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An update of impacts of harvesting on the abundance of Nunavik beluga

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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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TABLE OF CONTENTS

ABSTRACT

Harvests of the Eastern Hudson Bay (EHB) summer stock are limited by a management plan that ends in 2020. This document updates the status of the stock using new harvest (up until 2019) and genetics data (up until 2018). The analyses indicate that the overall proportions of EHB beluga in the Hudson Strait harvest were 11.7% in spring and 29.1% in fall; for Ungava Bay the proportion was 6% in spring. In northeastern Hudson Bay fall harvest the proportion was 44.5%. Limited sample size from the Ungava Bay fall and northeastern Hudson Bay spring harvests precluded the breakdown by season for these regions. The population model produced a median abundance estimate of 3,300 animals in 2019, a slight decrease from the previous estimate of 3,400 animals in 2014 (rounded to the nearest 100). The annual Sustainable Yield, which maintains a stable population (50% probability of decline), was 58 belugas for 5 years or 62 animals if evaluated over 10 years. The Potential Biological Removal is 14 animals per year assuming a recovery factor of 0.25.

Key words: beluga, *Delphinapterus leucas*, abundance, genetics, Nunavik, harvest

INTRODUCTION

A fundamental concept in wildlife and fisheries management is that of a stock. At its simplest, the term ‘stock’ is synonymous with an assessment or management unit that is established to avoid local depletions and loss of genetic diversity (Richard 2010). Others have defined a stock as a group of animals within the same species, in a common spatial arrangement that interbreed when mature. Unfortunately, in most cases, the resource being managed often exhibits some level of complex spatial structure, which adds uncertainties in defining what a stock actually is. This structure often requires more complex management approaches than initially considered, to account for this uncertainty and to minimize stock depletion (MoF 2007; Kerr et al. 2017; NMFS 2016).

In Canada, the initial concept of beluga stocks was based on the disjunct distribution of beluga summering aggregations (Sergeant 1973; Finley et al. 1982; Richard 2010). It was thought that animals likely returned to the same summering areas, year after year which made them vulnerable to local depletions. These stock separations have been further supported by evidence underlining that animals do show strong intra and inter-annual site fidelity based on behavioural observations and genetics (Caron and Smith 1990; Colbeck et al. 2013); telemetry has also shown little evidence for mixing between different summering groups (Bailleul et al. 2012), while genetic, isotopic and contaminant differences between groups further support the concept of different summering stocks that may or may not interbreed outside of the summer period (Brennin et al. 1997; Brown Gladden et al. 1997,1999; Colbeck et al. 2013; de March and Postma 2003; de March et al. 2002, 2004; Postma et al. 2012; Rioux et al. 2012; Turgeon et al. 2012). In areas where numbers have been severely depleted such as in Cumberland Sound, Ungava Bay and the St. Lawrence, there does not appear to have been any movement or ‘rescue effect’ from larger adjacent stocks into these depleted areas (unlike what has been observed in other species such as ringed seals). This also points to a significant level of separation and cultural conservatism between summering stocks.

In the waters surrounding Nunavik, at least four different beluga summering stocks have been identified. These different summering stocks are also considered as different management stocks and are identified as the: 1. Eastern Hudson Bay (COSEWIC 2004: Endangered); 2. Ungava Bay (Endangered); 3. Western Hudson Bay (Special concern); and 4. James Bay beluga (Unknown) stocks. These stocks are currently being re-assessed by COSEWIC.

Hunters from Nunavik harvest belugas from the eastern Hudson Bay stock (EHB), the western Hudson Bay stock (WHB)(N=54,500 whales) and the James Bay stock (JB)(N=10,600 whales). The EHB stock is the smallest of the three stocks, with an estimated abundance of 3400 (95% CI = 2200-5000) animals (Table 1) (DFO 2018; Hammill et al. 2017).

By the 1980s, there were concerns that the harvest levels of EHB whales were not sustainable and to provide protection, quotas were established to limit harvesting. Mitochondrial DNA analyses of samples provided by hunters from their catches have identified differences between the WHB and EHB summering stocks. These differences are used to identify the proportion of animals belonging to each stock that are taken in the harvest. Since then, the objective of managers/hunters in managing the harvest has been to redirect the harvest as much as possible away from the small EHB stock and towards the much larger WHB stock.

The harvesting of beluga in Nunavik is co-managed with the Nunavik Marine Region Wildlife Board (the Board) under the Nunavik Inuit Land Claims Agreement (NILCA 2008). The EHB beluga population is managed using a Sustainable Yield approach; the management objective is to maintain a stable population where for a given set of removals, the probability of decline in the stock does not exceed 50%. The stock has been managed under a three year management plan that ends in 2020. However, in the final year of the current plan the Total Allowable Take (TAT) was exceeded. The objective of this document is to update the analysis of genetic mixing among beluga stocks occurring in the Nunavik marine region and the Belcher Islands area with the new information; evaluate the impact of the harvest on the stock and to provide the Board with new information on the status of the stock as they develop a new management plan. A new survey is planned for summer 2020 and a more thorough review of the stock is planned for fall 2020/winter 2021.

METHODS

For this update, a population model is fitted to a time series of aerial survey abundance estimates (1985-2015) (Table 1), while incorporating reported harvest data (1974-2019) from each of the 14 communities in Nunavik and Sanikiluaq, Nunavut (Figure 1). It takes into account the proportion of EHB belugas in the harvest as determined from a genetic mixed model analysis of skin samples provided by hunters (Gosselin et al. 2017; Hammill et al. 2017; Mosnier et al. 2017).

