifères aquatiques. III. Chasse, biologie et valeur économique du marsouin blanc ou béluga (*Delphinapterus leucas*) du fleuve et du golfe du Saint-Laurent. Départment des Pêcherie, Gouvernement du Québec 14, 1–194.

Wade, P. R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14, 1–37. doi: 10.1111/j.1748-7692.1998.tb00688.x.

Wade, P. R. 2018. "Population Dynamics," in Encyclopedia of Marine Mammals (Elsevier), 763–770. doi: 10.1016/B978-0-12-804327-1.00204-1.

Wade, P. R., Reeves, R. R., and Mesnick, S. L. 2012. Social and Behavioural Factors in Cetacean Responses to Overexploitation : Are Odontocetes Less "Resilient" Than Mysticetes? J. Mar. Biol. 2012, 15. doi: 10.1155/2012/567276.

Walvoord, M. A., and Kurylyk, B. L. 2016. Hydrologic Impacts of Thawing Permafrost-A Review. Vadose Zone J. 15, vzj2016.01.0010. doi: 10.2136/vzj2016.01.0010.

Waples, R. S., and Gaggiotti, O. 2006. Invited review: What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Mol. Ecol. 15, 1419–1439. doi: 10.1111/j.1365-294X.2006.02890.x.

Watt, C. A., Orr, J. R., and Ferguson, S. H. 2016. A shift in foraging behaviour of beluga whales *Delphinapterus leucas* from the threatened Cumberland Sound population may reflect a changing Arctic food web. Endanger. Species Res. 31, 259–270. doi: 10.3354/esr00768.

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

Weilgart, L. S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Can. J. Zool. 85, 1091–1116. doi: 10.1139/Z07-101.

Whalen, D., Loseto, L. L., Hornby, C. A., Harwood, L., and Hansen-Craik, K. 2020. Mapping and Understanding the Role of Seabed Morphology in Relation to Beluga Whale (*Delphinapterus leucas*) Hotspots and Habitat Use in the Mackenzie Estuary, NT. Estuaries Coasts 43, 161–173. doi: 10.1007/s12237-019-00653-8.

Williams, W. J., Carmack, E. C., Shimada, K., Melling, H., Aagaard, K., Macdonald, R. W., and Ingram, R. G. 2006. Joint effects of wind and ice motion in forcing upwelling in Mackenzie Trough, Beaufort Sea. Cont. Shelf Res. 26, 2352–2366. doi: 10.1016/j.csr.2006.06.012.

Wilson, J. Y., Cooke, S. R., Moore, M. J., Martineau, D., Mikaelian, I., Metner, D. A., Lockhart, W. L., and Stegeman, J. 2005. Systemic effects of arctic pollutants in beluga whales indicated by CYP1A1 expression. Environ. Health Perspect. 113, 1594–1599. doi: 10.1289/ehp.7664.

FIGURES

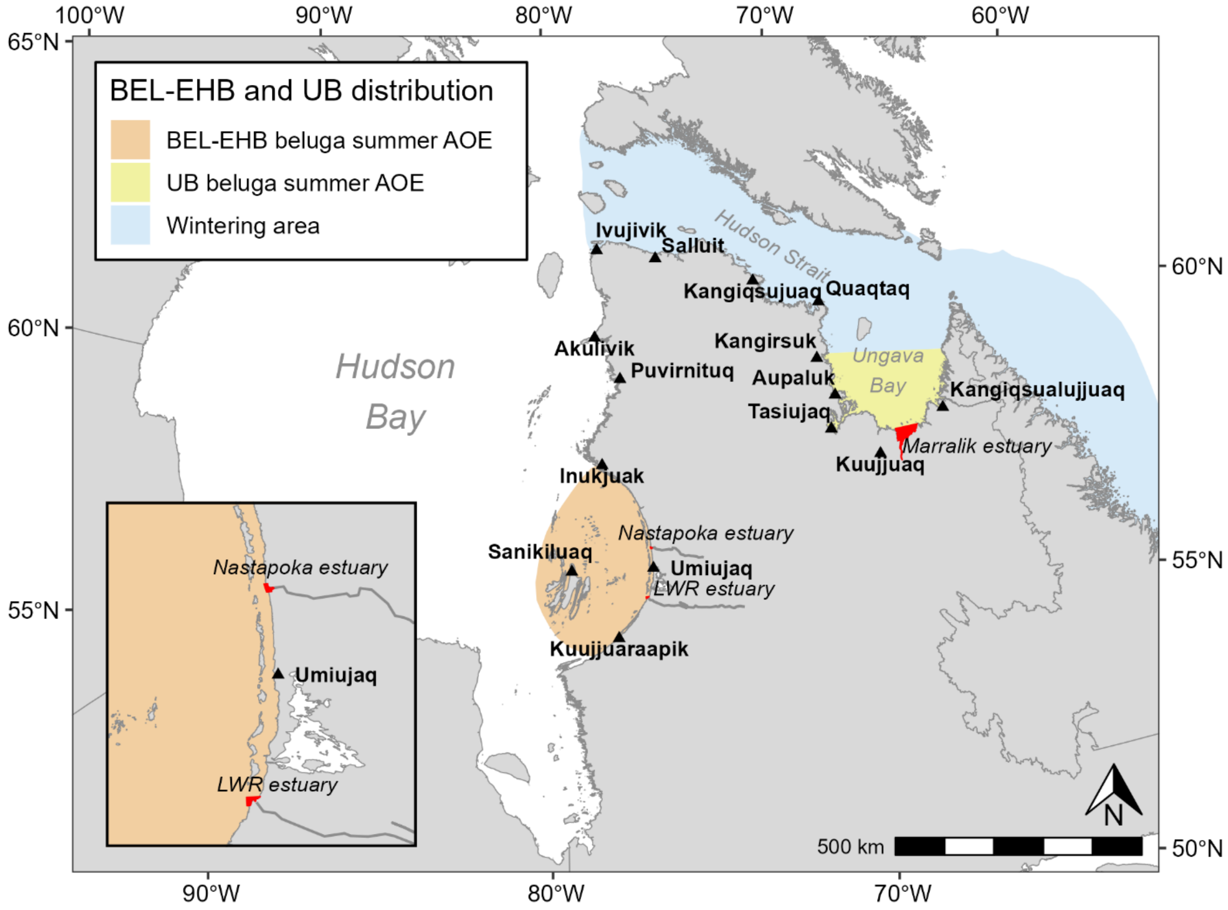

Figure 1. Geographic delimitation of summering and wintering areas of extent (AOE) for the Belcher Islands-Eastern Hudson Bay (BEL-EHB) beluga stock and the Ungava Bay (UB) beluga designatable unit. The red polygons represent the areas which are closed to harvesting year-round to protect BEL-EHB beluga (Nastapoka and Little Whale River (LWR) estuaries) and UB beluga (the south of Ungava Bay and Marralik Estuary).

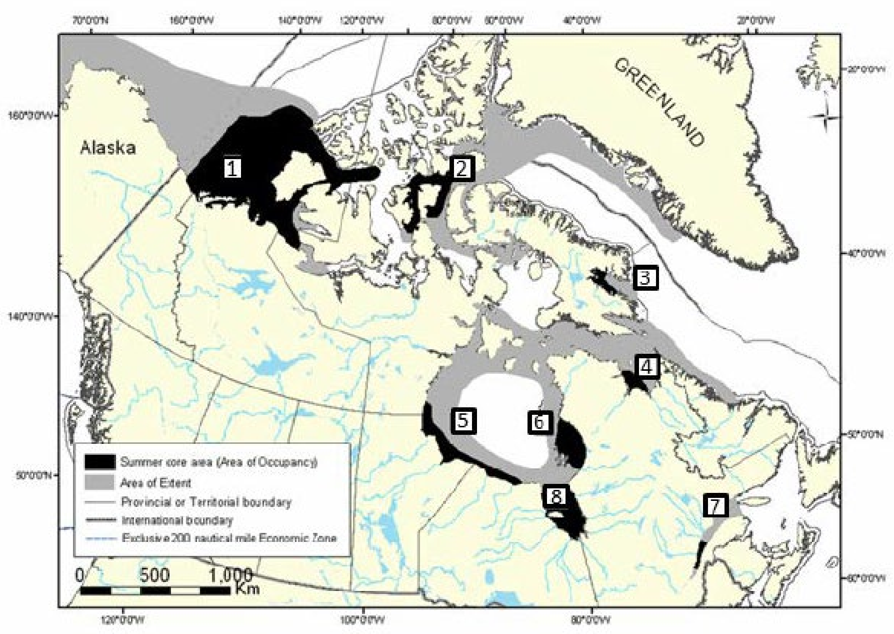

Figure 2. Distribution of beluga in Canada and recognized DUs: 1) Eastern Beaufort Sea (EBS); 2) Eastern High Arctic-Baffin Bay (EHA-BB); 3) Cumberland Sound (CS); 4) Ungava Bay (UB); 5) Western Hudson Bay (WHB); 6) Eastern Hudson Bay (EHB); 7) St. Lawrence Estuary (SLE); and 8) James Bay (JB). Source: COSEWIC (2020a).

