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Abundance of Eastern Hudson Bay belugas

Évaluation de l'abondance des belugas de l'est de la Baie d'Hudson

Mike O. Hammill
Véronique Lesage
Jean-François Gosselin

Fisheries and Oceans Canada
Maurice Lamontagne Institute
P.O. Box 1000, 850 route de la Mer
Mont-Joli, QC G5H 3Z4

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ABSTRACT

A population model was used to follow changes in the eastern Hudson Bay (EHB) beluga population since 1985. The model incorporating harvest information was fitted to aerial survey data by adjusting initial population size and estimates of the number of animals struck, but not reported. The number of belugas in eastern Hudson Bay has declined from approximately 4,200 (SE=300) animals in 1985 to 3,100 (SE=800) in 2004. In order to achieve this fit, 1.67 animals are estimated to be lost for every animal reported in the harvest. Overall harvest rates have declined under the current management plan. The rate of decline in this population has also likely slowed. To halt the decline, a reported harvest rates must be reduced to 61 animals (replacement yield).

RÉSUMÉ

Un modèle de population a été utilisé afin de suivre l'évolution de la population de bélugas de l'est de la Baie d'Hudson depuis 1985. Le modèle incorporant les informations concernant la chasse a été lié aux données d'inventaires aériens en ajustant la taille de la population initiale et les estimations du nombre d'animaux qui ont été blessés mais non récupérés. Le nombre de bélugas de l'est de la Baie d'Hudson aurait décliné d'approximativement 4,200 (SE=300) individus en 1985 à 3,100 (SE=800) en 2004. Pour qu'une telle tendance soit obtenue, on estime à 1.67 le nombre de belugas qui ont été perdus pour chaque animal déclaré tué. Globalement, les niveaux de chasse ont diminué dans le contexte des plans de gestion en place. Le taux de déclin de la population a probablement également ralenti. Afin de stopper le déclin, le niveau de chasse déclaré doit être réduit à 61 animaux (taux de remplacement).

INTRODUCTION

Systematic aerial surveys flown in the mid-1980's to assess beluga (*Delphinapterus leucas*) abundance along the Ungava and Hudson Bay coast of Quebec (Smith and Hammill 1986) led to limits placed on harvesting through a combination of quotas, and seasonal and regional closures to allow the stocks to recover (Reeves and Mitchell 1989). Concern for belugas in the waters adjoining Nunavik also led COSEWIC (Committee on the Status of Endangered Wildlife in Canada) to designate belugas in Ungava Bay as 'Endangered', and EHB belugas as 'Threatened' (Reeves and Mitchell 1989). The status of these stocks has recently been re-examined and both the eastern Hudson Bay (EHB) and Ungava Bay (UB) populations have been designated as 'Endangered' (COSEWIC). Continued subsistence hunting underlines a need to monitor changes in the EHB beluga population.

In this study, we fitted a population model to the aerial survey estimates, incorporating information on numbers of animals harvested and the stock composition of the harvest to monitor changes in the population over time within the context of challenges to managing a small beluga population subjected to a subsistence harvest.

MATERIALS AND METHODS

Changes in population size over time were examined using a discrete time parameterisation of the Pella and Tomlinson model (1969; Innes and Stewart 2002), where the estimated population size (N_{t+1}) at time t+1, is described by:

$$N_{t+1}=N_t+ N_t (\lambda_{max}-1)(1-(N_t /N_{1854})^{\theta})-b H_t$$

N_t is the population size at time t, N_{1854} estimated pristine population size in 1854 and θ is a shaping parameter of the density dependent response. λ_{max} is the maximum rate of increase, H_t is the reported harvest by the 14 villages in Nunavik, and the village of Sanikilluaq in Nunavut, which includes eastern Hudson Bay, Hudson Strait and Ungava Bay and b is a parameter to account for animals struck and lost. This term also includes animals that were wounded or killed, but not recovered and reported.