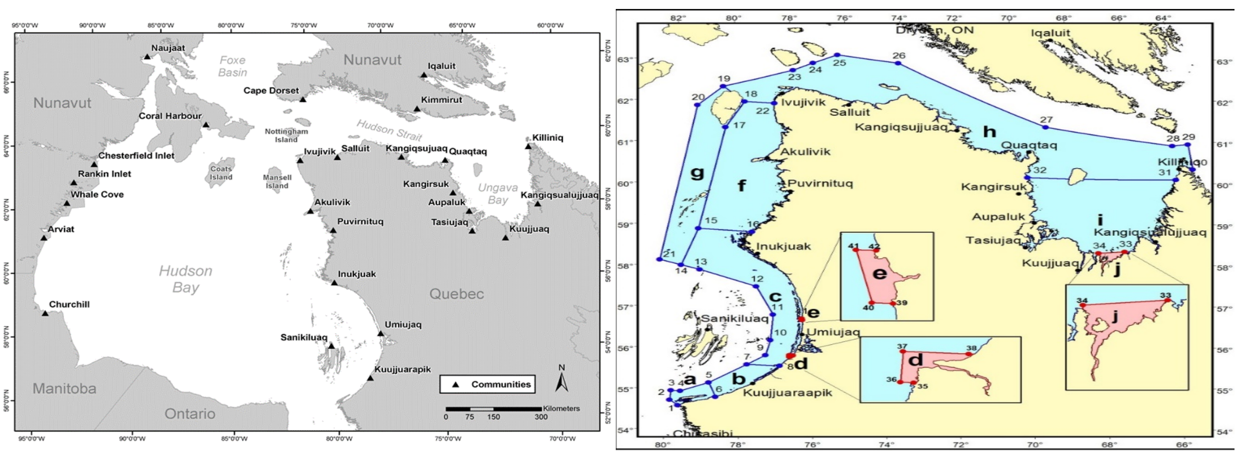

Figure 1. Map of area of interest (left) and management harvest regions (right) in eastern Hudson Bay that are considered as different hunting areas in the management plan, with different probabilities of EHB whales taken in each area.

Reported harvest information was available from Nunavik (1974-2019) and Sanikiluaq (1977-2018)(Figure 2). For the 2019 Sanikiluaq harvest, we used the average of the 2017 and 2018 harvests (Appendix 1; Table 1). We assumed that 84% of the reported harvest from this community occurred during the extended Spring (1-15 July) based on Mosnier et al. (2017). All beluga harvested directly in the eastern Hudson Bay arc during the summer are assumed to belong to the EHB summer stock (regions b and c, Figure 1). Animals harvested in the Long Island area are assumed to not belong to the EHB stock and are excluded here (region a, Figure 1). The proportions of EHB belugas harvested from other areas were determined using the genetic mixing model analysis. We used the same source stocks and source samples as the last assessment to classify the new samples as EHB or WHB animals (Mosnier et al. 2017). Sometimes the model is unable to assign an animal to either stock based on the source populations. The model classifies these animals as unknown. The authors consider that these samples are likely to be non-EHB animals. In addition, because the same haplotype can occur in the two populations, the model also estimates an error of misclassification.

*Table 1. Abundance estimates for the EHB and WHB beluga whale stocks from aerial surveys. Indices have been corrected for availability bias (Gosselin et al. 2017, Matthews et al. 2017). * No belugas have been seen on transect in UB. However, belugas have been detected offline. This information has been used to generate an estimate of less than 100 animals for this summer stock (Doniol-Valcroze and Hammill 2012).*

Year	EHB estimate (SE)	WHB estimate (SE)	James Bay	Ungava Bay
1985	4282 (557)	-	4720 (614)	*
1987	-	31,124 (6967)	-	-
1993	2729 (1092)	-	8205 (1969)	*
2001	2924 (1404)	-	17285 (4148)	*
2004	4274 (1581)	51,761 (15,875)	8364 (2509)	-
2008	2646 (1244)	-	19439 (12830)	*
2011	3351 (1642)	-	14967 (4490)	-
2015	3819 (1642)	54,473 (5,329)	10615 (2654)	-
	-	-	-	<100

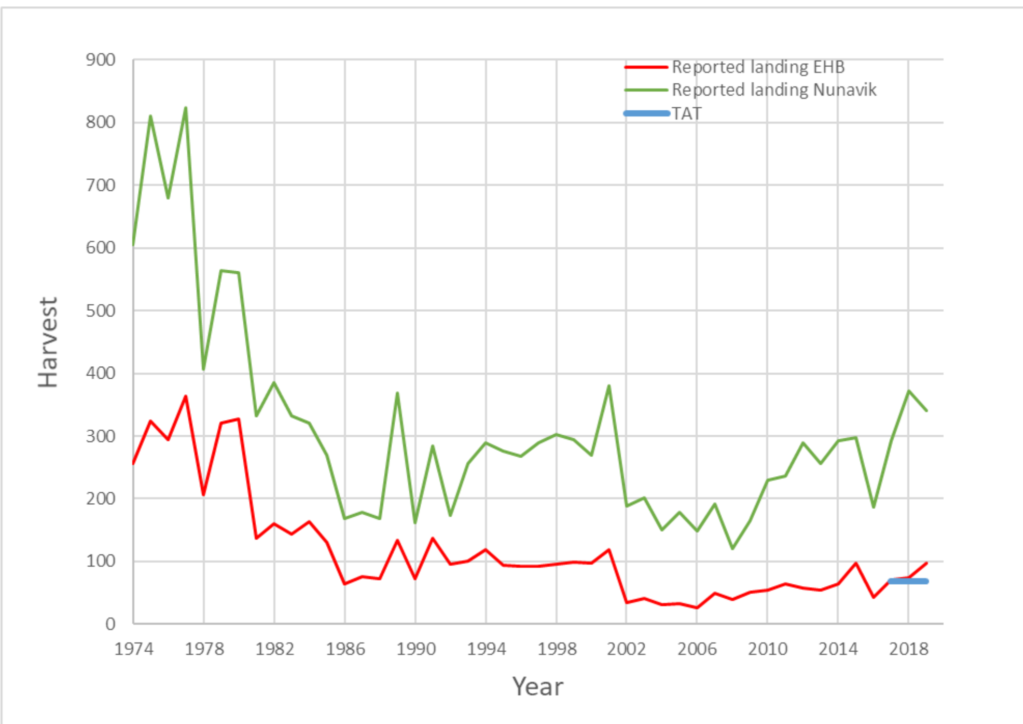

Figure 2. Total reported harvest of belugas in Nunavik (green), estimated landed harvest of Eastern Hudson Bay (EHB) (red) based on the proportions from the genetic analysis (Table 4) and the total Allowable Take (blue).

A stochastic stock-production model was fitted by Bayesian methods to estimate current abundance and evaluate the impact of different harvest levels on future population trend (Doniol-Valcroze et al. 2012a,b; Hammill et al. 2017).

$$N_t = (N_{t-1} + N_{t-1} \cdot (\lambda_{max} - 1) \cdot \left[1 - (N_{t-1}/K)^{\theta}\right]) \cdot \varepsilon_{p_t} - R_t \text{ , with } \varepsilon_{p_t} \sim \mathrm{logN}\left(0, \tau_p\right)$$

Where N is abundance at time t or t-1, K is environmental carrying capacity and theta (θ) defines the shape of the density-dependent function.