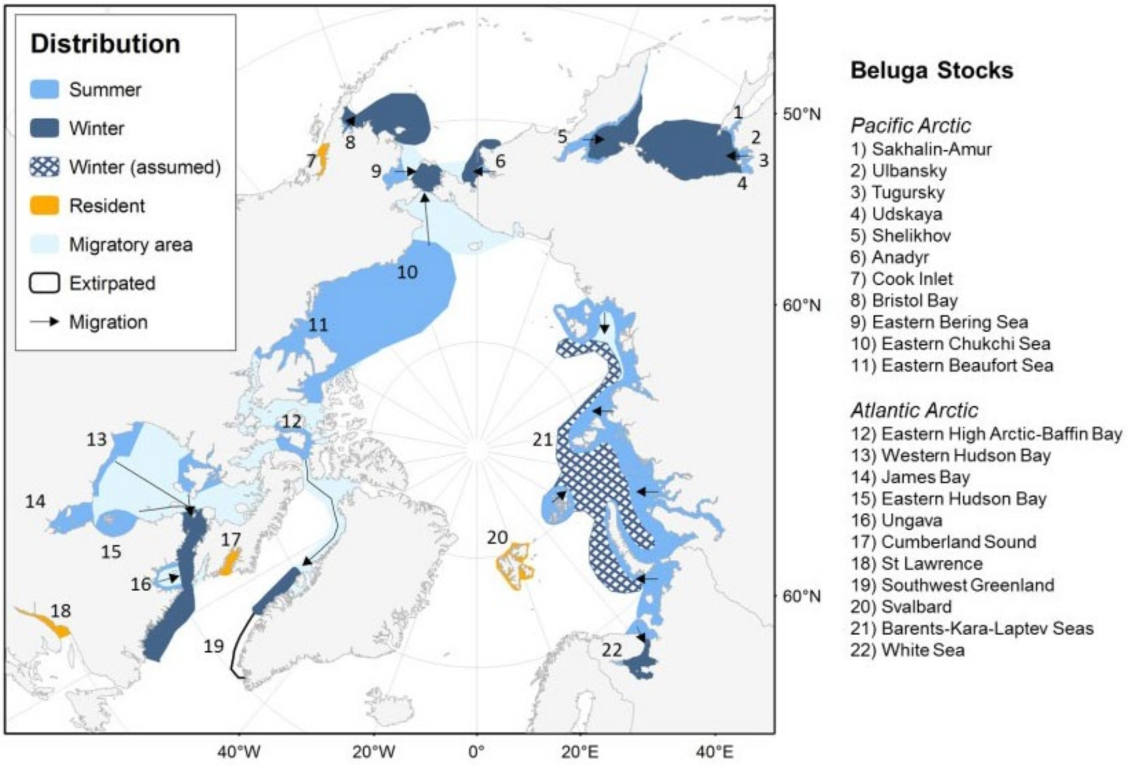

Figure 3. Global range of beluga, displaying currently recognized stock distribution and some indication of migratory movement. Source: NAMMCO (2018).

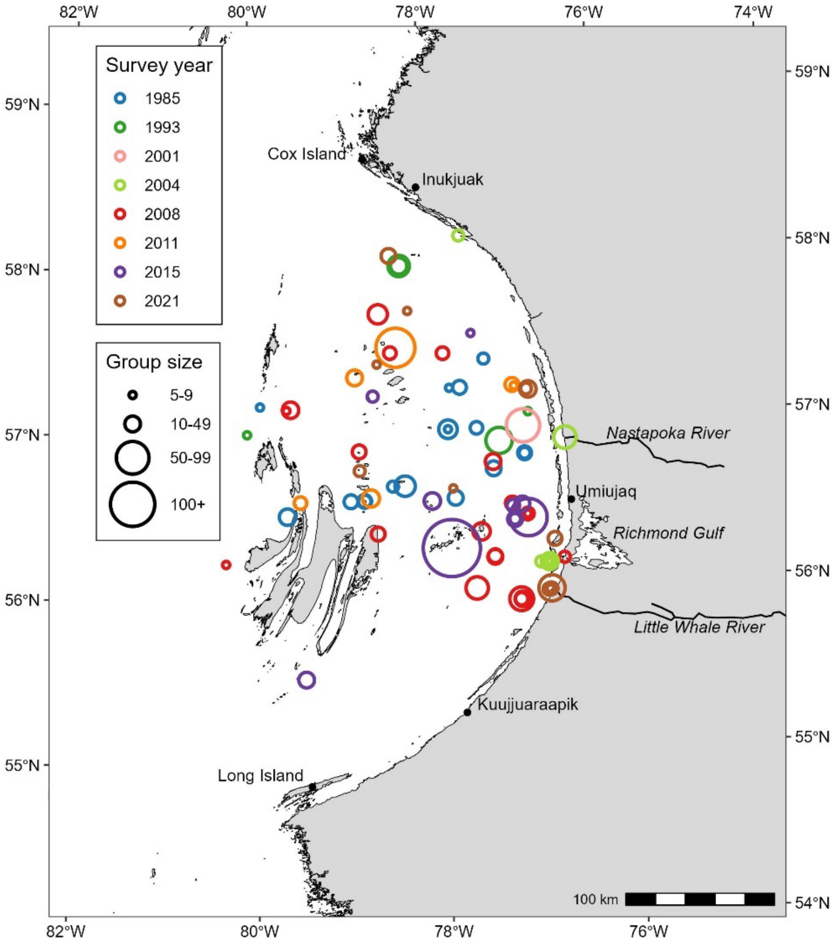

Figure 4. Spatial distribution of beluga aggregations (c.a., groups ≥ 5 individuals) detected during aerial surveys conducted from mid-July to September between 1985 and 2021. For the 2011, 2015 and 2021 surveys, which were flown using a double platform design, only the sightings from primary observers are depicted to avoid duplicates.

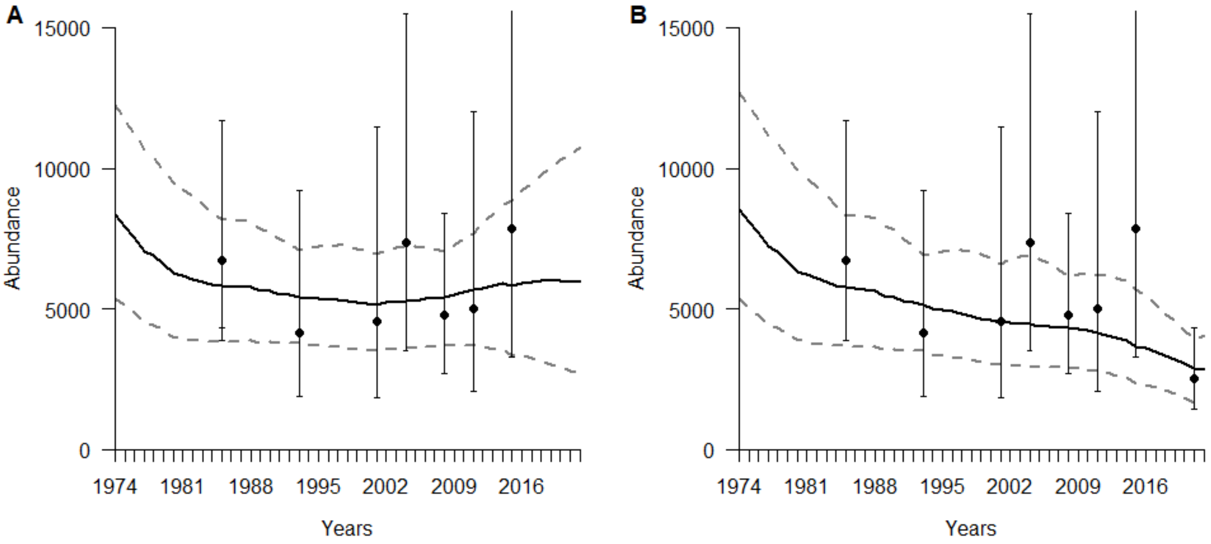

Figure 5. Estimated trajectory of the BEL-EHB beluga stock obtained by fitting a density dependent model to aerial survey abundance estimates, and accounting for reported harvests (1974-2022). Survey estimates (black circles ± 95% CI), median (black solid line) and 95% CI (grey dashed lines) are displayed. The model was fitted A) without and B) with the 2021 survey abundance estimate.