Index estimates for the eastern Hudson Bay population are available from aerial surveys flown in 1985, 1993, 2001 and 2004 (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin 2005). Correction factors were required to adjust the aerial survey numbers to account for animals not visible (diving), when the survey plane passed overhead. We used an estimated proportion (P_0) of animals visible from an aerial survey platform of 0.478 (SE 0.0625), which was developed from vertical overflight experiments in the St. Lawrence River estuary (Kingsley and Gauthier 2002). This area has similar visibility conditions to what we often observe in Hudson Bay. This parameter was assumed to follow a normal distribution, and was used here to obtain an estimate of population size (*N*), by correcting abundance estimates obtained from the line-transect surveys (N_{survey}). Belugas detected in estuaries ($N_{estuary}$) were assumed to represent total counts:

$$N_t = N_{survey} / P_0 + N_{estuary}$$

The variances for the correction factor and survey estimate combined assumes that N_{uncor} and P_i are independent and therefore the error variance of the quotient is given by (Mood et al. 1974):

$$V_i = N_{uncor}^2 \times V_p / P_i^4 + V_n / P_i^2$$

where:
V_p = the variance in the proportion estimated to have been present prior to survey *i*;
V_n = the variance in the uncorrected estimate for survey *i*.

Belugas are characterised by early reproduction (age 4-7 years), low reproductive rates (crude birth rate: 0.26-0.47) and a long lifespan (longevity = 35 years) (Sergeant 1973; Burns and Seaman 1985; Doidge 1990; Kingsley *et al.* 1995). Little information is available on the maximum natural rate of increase (λ_{max}) , but rates of increase of 1.026 to 1.037 have been suggested (Kingsley *et al.* 1995; Doidge 1990; Innes and Stewart 2002), which are similar to rates of 1.02 to 1.04 for species with similar life histories, such as Narwhal, pilot whale and spotted dolphin (Kingsley 1989; Barlow and Boveng 1991; Kasuya et al. 1988). Therefore, λ_{max} in the model was described by a Uniform distribution, which varied between 1.02 and 1.04.

Commercial harvesting of EHB belugas conducted by the Hudson Bay Company, began as early as the 1750s, but most effort was expended between the 1850s and 1860s (Reeves and Mitchell 1987b). Mitchell and Reeves (1987b) suggested that the minimum EHB population size could have been around 6,600–7,875 animals. These estimates may still be conservative owing to the incompleteness of the records (Reeves and Mitchell 1987b) and the fact that subsistence harvests of EHB animals by Inuit living along the EHB coast and in Hudson Strait were not incorporated into the calculations. We re-examined the estimate of pristine population size, using the Pella and Tomlinson model outlined above. We included the reported catch and adjusted the pristine population size so that at the end of the harvest period, there remained a minimum population of 1000 animals, as suggested by Reeves and Mitchell (1987b) (Table 1). We adjusted the struck and loss term between 1, 1.5 and 2. Theta (θ) was set at either 1 or at 4 and the maximum rate of increase was fixed at 0.04. This resulted in a series of estimates. We took the mean resulting in a mean pristine population estimate of 12,472 (range 8,447–17,117). Theta (θ) is a shaping parameter that describes where the maximum net productivity level occurs. This parameter was described by a uniform distribution lying between 1.17 and 7.14 (Innes and Stewart 2002).

Catch statistics are available from each of the communities since 1985 (Lesage et al. 2001; Lesage and Doidge 2005). Under the current management plan (2002–2004), the eastern Hudson Bay area, including the EHB arc is closed to hunting to Nunavik hunters. Hunters from the EHB arc (Inujjuaq, Umiujaq, Kuujjuaraapik) are to hunt either in Hudson Strait or to the south of the Long Island area, whereas Puvirnituq and Akulivik are to hunt in Hudson Strait. Therefore, catches from the EHB communities have been excluded, unless other information indicates that these animals belong to the EHB population.

Modeling of the trajectory of the eastern Hudson Bay population required that each beluga harvested by the Nunavik communities be assigned to a particular stock. Belugas in Hudson Bay were initially divided into stocks based on their summer distributions (Reeves and Mitchell 1987b). However, in order to gain a better understanding of the genetic structure of beluga stocks in Hudson Bay, a sampling program has been in operation in Nunavik since 1993. A similar program has also operated in several Nunavut beluga harvesting communities, including Sanikilluaq in Hudson Bay and Hudson Strait. Hunters were to provide a tooth for aging, and skin sample for molecular genetic analyses. These mitochondrial DNA analyses support the division between an EHB stock centered around the Hudson Bay arc and a WHB population encompassing one or several stocks from elsewhere in Hudson Bay (Brennin et al. 1997; Brown Gladden et al. 1997, 1999; de March et al. 2001; de March and Postma 2003) (Fig. 1). The latter study also indicated that Hudson Strait communities harvest beluga from different stocks (de March and Postma 2003). Unfortunately, too few samples were obtained from belugas in Ungava Bay and James Bay to clarify the population relationships of these animals to other belugas in Hudson Bay.