Removals (R_t) were calculated as $R_t = C_t \cdot (1 + SL)$,

where reported catches (C_t) of EHB whales are adjusted 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.

The observation process describes the relationship between true population size and observed data. In our model, survey estimates S_t are linked to population size N_t by a multiplicative error term ε_{s_t}:

$$S_t = N_t \cdot \varepsilon_{s_t} \text{ , with } \varepsilon_{s_t} \sim \mathrm{logN}(0, \tau_s)$$

In this update we used the same prior formulations as Hammill et al. (2017), with the exception of the upper limit for K. In the last assessment the upper limit was 25,000, but the upper posterior limit was 19,250. In this update we set the upper limit for the prior at 20,000 (Table 2). The maximum rate of population increase assumed a prior with uniform distribution with a range of 0.001 to 0.06 from the last assessment. Theta (θ) was set to 2.39 (Taylor and DeMaster 1993; Hobbs et al. 2006). Reported struck and loss (SL) rates for beluga range from around 18% to 66% (Hobbs et al. 2006; Richard 2008). We used a moderately informative prior with a median of 0.42 and quartile points at 0.12 and 0.78 (Hammill et al. 2017). The stochastic process error terms εpt were given a log-normal distribution with a zero location parameter. The precision parameter for this lognormal distribution was assigned a moderately informative prior following a bounded gamma (1.5, 0.001). The proportions of EHB beluga harvested in each zone are incorporated into the model as probabilities (Table 2). The genetic priors assumed a Beta distribution, as determined from the genetic mixing model. Harvest proportions were updated from the last assessment by including new samples from the harvest, collected during 2016-2018 (Tables 3, 4).

Table 2. Prior distributions, parameters and hyper-parameters used in Nunavik beluga population model. For each sub-region and season, the priors for the proportion of EHB belugas in the harvest are given. PHSUB = proportion EHB in Hudson Strait/Ungava Bay.

Parameters	Notation	Prior distribution	Hyper-parameters	Parameter value	Prior median	0.025 quantile	0.975 quantile
Survey error (t)	εst	Log-normal	μs / τs	0/estimated	1 / 3.46 e+53*	0	6385446*
Precision (Survey)	τs	Gamma	αs/ βs	2.5/0.4	5.44	1.04	16.04
Process error (t)	εpt	Log-normal	μp / τp	0/estimated	1/inf	0	inf
Precision (Process)	τp	Gamma	αp / βp	1.5/0.001	1183.2	107.9	4674.8
Theta	θ	Fixed	-	-	2.39	-	-
Struck-and-lost	S&L	Beta	αsl /βsl	3/4	0.421	0.118	0.777
Initial population	Start	Uniform	Nupp/ Nlow	15000/2000	8536	2312	24662
Carrying capacity	K	Uniform	Nupp/ Nlow	20000/2000	11077	2476	19513
Maximum annual growth rate	λmax	Uniform	Nupp/ Nlow	0.06/0.001	0.03	0.002	0.058
HSUB	PHS	Beta	αhs/ βhs	45/216	0.171	0.13	0.22
Sanikiluaq (extended spring)	PSAN	Beta	αsan/ βsan	4.67/90.58	0.046	0.015	0.1
Hudson St. (spring)	PHS_SP	Beta	Ahs_sp/ βhs_sp	29.45/222.43	0.116	0.08	0.16
Hudson St (Fall)	PHS_F	Beta	Ahs_f/ βhs_f	46.93/114.27	0.29	0.22	0.36
UB (spring)	PUB_S	Beta	αub_s/ βub_s	2.83/39.41	0.06	0.01	0.16
UB (fall, used HS fall)	PUB_F	Beta	Aub_f/ βub_f	46.93/114.27	0.29	0.22	0.36
NE HB (used HS spring)	PNEHB_S	Beta	Anehb_s/ βnehb_s	29.46/222.43	0.116	0.08	0.16
NE Hudson Bay (fall)	PNEHB_F	Beta	Anehb_f/ βnehb_f	8.38/10.42	0.44	0.23	0.668

We obtained posterior estimates of all the parameters using a Gibbs sampler algorithm implemented in JAGS (Plummer 2003). Results including mixing of chains and convergence were examined as outlined in Doniol-Valcroze et al. (2014) and Hammill et al. (2017)).

The 2017-2020 management objective for this stock is to maintain a stable population of 3,400 animals, where for a given harvest, the probability of a decline in abundance does not exceed 50%.

We also examined the impacts of three scenarios, where the TAT for EHB belugas was increased from the current management framework of 68 animals to levels of 100, 125 and 150 animals for a period of two years (i.e. 2020 and 2021) and then setting the harvest from 2022 onwards at levels that would allow the population to recover to 3400 animals over five to 30 years.

Total allowable removals were also calculated using the Potential Biological Removal (PBR), using the equation: $PBR = 0.5 \cdot R_{max} \cdot F_R \cdot N_{min}$;

where R_{max} is the maximum rate of population increase (set to cetacean default value of 1.04), F_R is a recovery factor (between 0.1 and 1), and N_{min} is the estimated population size using the 20-percentile of the lognormal distribution (Wade 1998).

RESULTS

Since the last assessment, the number of samples available to estimate the proportion of EHB belugas in the harvest has increased from 1063 to 1382 in Nunavik and from 746 to 757 from Sanikiluaq (Tables 3, 4).

Overall, there has been little change in the estimated proportion of EHB belugas in the harvest, with the exception of fall samples from northeast Hudson Bay (NEHB), where the proportion of EHB animals in the harvest increased markedly from 30.2% in the last assessment, to 44.5% in this assessment (Tables 3, 4); in most cases the increase in sample size has contributed to reducing the uncertainty associated with the estimates of the proportion of EHB belugas in the catch (Tables 3, 4).

Table 3. Results of the genetic mixture analysis using the Pella-Masuda model for the baselines from the last assessment which included data from 1982-2015 (Mosnier et al. 2017). Nsamp is the number of tissue samples, whereas Nevent is the number of days where samples were obtained, percent western Hudson Bay belugas (% WHB) in the catch, coefficient of variation (CV), percent eastern Hudson Bay belugas (% EHB) and the percentage of samples that could not be assigned to either the WHB or EHB stock (i.e. unknown).