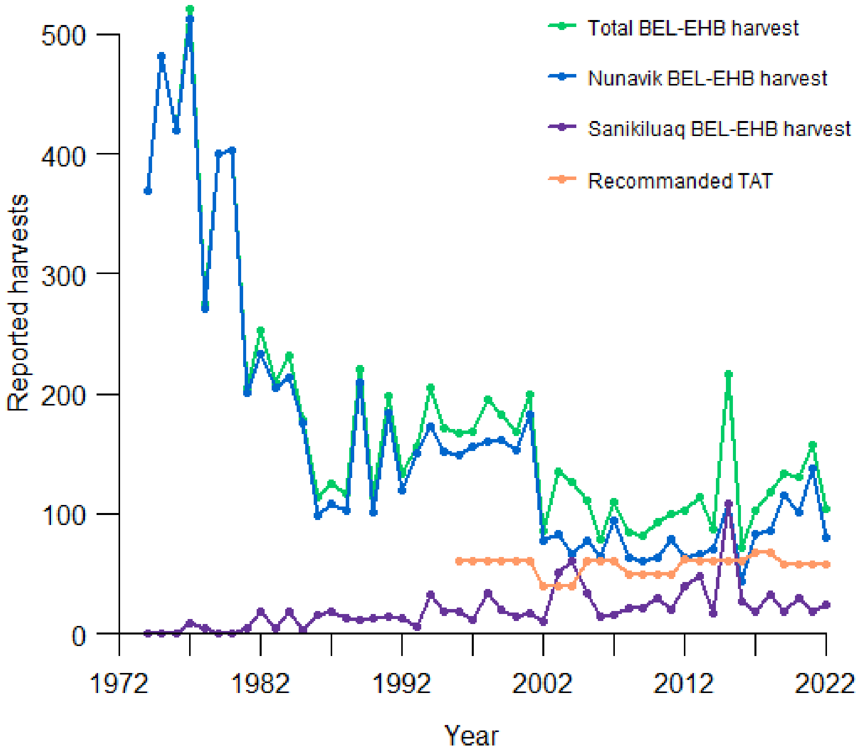

Figure 6. Harvest statistics derived using total reported harvest of beluga in Nunavik and revised season- and location-specific proportions of total landing representing BEL-EHB animals based on genetic data (Hammill et al. 2023; Parent et al. 2023). The total allowable take for BEL-EHB beluga is shown for reference.

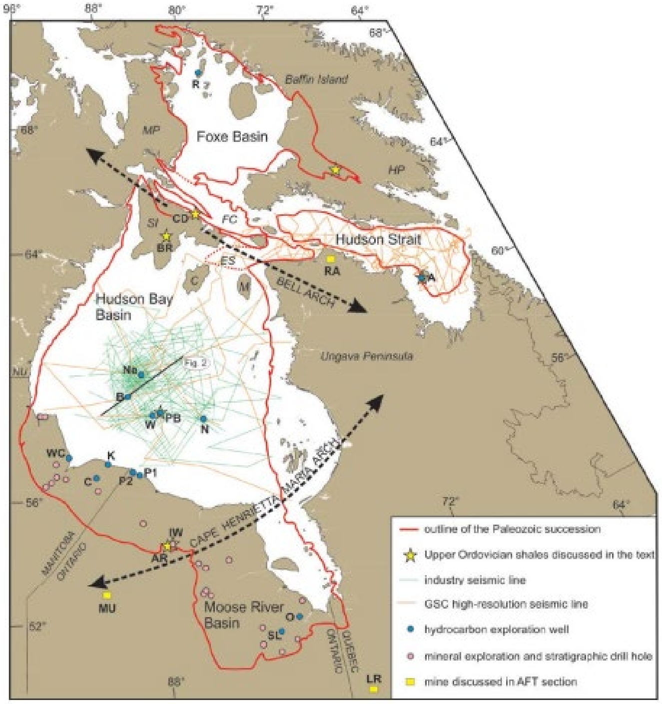

Figure 7. Distribution and extent of seismic research activities conducted under the Geomapping for Energy and Minerals programs between 2008 and 2018 in Hudson Bay Basin and adjacent basins. Multichannel industry seismic lines and Geological Survey of Canada (GSC) high-resolution seismic lines are depicted. Source: Lavoie et al. 2019.

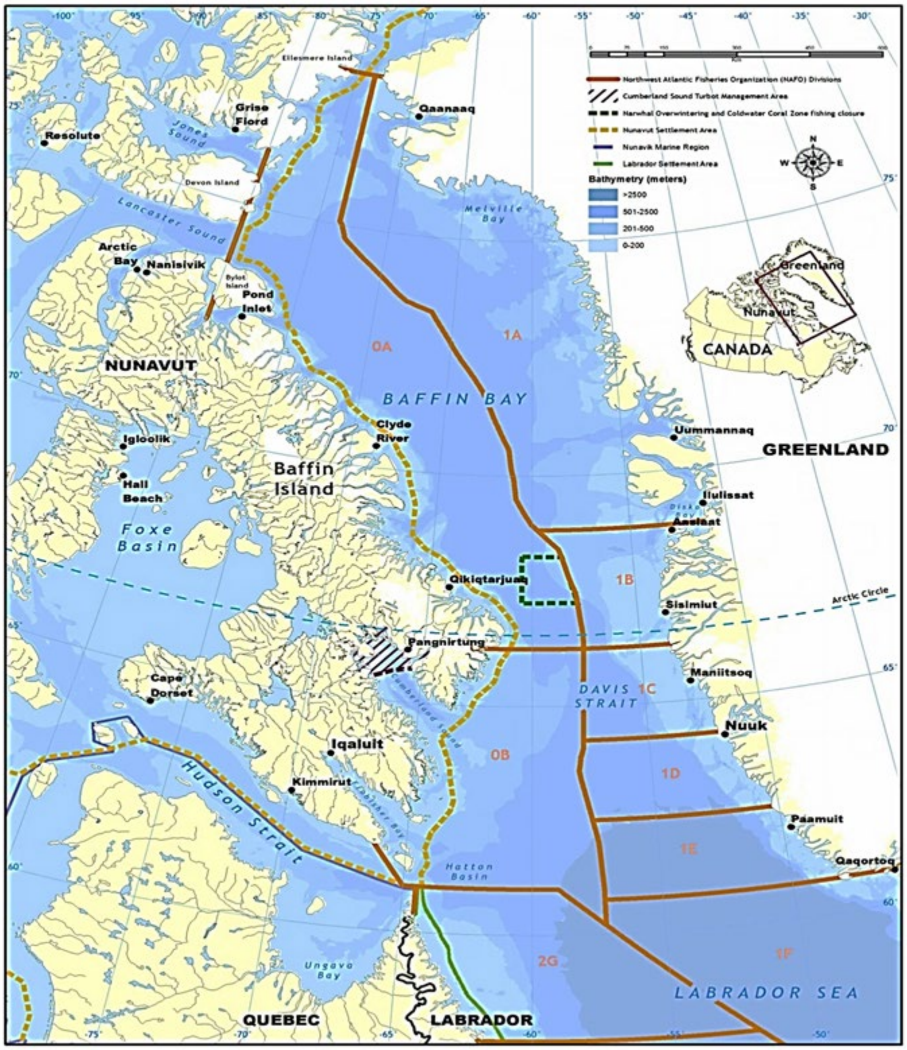

Figure 8. Northwest Atlantic Fisheries Organization Subareas and Divisions relevant to the Greenland Halibut fishery. Source: DFO (2014c).

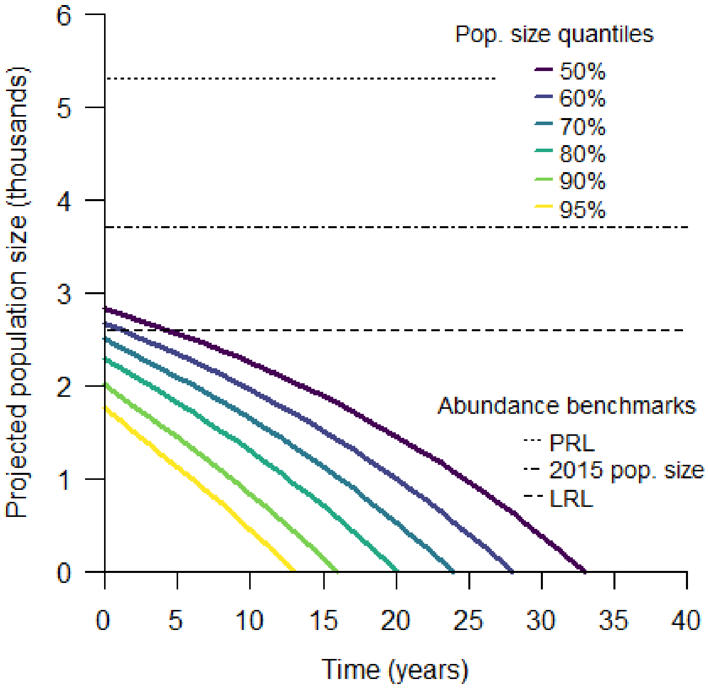

Figure 9. BEL-EHB stock abundance projected over the next decades under current harvesting levels (BEL-EHB: harvest = 110).