Given the variable and in some years, low participation in the sampling program, some assumptions were made regarding the assignment of harvested individuals to putative stocks. Catches from the EHB arc communities prior to 2002 were all assumed to be part of the EHB population Catches by Puvirnituq were assigned differently, depending on whether the harvest took place prior to or after 1995 since this community has drastically changed their hunting patterns over time. Prior to 1995, Puvirnituq hunted largely at the Nastapoka River, but since then, has shifted most of their hunting effort towards Hudson Strait (Lesage and Doidge 2005). Therefore, prior to 1995, all of the harvest by Puvirnituq was attributed to the EHB area, whereas in 1995 and subsequent years, all of the harvest was assumed to have been taken near Ivujivik. A second village in this area, Akulivik is also assumed to harvest near Ivujivik. The proportion of EHB animals in the harvest of the communities harvesting from Hudson Strait or Ungava Bay was obtained from mitochondrial DNA analysis of extended haplotypes (how many base pairs) of beluga sampled between 1997 and 2003. Probability of assignment of an individual to a particular stock was based on the haplotype composition of beluga harvested in the different areas (Hammill et al. 2004). The contribution of EHB animals to the harvest was described by a Binomial distribution (Bin (p, n)) where p is the estimated mean proportion and n is the number of animals harvested from that area in year (t)(Hammill et al. 2004).

Harvest statistics are based on verbal reports to a community agent during the hunting season (Lesage et al. 2001; Lesage and Doidge 2005). Hunters are supposed to report the numbers of animals that are struck and lost, but the bias accuracy of these reports is not known. A parameter for non-reporting (*b*) was included in the model, but was constrained to lie between 1 and 4 (Innes and Stewart 2002).

Changes in estimated population size of EHB belugas were determined by fitting the model to the 1985, 1993, 2001 and 2004 aerial survey estimates (corrected for diving animals). The difference between the model estimates and the aerial survey estimates were minimized by adjusting the 1985 population size, which represents the start of the modelling period and *b*, the struck-and-lost parameter (Risk Optimizer, Palisade Corporation, Newfield, NY, USA). The algorithm operated as follows: 1) select values for the 1985 population size and for struck-and-lost (b); 2) sample from the assigned distributions for each input variable; 3) calculate the population trajectories and the sum of squares for the trajectory; 4) repeat steps 2 and 3, 500 times; 5) calculate the mean of the sum of squares (MSS) for the 200 iterations; 6) repeat steps 4 and 5, 1000 times. After 5000 simulations, the values for the 1985 population size and b, in the model, which generated the smallest MSS were retained. The expected impacts of continued hunting at current levels, and estimates of acceptable harvest levels that would result in no change in the population size (replacement yields) were examined by re-running the model (N=5,000), keeping the 1985 population size, estimated above by the model fixed, but allowing the struck-and-lost term to vary by assuming a normal distribution with mean equal to the fitted value and a coefficient of variation for this term of 30%. Other parameters in the model were allowed to vary according to the statistical distributions defined above for each variable. For each run of the model, values from the sample distributions were drawn (latin hypercube) and a population trajectory was calculated (@Risk; Palisade Corporation, Newfield, NY, USA). A sensitivity analysis, which used a rank correlation analysis, was conducted to estimate the correlation between the model output and each set of sampled input values. Sensitivity of the model to changes in input values are correlated with the magnitude of the changes in the output values.

RESULTS

Genetic samples have been obtained from less than a third of the animals reported harvested in Hudson Strait and Ungava Bay since 1997 (Fig. 2). Hunters provided samples from about 24% of the reported harvest in Hudson Strait and 16% of the harvest from Ungava Bay. There is considerable inter-annual variability in the number of EHB animals in the harvests from Hudson Strait and Ungava Bay. Since 1997, 12.6% (SE=13.4, N=80) and 21.2% (SE=14.6, N=269) of the animals harvested in Ungava Bay and Hudson Strait, respectively have been EHB animals (Fig. 3). Data from Sanikiluaq, collected between1990-2004 in Nunavut indicate that 11.5% (SE=0.03, N=108) of the animals in the harvest from that community are from the EHB population. Assuming that since 1985, harvests by Nunavik communities in the EHB arc are EHB animals, and that the proportion of EHB animals in the harvests from other communities has not changed since the beginning of the modelling period (ie 1985), then on average 35% (SD=8.1) of the harvest consisted of EHB beluga. Closure of EHB to harvesting since 2002 led to a decline in the proportion of EHB animals in the harvest to about 23% (SD=4.6) (Fig. 4). Total reported harvests were as high as 417 belugas in 2001, including the Sanikiluaq harvest, of which 123 whales would have belonged to the EHB stock. Total reported harvests declined to 193 belugas in 2004, of which an estimated 37 belonged to the EHB population.