Spring (Feb 1 - Aug 31)

	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples / events)	% Unk
Hudson Strait	611	278	83.1	78.3 - 87.4	10.8	7.1 - 15.2	0.18/0.19	6.1
NE Hudson	2	1	ND	-	ND	-	-	-
Ungava Bay	75	49	82.3	68.1 – 92.9	8.4	0.9 - 23	0.60/0.70	9.3

Fall (Sept 1 - Jan 31)

	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples / events)	% Unk
Hudson Strait	352	146	71.1	63.4 - 78.1	26.1	19.3 - 33.6	0.12/0.14	2.8
NE Hudson	20	8	59.8	31.1 - 85.2	30.2	12.1 - 52.3	0.40/0.35	10.0
Ungava Bay	3	3	ND	-	ND	-	-	ND

Sanikiluaq

Season	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples / event)	% Unk
Spring (April 1 - June 30)	297	107	77.3	70.0 - 83.9	1.5	0.0 - 5.7	1.07/1.08	21.2
Extended spring (April 1 - July 14)	320	120	75.6	67.9 - 82.5	4.4	1.1 - 9.9	0.43/0.52	20.0
Summer (July 1 - August 31)	31	18	61.5	33.6 - 85.7	25.6	5.2 - 55.1	0.37/0.51	12.9
Fall (Sept1 - Nov 30)	42	28	97.6	91.3 - 99.9	0.0	-	-	2.4
winter (Dec. 1 - Mar 31)	56	7	31.3	7.4 – 63.0	36.6	10.5 -68.2	0.21/0.41	32.1

Table 4. Results of the updated genetic mixture analysis (1982-2018) using the Pella-Masuda model to determine the proportions of beluga (%) from each source stock in the harvest of Nunavik hunt areas (upper part) and Sanikiluaq harvest (lower part). Nsamp: number of individual samples; Nevent: number of different hunting dates; WHB: Western Hudson Bay; EHB: Eastern Hudson Bay; 95% CI: 95% confidence interval based on variance among hunting events; ND: not determined (small sample size). Unknown means samples could not be assigned to the WHB or EHB stock.

Spring (Feb 1 - Aug 31)

	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples/ events)	% Unk
Hudson Strait	770	347	82,9	78.5 - 87	11,7	8.1 - 16	0.15/0.17	5,3
NE Hudson	2	1	ND	-	ND	-	-	-
Ungava Bay	122	76	87,4	77.8 - 94.6	6,0	0.8 - 15.8	0.63/0.65	6,6

Fall (Sept 1 - Jan 31)

	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples/ events)	% Unk
Hudson Strait	454	180	67,6	60.3 - 74.5	29,1	22.4 - 36.3	0.09/0.12	3,3
NE Hudson	31	14	49,1	26.4 - 72	44,5	23.5 - 66.5	0.26/0.25	6,5
Ungava Bay	4	4	ND	-	ND	-	-	ND

Sanikiluaq

Season	N samp	N event	% WHB	95% CI	% EHB	95% CI	(CV samples / events)	% Unk
Spring (Apr 1 - June 30)	301	107	76,8	69.2 - 83.7	1,6	0 - 6.6	1.01/1.17	21,6
Ext. spring (Apr 1 - July 14)	324	120	75,1	67.2 - 82.2	4,6	1.1 - 10.2	0.43/0.52	20,4
Summer (July 1 - Aug 31)	31	18	61,5	32.8 - 86.2	25,6	4.9 - 56	0.37/0.53	12,9
Fall (Sept 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	0.21/0.45	32,1

Fitting the model to the aerial survey data resulted to significant updates to the lambda, initial population and carrying capacity priors, and a moderate update to the S&L prior (Table 5, Figure 3). The model estimates, rounded to the nearest 100, were K = 8,200 and a starting population of 6,600 in 1974. The model indicates that the population declined from 1974 reaching a minimum of 3,100 in 2001 and then increasing to 3,400 by 2014. Since then, the population has been relatively stable or declined slightly to 3,300 (Table 5, Figure 4).

Table 5. Model estimates and prior distributions for carrying capacity (K), the starting population size in 1974 (startpop), rate of increase (λ), struck and loss (S&L), and abundance estimate in 2019 (N2019), as well as values for the proportions of EHB animals harvest in the Hudson Strait in fall (pFALL), Hudson Strait and Ungava Bay combined (pHSUB), northeast Hudson Bay fall and spring (pNEHBFA or SP), Sanikiluaq (pSAN), Hudson Strait in spring (pSPRING), and Ungava Bay (UB) in spring (SP) and fall (FA).

					Quantiles		
	Mean	**SE**	**2.50%**	**25%**	**50%**	**75%**	**97.50%**
K	9978	4177	5348	6689	8241	12866	19276
K.prior	11031	5206	2476	6499	11077	15552	19513
startpop	6713	1169	4738	5875	6589	7434	9303
startpop.prior	8521	3767	2312	5233	8536	11798	14662
λ	0.032	0.014	0.005	0.022	0.033	0.044	0.058
λ.prior	0.031	0.017	0.002	0.016	0.03	0.045	0.058
S&L	0.4	0.172	0.107	0.27	0.389	0.519	0.755
S&L.prior	0.427	0.176	0.116	0.294	0.419	0.552	0.779
N2019	3371	837	1882	2797	3327	3882	5175
pFALL	0.291	0.035	0.225	0.266	0.290	0.314	0.364
pHSUB	0.171	0.023	0.128	0.155	0.171	0.187	0.219
pNEHBFA	0.445	0.111	0.235	0.366	0.442	0.520	0.666
pNEHBSP	0.117	0.020	0.080	0.103	0.116	0.130	0.159
pSAN	0.049	0.022	0.015	0.033	0.046	0.062	0.100
pSPRING	0.117	0.020	0.080	0.103	0.116	0.130	0.160
pUBFA	0.291	0.035	0.225	0.267	0.290	0.315	0.363
pUBSP	0.067	0.038	0.013	0.039	0.060	0.088	0.159