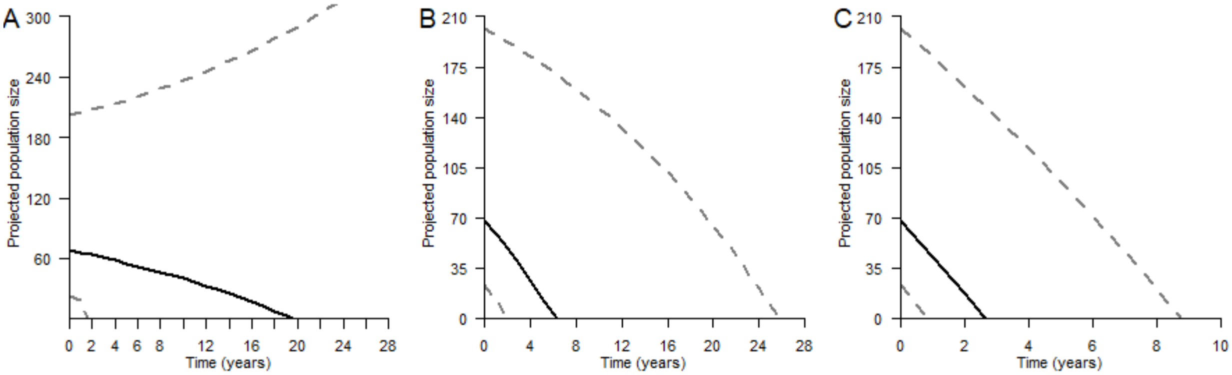

Figure 10. UB beluga population size projected over the next decades using a 4% exponential growth curve and the 2022 aerial survey estimate (full black line) and 95% confidence interval upper and lower limits (grey dashed curves) as initial population sizes under current harvest levels. Current harvest levels were estimated based on 2022 harvests taken in Ungava Bay between: A) August and September (harvest = 4), B) Mid-July and September (harvest = 10), and C) July and September (harvest = 22) of 2022.

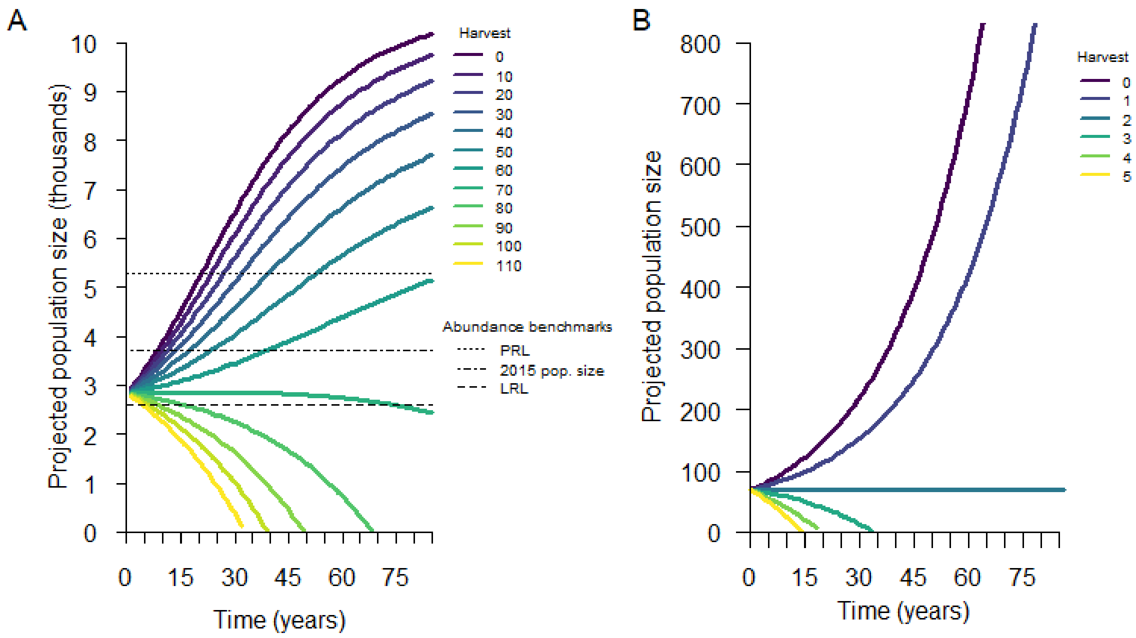

Figure 11. A) Median BEL-EHB and B) UB beluga stock abundance projected over the next three generations based on different harvest levels. Initial year is 2022. Projections are based on a population model for BEL-EHB and use a 4% exponential growth curve in the case of UB beluga. Colored curves refer to different annual harvest levels. Precautionary approach (PRL, dotted line) and limit reference (LRL, dashed line) levels are shown, as well as the 2015 abundance estimate (two-dashed line) as suggested recovery objectives.

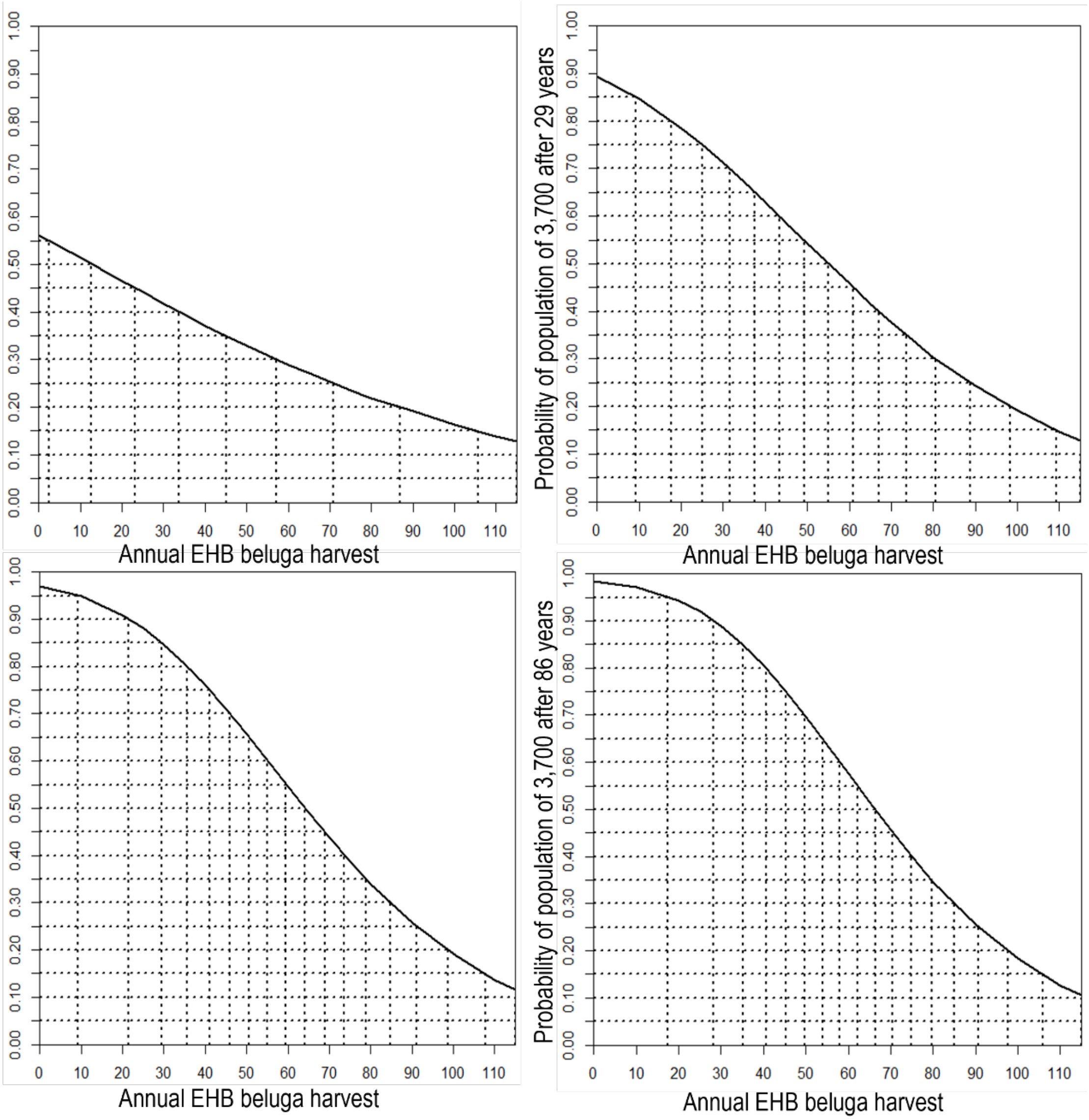

Figure 12. Probability that the BEL-EHB beluga stock would be greater than the 2015 abundance estimate after 10 years, or one, two or three generation times.

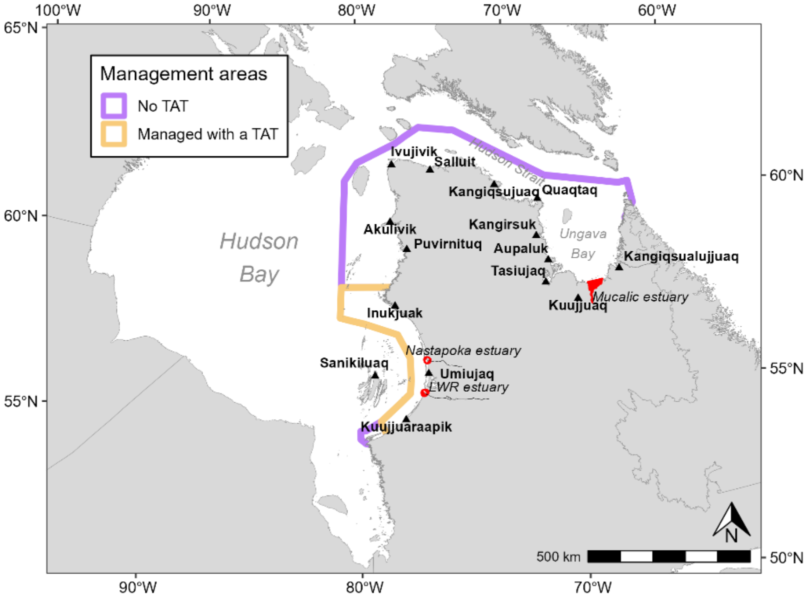

Figure 13. Nunavik beluga management areas, characterized by a total allowable take (TAT) and non-quota limitations (yellow contour), non-quota limitations only (purple contour), and estuaries closed to hunting (red zones).

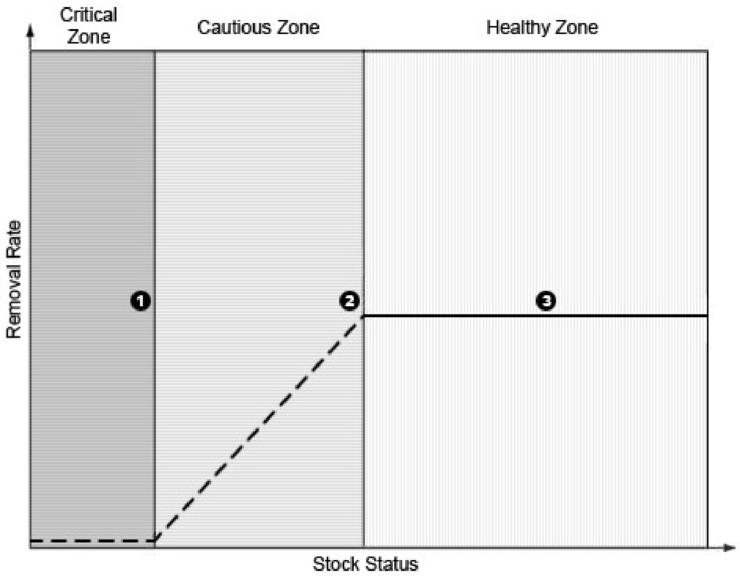

Figure 14. Suggested precautionary approach framework for Fisheries and Oceans Canada (DFO). 1) The limit reference level (LRL); 2) the precautionary preference level (PRL); and 3) a removal rate identified to maintain the resource within the Healthy zone (DFO 2006).

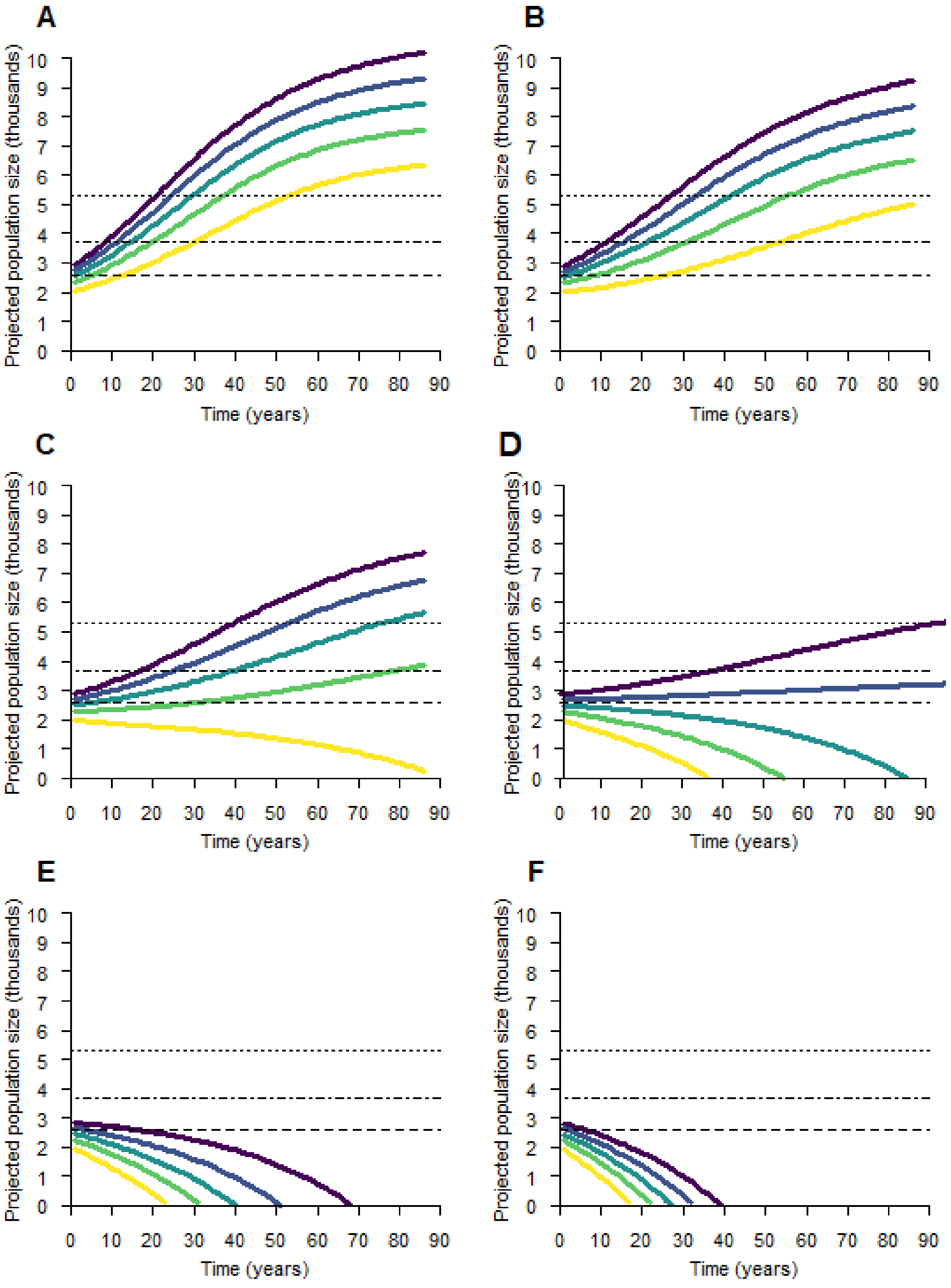

Figure 15. Population model projections for BEL-EHB beluga abundance over the next three generations (86 years). Initial year is 2022, and panels A, B, C, D, E, and F display projections assuming annual harvests of 0, 20, 40, 60, 80 and 100 whales, respectively. Dark purple, purple, blue, green and yellow lines represent > 50%, >60%, >70%, >80% and > 90% population percentiles, respectively. Precautionary approach (PRL, dotted line) and limit reference (LRL, dashed line) levels are shown, as well as the 2015 abundance estimate (two-dashed line) as a suggested recovery objective.

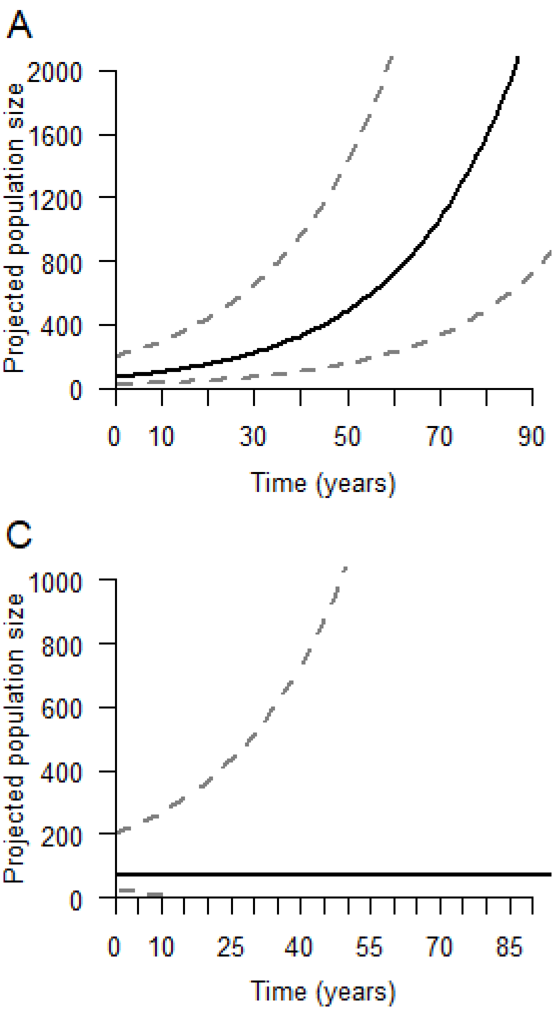

Figure 16. UB beluga population size projected over the next three generations using a 4% exponential growth curve and the 2022 aerial survey estimate (full black line) and 95% confidence interval upper and lower limits (grey dashed curves) as initial population sizes assuming annual harvests of 0, 1, 2 and 3 whales, for panels A, B, C and D, respectively. Note differences in y-axis scales between panels A-B and C-D.