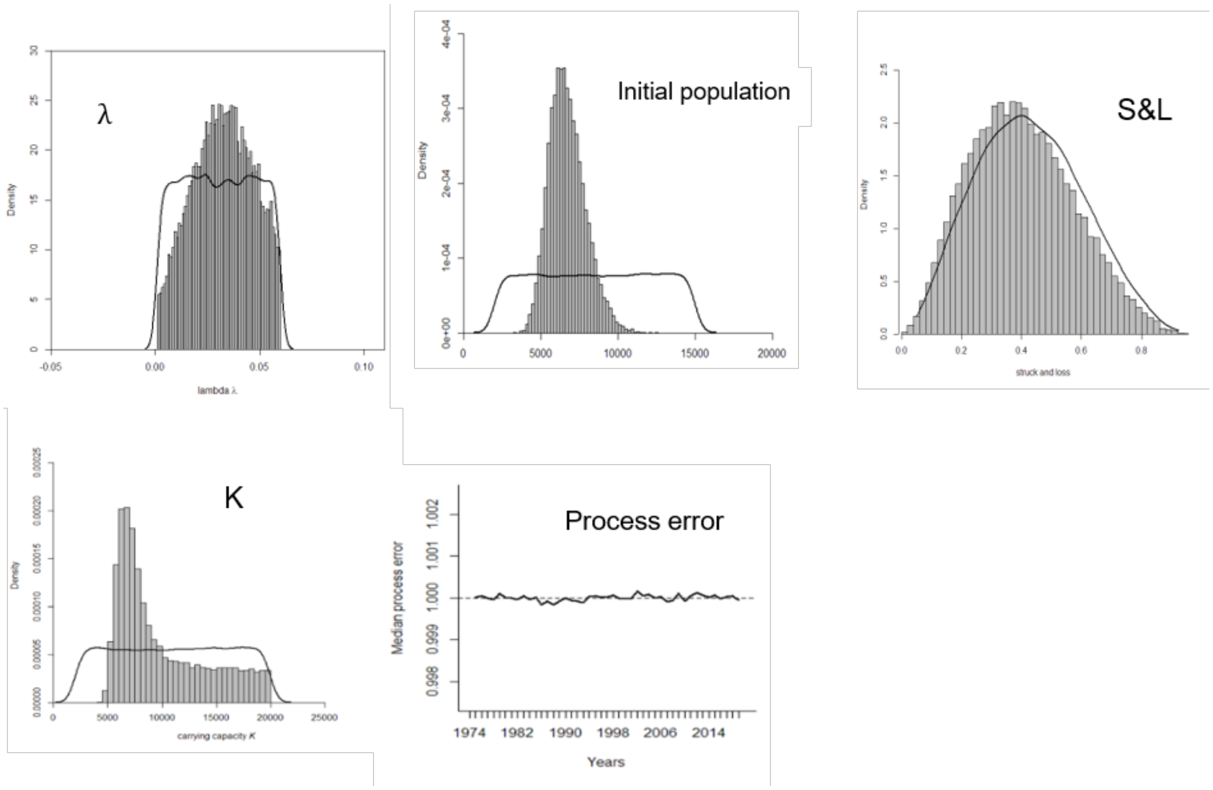

Figure 3. Prior (dark lines) and posterior (vertical columns) distributions for lambda, the initial population size in 1974, struck and loss and carrying capacity. The last figure shows the median process error.

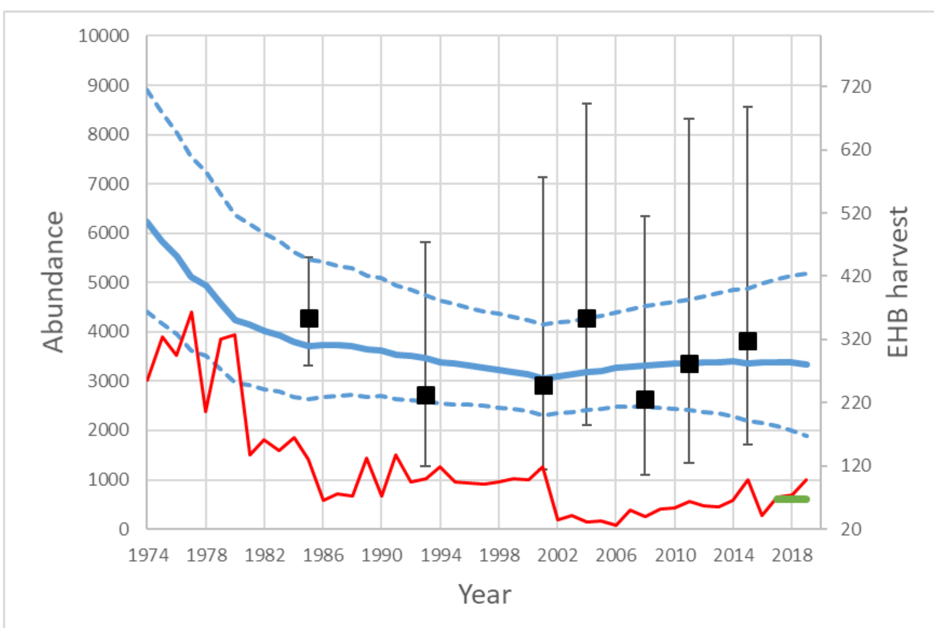

Figure 4. Model estimates of stock abundance for Eastern Hudson Bay beluga (EHB) (solid blue line ±95% CI), aerial survey estimates (black squares ±95% CI), estimated harvests of EHB beluga (red line) and Total Allowable Take (TAT) of 68 (green line) under the 2017-2019 management plan.

The 2017-2020 management objective is to maintain the population at or above 3,400 animals. An annual harvest of 58 EHB belugas would have a 50% probability that the population would be 3,400 or more whales after five years, while a harvest of 62 whales would have a 50% probability that the population would be 3,400 or more whales after 10 years (Figure 5).

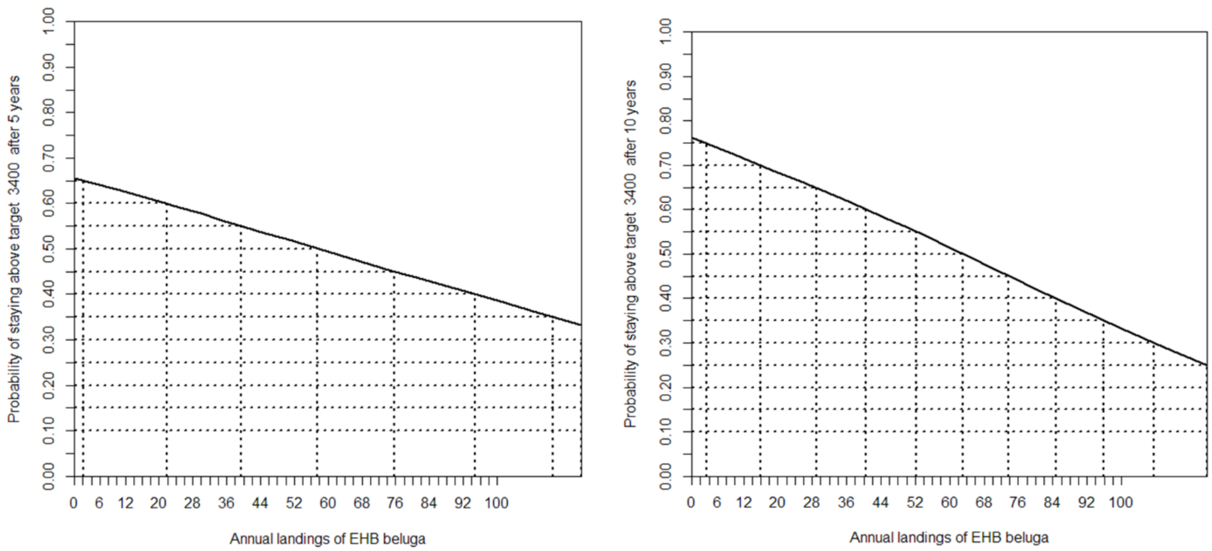

Figure 5. Probability of a population decline from current levels over 5 years (left) and 10 years (right) at different levels of harvests of EHB belugas.