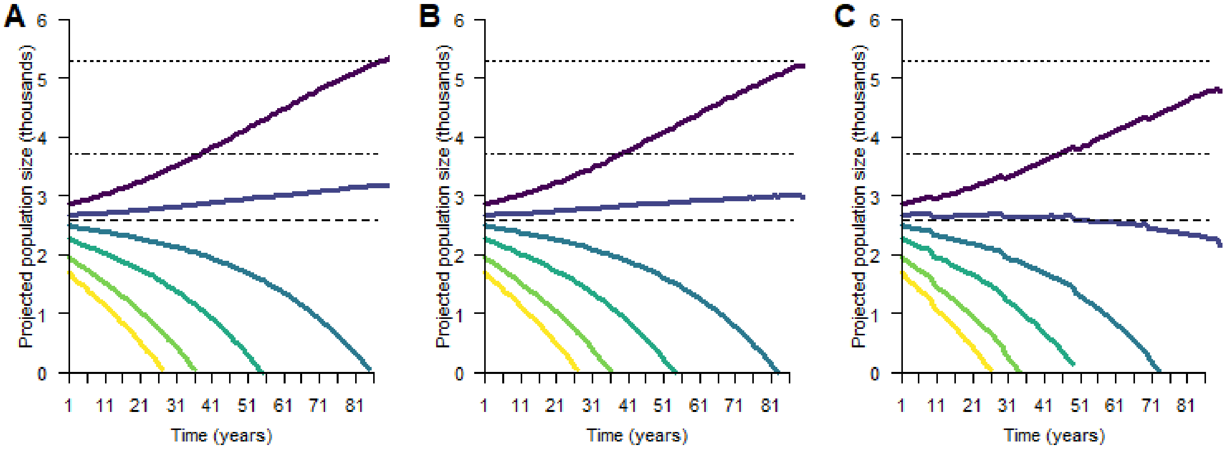

Figure 17. Exploration of the effects of UME on BEL-EHB beluga stock demography. Baseline harvest is set to 60 removals annually, and an UME occurs every 20 years of the simulation. A) No UME; B) An UME causing the mortality of 10 beluga every 20 years; C) An UME causing the mortality of 50 beluga every 20 years. Dark purple, purple, blue, turquoise, green and yellow lines represent > 50%, >60%, >70%, >80%, > 90%, and > 95% population percentiles, respectively. Precautionary approach (PRL, dotted line) and limit reference (LRL, dashed line) levels are shown, as well as the 2015 abundance estimate (two-dashed line) as a suggested recovery objective.

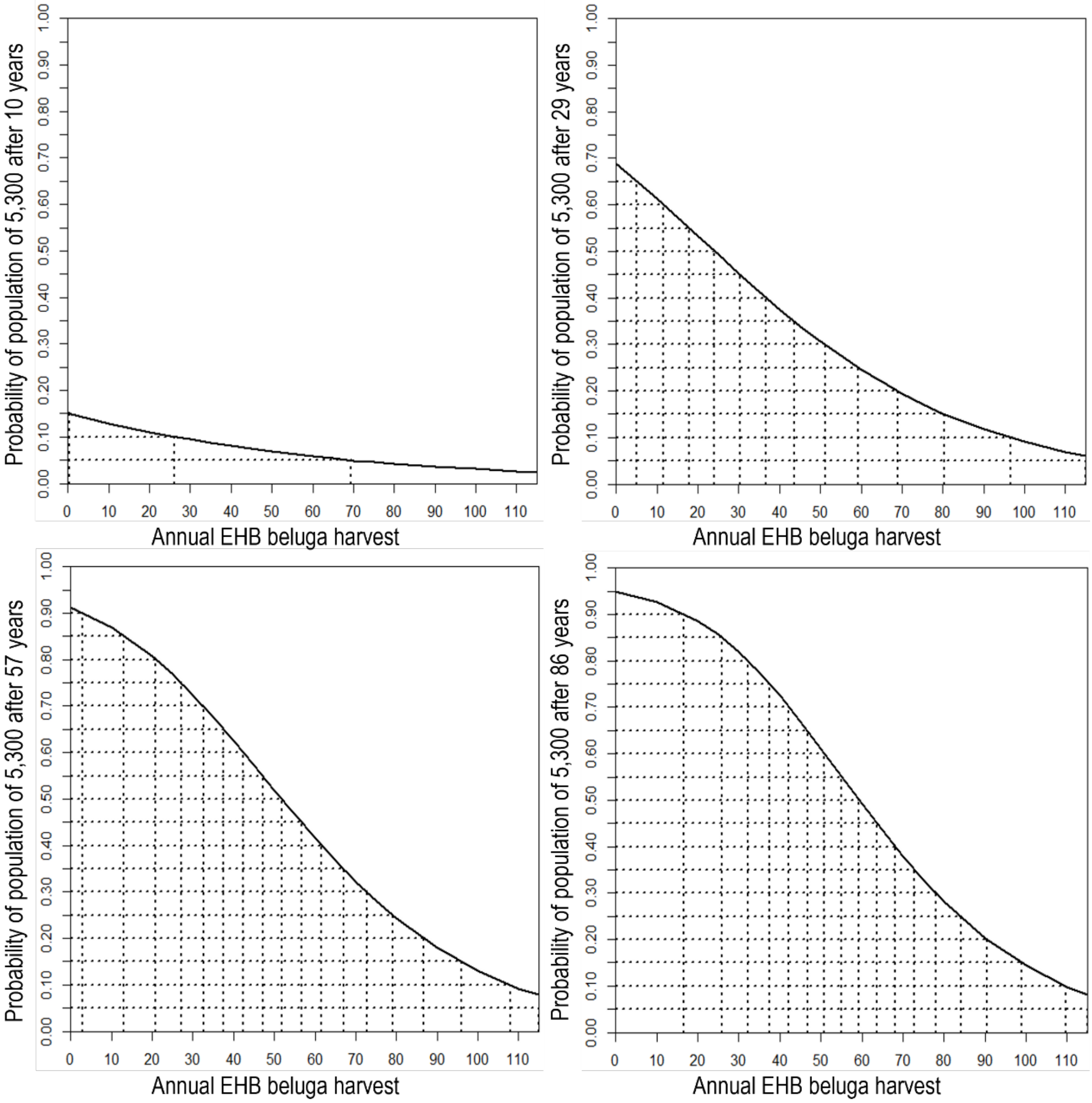

Figure 18. Probability that the BEL-EHB beluga stock would be greater than the PRL (5,300 whales) after 10 years, or one, two or three generation times.