We also examined the impacts of a two year harvest, where the TAT for EHB belugas was increased from the current management framework of 68 animals to levels of 100, 125 and 150 animals for a period of two years (i.e. until 2021) and then setting the harvest from 2022 onwards at levels that would allow the population to recover to 3400 animals over five to 30 years (Table 6, Figure 6).

The estimated PBR from the population model assuming a recovery factor of 0.25 (DFO 2018) is 14. The PBR from the aerial survey is also 14.

DISCUSSION

The objective of an EHB summer beluga harvest is to avoid the depletion and loss of genetic diversity associated with beluga that summer in the area approximated by the Hudson Bay arc, extending from the coast offshore to approximately 81° W longitude. Abundance estimates for this stock are available from a time-series of aerial surveys that extend back to 1985 (Gosselin et al. 2017). Complicating the management of this relatively small stock is that they overwinter in Hudson Strait, with a much larger herd, the western Hudson Bay summering stock (DFO 2018). In Hudson Strait, animals are harvested by hunters from communities in the Strait as well as hunters travelling to the Strait area from villages in northeastern Hudson Bay and Ungava Bay. Differences in genetic signatures between the EHB and WHB belugas (see Introduction) provides information on the stock composition of the hunt and has enabled management efforts to increase harvesting of WHB animals, while trying to reduce impacts on the smaller EHB stock. The current stock definition is likely to be conservative, since the source material for the Genetic Mixing model is based only on samples from Little Whale River and Nastapoka River estuaries; these estuaries have been closed to hunting for quite some time and it is uncertain how representative these samples are for the animals currently occupying the larger EHB area. As such, it remains unclear if animals outside of these estuaries and in the offshore areas have different signatures. And if so, then the genetic signature of this stock may need to be expanded since more animals could be assigned to the EHB stock. This may impact harvesting in overlap areas. A review of the genetic methods and stock composition of the harvest will be included as part of a new assessment planned after the 2020 aerial survey.

In the current update, the same source material as used in the last assessment was used. Additional samples from hunters allowed some refinement of the proportions of EHB animals taken in the harvest, and in some case contributed to reducing the uncertainty associated with these estimates. Nonetheless, in some areas (e.g. Ungava Bay) samples sizes remain too small to make inferences. Part of this is due to management activities which have restricted harvesting.

There was a noticeable increase in the proportion of EHB animals taken in the fall harvest from the northeast Hudson Bay region compared to the last assessment (44.5% vs 30.2%). Although uncertainty remains high due to a low sample size, harvests from this area now have the second highest proportion of EHB animals in their catch (Table 4). For the moment, harvests from this area are not considered to have a major impact, but numbers harvested in this zone should be monitored, since any increase will have an important impact on the EHB stock. Overall, the proportion of EHB animals in the Nunavik and Nunavut hunt was about 22% during 2017-2019. If samples from the Nunavut harvest are excluded, then this proportion increases slightly to 24%

The Sanikiluaq harvest is not managed under a quota system. Instead, this hunt continues to be managed using a Non-Quota Limitation approach, where harvesting is closed between mid-July and 1 September. Outside of the closed season, the proportion of EHB animals in the harvest is very low (<5%) and at current harvest levels very few EHB animals are taken.

The population model trajectory shows that the EHB stock continued to decline even after quotas were introduced in the mid-1980s, as catches of EHB animals remained high throughout this period (Figure 4). Since the early 2000s, there has been considerable effort to redirect harvesting towards the Hudson Strait, and limit harvesting in the eastern Hudson Bay Arc area. This succeeded in reducing the removal of EHB belugas and resulted in stabilisation or a slight increase in the stock to an estimated abundance of 3,400 animals (Figure 4) (Hammill et al. 2017; DFO 2018). The current modeling effort that incorporated more recent harvests and genetics information, indicates that the population is stable or may have declined slightly since the last review from 3400 to 3300 animals. The 2017-2020 management objective for this stock is to set harvest levels such that the probability of decline in abundance from 3,400 animals is 50% or less. Under the management plan the TAT was set at 68 animals, including harvests by Sanikiluaq (Nunavut). However, reported harvests of EHB animals were 70, 74, and 98 in 2017, 2018, and 2019 respectively. Harvests in Sanikiluaq account for one to two animals in each year, the remaining animals were taken in Nunavik. To meet the management objective that there is a 50% probability that the EHB beluga population numbers 3,400 or more animals, the annual Total Allowable Take (TAT), including harvests in Sanikiluaq would be 58 animals if evaluated over a 5 year timeframe, or 62 belugas if evaluated over a 10 year timeframe. The differences reflect the greater time for the extrapolation. The 5 year timeframe is more appropriate since it is more in line with the duration of the management cycle. Also, the longer the projection the greater the uncertainty in whether model assumptions continue to be valid. ..

Considerable scientific and traditional knowledge exists for the management of this stock, particularly when considered within the context of other marine mammal stocks assessed by the Department. This information has enabled managers to respect the rights of harvesters and to stabilise the stock. Using Bayesian methods in the population model allowed us to explicitly incorporate uncertainty around model parameters (Wade 2000), which are represented in the model by using stochastic distributions instead of single values. Bayesian fitting also ensured that uncertainty was propagated throughout the analysis, and that the correlations among parameters were preserved (Hoyle and Maunder 2004). However, there remains uncertainty that is poorly understood, associated with some of the information that has been collected and its impact on the management approach. For example, we have outlined above the need to re-examine the source definition of the EHB stock and new abundance information is needed since the last aerial survey was flown in 2015. Additional uncertainty related to the stock composition of the harvest is addressed to some extent by the hunter supported sampling program and within the framework of the Bayesian model, but additional work is needed to address uncertainty associated with the age structure of the harvest, maximum rate of increase, struck and loss and process error. Hunters have provided a tooth from their harvests, which, along with genetic sexing could be used to model the age/sex structure of the catch. We know little of the dynamics of this stock, but additional sampling from the harvests might provide insights into demographic parameters such as age specific productivity.