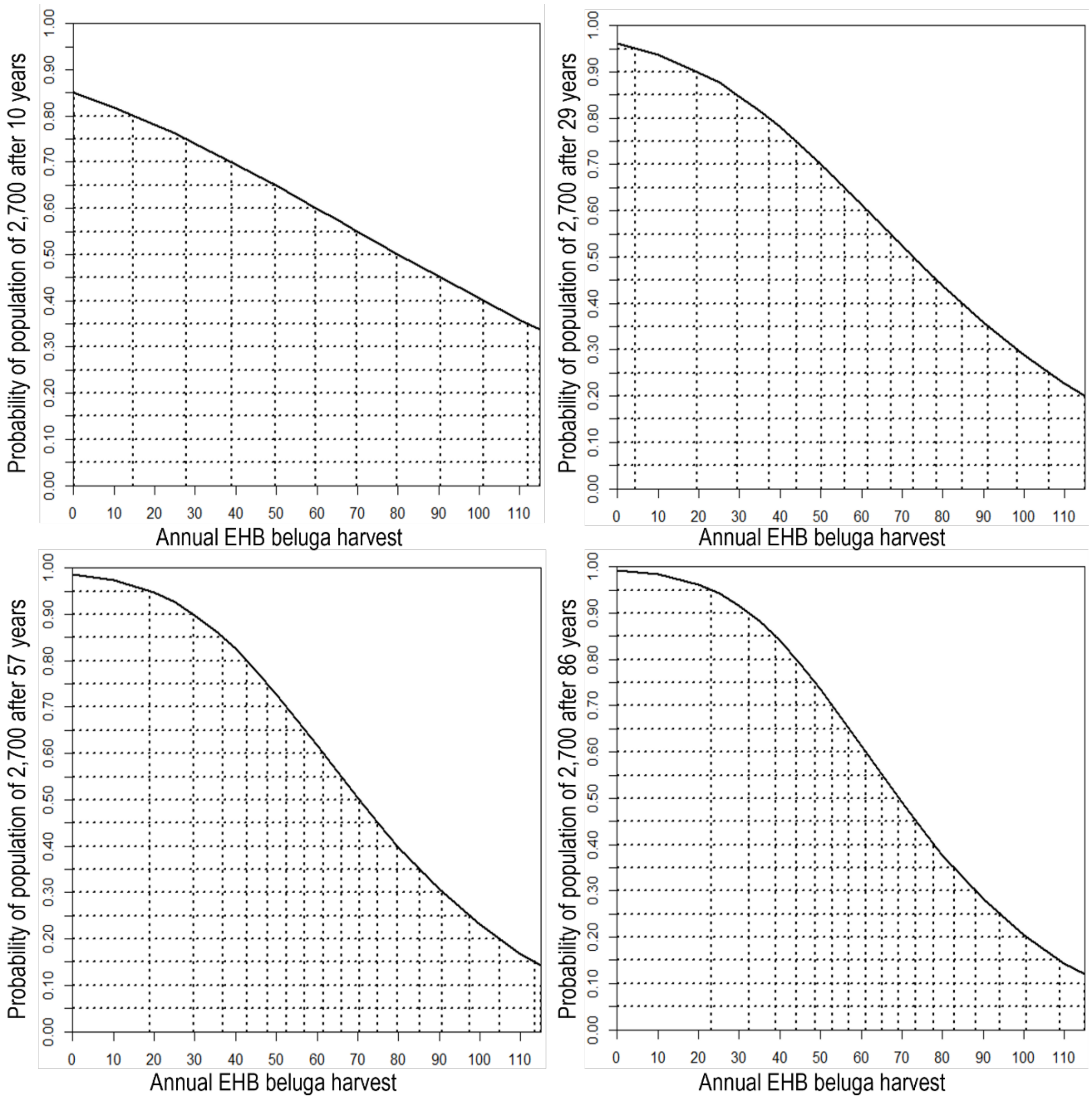

Figure 19. Probability that the BEL-EHB beluga stock would be greater than the LRL (2,700 whales) after 10 years, or one, two or three generation times.

TABLES

Table 1. Life history parameters for BEL-EHB and UB beluga. Parameters from studies where age was estimated assuming the deposition of two growth layer groups (GLG) per year were adjusted to reflect the fact that beluga deposit only one GLG per year. (F): female, (M): male.

Life-history parameter	Value	Reference
Age at sexual maturity	(F) 8-14 years (M) 8-22 years	Doidge 1990b; Sergeant 1973; Ferguson et al. 2020
Age at physical maturity (BEL-EHB only)	(F) 15 years (M) 10 years	Derived from Gompertz curves in Doidge 1990a
Age of reproductive senescence of females	35-50 years (but can be > 70 years)	Burns and Seaman 1986; Ellis et al. 2018; Ferguson et al. 2020
Longevity	45-89 years	McAlpine et al. 1999; Hobbs et al. 2015; Lesage et al. 2014; Ferguson et al. 2020
Gestation time	12.8-15 months	Doidge 1990b; Matthews and Ferguson 2015
No. of offspring per birth	1	Doidge 1990b; Matthews and Ferguson 2015
Lactation duration	2 years	Doidge 1990b; Matthews and Ferguson 2015
Inter-birth interval	3 years	Doidge 1990b; Matthews and Ferguson 2015
Generation time	26.8 years	Lowry et al. 2017
Adult natural mortality		Hoenig 1983, Burns and Seaman 1986; Doidge 1990b; Hobbs et al. 2015; Mosnier et al. 2015; Hammill and Lesage 2019; Tinker et al. 2024
Young adults (9-44 years)	1-6%	
Old adults (> 45 years)	8-17%	

Table 2. Threat assessment for the BEL-EHB and UB belugas based on DFO (2014a) guidelines. H: Historical, C: Current, A: Anticipatory.

Threat	Likelihood of Occurrence	Level of Impact	Causal Certainty (Rank)	Population-Level Threat Risk	Population-Level Threat Occurrence	Population-Level Threat Frequency	Population-Level Threat Extent
Subsistence Harvest	Known	High (BEL-EHB), Extreme (UB)	Very high	High	H, C, A	Continuous	Extensive
Anthropogenic noise	Known	Medium-low	High-Medium	Unknown	C, A	Recurrent	Extensive
Chemical pollution	Unlikely	Low	Medium	Low	A	Continuous	Extensive-Narrow*
Industrial development	Likely	Unknown	Medium	Unknown	H, C, A	Continuous	Narrow
Vessel traffic	Likely	Unknown	Medium	Unknown	C, A	Recurrent	Broad
Commercial fisheries	Known	Unknown	Low	Unknown	C, A	Recurrent	Broad
Climate change	Likely	Unknown	Very low	Unknown	C, A	Continuous	Extensive

**Population-level threat extent may vary depending on the type of chemical pollution. A small restricted oil spill will only impact a fraction of the population in comparison to continuous inputs of chemicals widespread in the ecosystem which may affect the population as a whole.*

Table 3. Temporal population size benchmarks related to the recovery targets identified for BEL-EHB beluga. The total number of beluga are presented along with the number of mature individuals in parentheses. These numbers are subject to change based on future survey results and population model simulations informed by the latter.

Recovery target	Population in 10 years	Population in one generation (28.6 years)	Population in two generations (57.2 years)	Population in three generations (85.8 years)
1. Attain or exceed the 2015 abundance estimate.	3,700 (2,500)	3,700 (2,500)	3,700 (2,500)	3,700 (2,500)
2. Attain a population ≥ PRL in 3 generations	3,000* (2,000)	3,400* (2,300)	4,300* (2,900)	5,300 (3,600)
3. Attain a population size corresponding to the maximal demographic growth given no harvest	3,900 (2,600)	6,300 (4,300)	9,100 (6,200)	10,200 (6,900)

*Based on a harvest level of 60 beluga annually, which represents the highest harvest level compatible with this objective. Inter-annual variations in harvest levels would result in various scenarios to attain this recovery target.

Table 4. Temporal population size benchmark related to the recovery targets identified for UB beluga. The total number of beluga are presented along with the number of mature individuals in parentheses. These numbers are subject to change based on future survey results and population growth functions informed by the latter.

Recovery target	Population in 10 years	Population in one generation (28 years)	Population in 2 generations (57 years)	Population in 3 generations (86 years)
1. Maintain the population at or above the 2022 abundance estimate	70 (50)	70 (50)	70 (50)	70 (50)
2. Attain a population size corresponding to the maximal demographic growth given no harvest	100 (70)	200 (140)	640 (440)	1,980 (1,300)

Table 5. Overview of feasible mitigation measures and alternatives to activities considered as threats to the BEL-EHB and UB beluga in Canada.

Threat	Mitigation measures and/or alternatives to activities
Subsistence harvest	1) Continue to develop co-management strategies for traditional whaling, in support of treaty negotiated rights. 2) Implement precautionary approaches in co-management strategies. 3) Manage beluga harvest at the estuary level, and develop management measures to avoid over harvesting within family groups of beluga who may be vulnerable to single, large harvest events. 4) Public outreach and communication within eastern Hudson Bay and Ungava Bay communities on the status and population trends of BEL-EHB and UB beluga to improve support and compliance with management measures, and improve reporting of struck and loss.
Anthropogenic noise	1) Apply DFO standards for mitigation of seismic noise, regional implementation protocols (i.e., The Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment). 2) Ensure adequate enforcement of the Canadian *Marine Mammal Regulations* (MMR) regional guidelines. 3) Avoid, reduce or shift (geographically and/or temporally) underwater anthropogenic noise sources which overlap or are in close proximity to important habitat for BEL-EHB and UB beluga. 4) Promote development of quieting technologies for vessels.
Industrial development	1) Avoid coastal development, industrialization, or any other activity with the potential to disrupt or destruct costal summering habitat used by BEL-EHB and UB beluga. 2) Review project proposals with potential to impact to areas used by BEL-EHB and UB beluga (e.g., use of seismic or sonar surveying) and provide project-specific advice for mitigation or avoidance with respect to beluga habitat use.
Chemical pollution	1) Document and identify sources of marine pollution. Investigate how to reduce marine pollution at the source. 2) Ensure preventative measures are in place to avoid toxic spills of any nature. 3) Develop a comprehensive toxic spill response to mitigate or avoid impacts to beluga whales or their habitat in Canada. 4) Ensure those responsible for toxic spills have appropriate teams, training and materials to rapidly respond to and remediate spill events.
Fisheries	1) Initiate and promote a beluga entanglement reporting system in the Nunavik Marine Region and Labrador Sea. 2) Public outreach and communication on the importance of reporting beluga bycatches. 3) Undertake a spatial-temporal mapping exercise to document fishing efforts in the beluga wintering grounds. 4) Acquire more data on beluga distribution in wintering grounds, areas important for foraging, diet, and energetic requirements to quantify any competition between BEL-EHB and UB beluga and commercial fisheries.
Vessel traffic	1) Initiate and promote a vessel strike reporting system in the Nunavik Marine Region 2) Ensure adequate enforcement of the Canadian *Marine Mammal Regulations* (MMR) regional guidelines.