The model estimates a S&L rate of 39%, with only minimal updating from the prior. This value lies at the upper end of the range of values found in the literature that are more frequently associated with harvesting practices where animals are not harpooned first (see above). More information is needed to determine if this might the case in Nunavik, but the S&L value estimated by the model also includes non-reporting of harvests, which is often not considered in most published studies. If S&L is more in line with observations from other studies (i.e. ~20%) and the remainder is due to non-reporting, then this represents a significant source of undocumented mortality. More information on S&L and greater compliance in reporting would reduce uncertainty associated with modeling the dynamics of this stock.

The process error term was included in the model to account for variability in the dynamics of the population. Here, we have assumed that beluga dynamics show little inter-annual variability in population vital rates (i.e. survival and fecundity). However, we have recently seen in other stocks (e.g. harp seals), that recruitment and mortality may vary significantly between years due to variability in ice and food resource conditions. We have less information on variability in demographic rates of beluga, but the uncertainty associated with this parameter may need to be re-examined.

Table 6. Impacts of different levels of harvest on the EHB stock over 5 to 30 years using a SY management framework to maintain the population at 3,400. The TAT is set to have a 50% probability for the population being above 3400 animals during 5 to 30 years. Additional scenarios assumed a two year harvest for 2020 and 2021, of 100, 125 or 150 EHB belugas followed by a TAT associated with a 50% probability that the population is 3400 or more animals during 5 to 30 years. All estimates were rounded to the nearest 100.

Scenario	Estimated population in 2019	TAT for 5 years	TAT for 10 years	TAT for 15 years	TAT for 20 years	TAT for 25 years	TAT for 30 years
Current approach	3300	58	62	66	66	66	66
(harvest 2020-21)	Estimated population in 2021	-	-	-	-	-	-
100	3200	42	52	58	60	62	62
125	3200	32	50	56	58	58	60
150	3100	22	44	52	54	56	58

The harvesting of Nunavik beluga has been limited by a TAT since the mid-1980s. This framework has resulted in stabilisation of the herd, but has not allowed for recovery to previous abundances. While the beluga population has stabilised, pressure to harvest has increased due to a combination of an increasing harvester population (the Nunavik population increased by 30% between 2006 and 2016; Levesque and Duhaime 2019) and an increased interest to move towards more local and regional management of beluga harvesting in Nunavik as allowed under the Land Claims Agreement (NILCA 2008). During this transition to a new management framework, harvests are likely to fluctuate as a new approach is implemented, with different impacts on the EHB stock (Table 6, Figure 6). If the new approach does not respect the current management objectives, the stock may decline in the short-term unless harvest levels of EHB animals are reduced (Figures 5, 6). An alternative to this framework is to set short, medium and long-term management objectives that identify critical population size where harvesting must be limited, establish the risk levels that will be tolerated before triggering a management response, and establish a timeframe leading to the recovery of this stock.

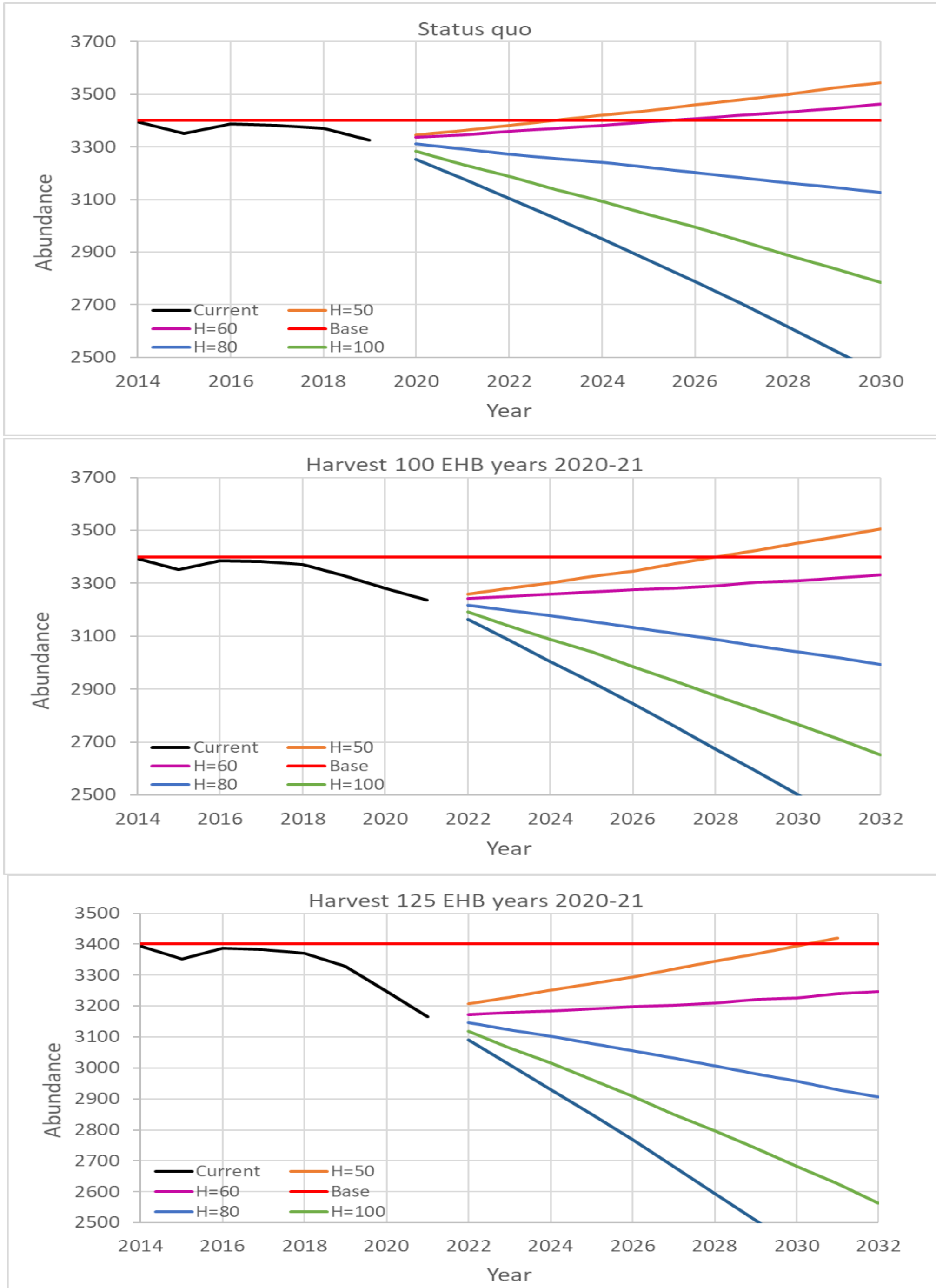

Figure 6. Estimated impacts of different harvest strategies on trends in EHB beluga abundance. The objective is to maintain the stock at or above 3,400 animals (Base)(red). The top panel represents the estimated 2014-2019 abundance with reported EHB harvests for 2014-2019. The expected trajectories for the population under different harvest levels (H) of 50, 60, 80 or 100 EHB animals are presented starting in the year 2020. The middle panel uses the 2014-2019 trajectory and assumes that 100 EHB animals will be harvested in 2020 and 2021. The expected trajectories for the population under different harvest levels (H) of 50, 60, 80 or 100 EHB animals are presented starting in the year 2022. The bottom panel is similar to the middle panel, but assumes that 125 EHB belugas are harvested in 2020 and 2021. The expected trajectories for the population under different harvest levels (H) of 50, 60, 80 or 100 EHB animals are presented starting in the year 2022 for this scenario.

The management of beluga harvesting in Nunavik is complex because harvesting impacts four different beluga stocks of differing conservation status, and involves 15 communities in two jurisdictions. The current management framework has succeeded in stabilising the EHB stock by directing harvesting towards the large WHB stock. The current PBR for the WHB stock is 753 animals (F_R=0.75), with total removals of 584 animals in 2015 (Hammill et al. 2017). This leaves some scope for increasing harvests of WHB animals by Nunavik hunters, although at some point harvests may reach levels requiring more stakeholder groups to become involved in beluga management. While such limits are unlikely to be reached for some time, alternative approaches to limiting harvests need to be considered.

The United States (USA) expects countries exporting fish products into the United States market to develop marine mammal monitoring systems and sustainable removals that are comparable to those currently in place in that country by 2021. In the US, PBR is considered to be a sustainable level of removals. In eastern Hudson Strait and neighbouring waters there are commercial shrimp and turbot fisheries, although beluga are currently not considered at risk of bycatch in these fisheries. The PBR for the EHB stock would be 14 animals, which is much lower than a suggested TAT of 58 animals (including Sanikiluaq). The differences between the two estimates reflects the differences in management objectives of the two approaches. The current management objective for EHB belugas is to set harvest levels such that the probability of a decline in the population below 3,400 animals does not exceed 50%. The management objective of the PBR approach is to identify harvest levels that have a 95% probability of the population being above the Maximum Net Productivity Level, over a period of 100 years (Wade 1998).

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APPENDIX

Appendix 1, Table 1. Reported harvests from communities in Nunavik and from Sanikiluaq (Nunavut). for Sanikiluaq the average of the 2017 and 2018 harvests was used for 2019. The ARC represents the communities of Kuujjuarapik, Umiujaq and Inukjuak. HSUB represents an early period where Hudson Strait and Ungava Bay catches were combined. SAN is Sanikiluaq. spring and fall represent are reported catches from the Hudson Strait area in spring (1 february-31 august) and fall (1 September-31 January). UBSP and UBFA are Ungava Bay spring and fall, respectively. NEHBSP and NEHBFA are northeastern Hudson Bay spring and fall, respectively (Hammill et al. 2017).

YEAR	ARC	HSUB	SAN	SPRING	FALL	UBSP	UBFA	NEHBSP	NEHBFA	Total
1974	184	421	0	0	0	0	0	0	0	605
1975	224	586	0	0	0	0	0	0	0	810
1976	216	463	0	0	0	0	0	0	0	679
1977	269	554	14	0	0	0	0	0	0	823
1978	164	243	6	0	0	0	0	0	0	407
1979	271	293	0	0	0	0	0	0	0	564
1980	280	281	0	0	0	0	0	0	0	561
1981	97	236	6	0	0	0	0	0	0	333
1982	114	271	30	0	0	0	0	0	0	385
1983	105	227	7	0	0	0	0	0	0	332
1984	131	189	28	0	0	0	0	0	0	320
1985	103	166	5	0	0	0	0	0	0	269
1986	43	126	25	0	0	0	0	0	0	169
1987	53	125	28	0	0	0	0	0	0	178
1988	52	117	20	0	0	0	0	0	0	169
1989	84	284	19	0	0	0	0	0	0	368
1990	53	109	20	0	0	0	0	0	0	162
1991	106	178	22	0	0	0	0	0	0	284
1992	78	96	20	0	0	0	0	0	0	174
1993	67	189	10	0	0	0	0	0	0	256
1994	82	207	50	0	0	0	0	0	0	289
1995	55	221	30	0	0	0	0	0	0	276
1996	56	211	30	0	0	0	0	0	0	267
1997	51	239	19	0	0	0	0	0	0	290
1998	50	252	54	0	0	0	0	0	0	302
1999	57	238	32	0	0	0	0	0	0	295

YEAR	ARC	HSUB	SAN	SPRING	FALL	UBSP	UBFA	NEHBSP	NEHBFA	Total
2000	62	208	23	0	0	0	0	0	0	270
2001	73	241	27	0	0	66	0	0	0	380
2002	5	161	15	0	0	23	0	0	0	189
2003	8	168	80	0	0	26	0	0	0	202
2004	3	144	94	0	0	4	0	0	0	151
2005	1	172	53	0	0	5	0	0	0	178
2006	0	147	22	0	0	2	0	0	0	149
2007	21	165	24	0	0	6	0	0	0	192
2008	23	92	33	0	0	5	0	0	0	120
2009	21	0	34	68	70	6	0	0	0	165
2010	16	0	47	138	61	8	7	0	0	230
2011	19	0	32	115	86	0	17	0	0	237
2012	13	0	61	208	56	10	2	0	0	289
2013	8	0	76	150	90	8	0	0	0	256
2014	22	0	26	208	37	11	0	1	14	293
2015	36	0	170	106	94	28	3	0	30	297
2016	17	0	43	121	19	24	3	0	3	187
2017	18	0	30	150	85	23	4	0	13	293
2018	14	0	50	146	91	100	2	2	17	372
2019	35	0	40	144	110	23	2	2	24	340