Threat	Mitigation measures and/or alternatives to activities
	3) Acquire more data on BEL, EHB and UB migration routes and timing, and undertake a spatial-temporal mapping exercise to identify high-risk areas and periods for vessel strikes, icebreaker-induced ice entrapments, and physical and noise disturbance caused by vessels. These high-risk areas and periods could be targeted for mitigation measures aimed at reducing the threat to BEL-EHB and UB beluga recovery posed by vessel traffic.
Climate change	Mitigation measures to limit climate change are global and non-specific to beluga populations. All efforts aiming at reducing emissions of greenhouse gases are susceptible to moderate the impacts of climate change on BEL-EHB and UB beluga.

Table 6. Posterior estimates of carrying capacity (K), maximum rate of increase (λmax), struck and loss, and population abundance in 2022 (N_{2022}) for the BEL-EHB stock.

Parameter	BEL-EHB estimate (95% CI)
K	11, 043 (6,437-19,410)
Lambda max	0.035 (0.021-0.055)
Struck and loss	0.273 (0.017-0.756)
N_{2022}	2,833 (1,541-4,073)

APPENDIX A – LIST OF MEETING PARTICIPANTS

Table A.1. This Research Document is from the February 20-24, 2023 national peer review on Recovery Potential Assessment of Beluga Whale (Eastern Hudson Bay and Ungava Bay populations).The authors which to acknowledge the meeting participants who contributed to the revision and improvement of the present RPA.

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APPENDIX B – TERMS USED TO DESCRIBE SUB-UNITS OF A SPECIES, AND APPLICATION TO BELCHER ISLANDS-EASTERN HUDSON BAY (BEL-EHB) AND UNGAVA BAY (UB) BELUGA

Sub-unit term	Definition	Application to BEL-EHB beluga	Application to UB beluga
Stock	A group of animals capable of independent exploitation or management (Royce 1972). A stock therefore refers to animals located within a management unit and may include more than one population, or only a subset of individuals from a population.	Aerial surveys conducted to estimate beluga abundance in the eastern Hudson Bay area extend from the Hudson Bay coast to the East, to West of Belcher islands. Population models and derived projections and harvest advices therefore encompass all beluga summering in that management unit. Based on most recent genetic data, beluga from this area form a genetically mixed BEL-EHB stock (Parent et al. 2023), and there is currently no data to inform the relative size of these two populations forming the stock.	Aerial surveys conducted to estimate abundance of beluga summering in Ungava Bay encompasses the entire bay, from bottom to 61.0ºN, as well as most estuaries in southern Ungava Bay. Harvest advices derived from this survey data thus apply to beluga harvested in summer throughout Ungava Bay, including its southern estuaries.
Population	A group of interbreeding individuals occurring together in time and space (Waples and Gaggiotti 2006). A population therefore captures the notion of genetic structure among geographically delineated areas. Beluga populations are geographically defined based on their summer habitat, as less is known about beluga winter distribution and there is potential spatial overlap among populations during winter.	In the Belcher Islands-eastern Hudson Bay area, two genetically distinct beluga populations are identified during summer: one harvested around the Belcher Islands (BEL), and one harvested along the coast of eastern Hudson Bay (EHB) (Parent et al. 2023). In previous genetic studies that used a shorter haplotype for genotyping, most BEL beluga were indistinguishable from Western Hudson Bay (WHB) individuals (Parent et al. 2023).	No endemic population summering in Ungava Bay could be identified based on mitochondrial DNA analyses (Parent et al. 2023). However, sample size for this area is very limited, especially for the south of the Bay where historical aggregations occurred. Obtaining addition samples from southern Ungava Bay and its estuaries in summer is necessary to assess whether beluga summering in the area form a genetically distinct population.
Designatable unit (DUs)	Discrete and evolutionarily significant units of the taxonomic species (COSEWIC 2020b). Discreteness refer to little or no transmission of heritable information between units, and encompasses genetic differentiation, natural disjunction between portions of the species range, or ecological isolation. Evolutionary significance refer to the importance of the unit to the evolutionary legacy of the species, and that if lost the individuals forming the unit would not be replaced through natural dispersion.	The EHB DU is defined by estuarine concentrations at the Nastapoka, Great Whale, and Little Whale rivers, with the main area of summer coastal occupation extending from Kujjuarapik to Inukjuak (COSEWIC 2016). Individuals perform repeated inshore-offshore movements extending out to the Belcher Islands (Bailleul et al. 2012a), where they mix with beluga from other DUs (WHB, JB) during summer (COSEWIC 2016). The genetic distinctiveness of EHB beluga was used to support the discreteness and evolutionary significance criteria in the last COSEWIC assessment (2016), before the identification of the BEL population. Therefore, the beluga DU structure in the eastern Hudson Bay and Belcher Islands area may eventually be redefined by COSEWIC.	The UB beluga DU is defined based on a historical aggregation centered near the Marralik River estuary, with additional smaller concentrations at the George, Soak, Leaf, and Whale river. The recognition of the UB DU is based primarily on TEK and historical harvest records. There are no genetic data to support or refute the discreteness or significance of this DU. However, COSEWIC considers that migrating beluga from other DUs occur in Ungava Bay in spring, fall and winter, but not summer. Hence, if the UB DU were to become extirpated, or has been already, much of southern Ungava Bay would remain unoccupied by beluga during summer (COSEWIC 2016).

APPENDIX C – PRIORS USED TO FIT BELUGA POPULATION MODELS

Table C.1. Prior distributions, parameters, and hyper-parameters used in the BEL-EHB beluga population models. Median and 0.025 and 0.975 quantiles are shown.

.Parameters	Notation	Prior distribution	Hyper-parameters	Parameter value	Prior median	0.025	0.975
Survey precision (t)	ε_{S_t}	Fixed		1 / (Survey standard error)^2	-	-	-
Process error (t)	ε_{pt}	Log-normal	μp / τp	0 / estimated	1 / inf	0	inf
Precision (Process)	τp	Gamma	αp / βp	1.5 / 0.005	236.6	21.6	934.8
Theta	θ	Fixed	-	-	2.39	-	-
Struck and loss 25%	SL	Beta	αsl / βsl	1.135 / 2.763	0.25	0.015	0.755
Initial population (BEL-EHB)	Start	Uniform	Nupp / Nlow	15,000 / 2,000	8,500	2,325	14,675
Carrying capacity (BEL-EHB)	K	Uniform	Nupp / Nlow	20,000 / 5,000	12,500	5,375	19,625
Maximum rate of increase	λ_{max}	Beta	αsl / βsl	15.618 / 373.015	0.039	0.023	0.062

Table C.2. Prior distributions used in the population model for the proportion of BEL-EHB animals harvested in Nunavik and Nunavut, by region. HSUB = prior to 2009 most samples were from the Hudson Bay-Ungava Bay area from the fall but harvest area is not known. These are assigned the same parameters as HS_F. Median and 0.025 and 0.975 quantiles are shown.

Nunavut

Parameters	Notation	Prior distribution	Hyper-parameters	Parameter value	Prior median	0.025	0.975
Sanikiluaq (Spring)	PSAN_S	Beta	αsan / βsan	45.778 / 27.164	0.629	0.515	0.734
Sanikiluaq (Fall)	PSAN_F	Beta	αsan / βsan	8.194 / 5.323	0.6113	0.344	0.837
Sanikiluaq (Winter)	PSAN_W	Beta	αsan / βsan	3.697 / 5.493	0.396	0.131	0.7151
Sanikiluaq (Summer)	PSAN_SU	Fixed	-	-	1	-	-

Nunavik

Parameters	Notation	Prior distribution	Hyper-parameters	Parameter value	Prior median	0.025	0.975
Hudson Strait (Spring)	PHS_S	Beta	Ahs_sp / βhs_sp	32.11 / 229.09	0.122	0.086	0.165
Hudson Strait (Fall)	PHS_F	Beta	Ahs_f / βhs_f	50.58 / 64.36	0.44	0.351	0.532
HSUB *	PHSF	Beta	αhs / βhs	50.58 / 64.36	0.44	0.351	0.532
Ungava Bay (Spring)	PUB_S	Beta	αub_s / βub_s	3.13 / 57.43	0.047	0.015	0.12
Ungava Bay (Fall, used HS Fall)	PUB_F	Beta	Aub_f / βub_f	50.58 / 64.36	0.44	0.351	0.532
Northeast Hudson Bay (used HS spring)	PNEHB_S	Beta	Anehb_s / βnehb_s	32.11 / 229.09	0.122	0.086	0.165
Northeast Hudson Bay (Fall)	PNEHB_F	Beta	Anehb_f / βnehb_f	6.228 / 6.20281	0.50	0.24	0.762