The population model was fitted to the EHB aerial survey estimates from the DISTANCE analyses (Gosselin 2005) (Table 2). The aerial survey estimates were corrected for diving animals (taking into account the SE of the correction factor) resulting in survey estimates of 4,278 (SE=728), 2727 (SE=1,083), 2,922 (SE=1,381), and 4,269 (SE=1,563) for 1985, 1993, 2001 and 2004 respectively. For the 1985 survey, it was assumed that the coefficient of variability (cv) for the line transect estimates was similar to the cv from the strip transect aerial survey estimates. The model estimated a struck-and-lost value (b) of 1.67, and had a population size of 4,200 (SE=300) in 1985 (Fig. 5). The model indicated that the population has declined to a mean estimate of 3,100 (SE=800)(rounded to the nearest 100) in 2004. When the model is run using the original estimate of pristine population size (N_{1854}=7,875; Hammill et al. 2004), the model estimated a struck-and-lost value (b) of 1.65, and the population declined to 3,000 (SE=700).

However, there is considerable uncertainty associated with model outputs, as shown by the large standard errors associated with the predicted trajectory. Replacement yield defined as the reported number of animals that can be harvested over a short period of time, e.g., 5 years, that will result in no net decline in estimated median population size would be 61 (Fig. 6). After 5 years, the estimated population would remain at around 3,100 animals (rounded to the nearest 100) with a very large standard error around this estimate (SE=1000).

Model outputs were most sensitive to changes in the struck-and-lost factor (Rank correlation=-0.82), the rate of increase (Rank correlation=0.34), and the correction factor applied to the aerial survey estimates to correct for diving animals (Rank correlation=0.31), while changes in population estimates were weakly correlated to theta, the density-dependent shaping parameter (Rank correlation=0.191) (Fig. 7).

DISCUSSION

In this study, the survey estimates were multiplied by 2.09 (reciprocal of 0.478) to account for availability bias (Kingsley and Gauthier 2002). This correction factor is within the range of factors of 180–290% suggested from satellite telemetry studies that have provided dive information (see Kingsley and Gauthier 2002) and is the same as a correction factor of 209% that can be derived from satellite transmitters deployed on belugas in Eastern Hudson Bay at the same time that our surveys were flown (Kingsley et al. 2001). It provides a minimum correction to aerial survey estimates because satellite transmitters have not been deployed on small belugas, which are less visible than adult animals (Kingsley and Gauthier 2002).

The model tracked the population decline since 1985, but the standard errors around the population trajectory are quite wide, indicating considerable uncertainty associated with current population size. Nonetheless, the EHB beluga population has declined from an estimated 4,200 (SE=300) animals (corrected for diving) in 1985, to 3,100 (SE=800) in 2004. Using the same model, but with only three aerial survey estimates, Hammill et al. (2004) estimated a 1985 population of 3743 (SE=286) animals, and a predicted 2004 estimate of 2400 (SE=800). Differences between the two studies result from the effects of the higher estimate of the pristine population, which results in a higher rate of increase owing to the impacts of the density dependent component of the model, and to the effects of the higher estimate from the 2004 aerial survey (Gosselin 2005).

Some of this uncertainty is also due to the very short time series to which the model was fitted. Our impressions of this population are based on only four aerial survey estimates since 1985. Additional uncertainty is associated with the population maximum rate of increase, the true form of the density dependent factor, the factor applied to correct for diving animals and estimates of struck and loss. We tried to account for some of this uncertainty by linking model parameters to defined statistical distributions, and re-sampling from these distributions during different model runs, instead of representing them by single values. This approach must only be viewed as approximations for Nunavik belugas, because the true values and distribution of the model parameters (λ_{max}, N_{1854}, θ, and b) are not known.

Model simulations showed that changes in the struck-and-lost parameter had the greatest impact on model predictions. This is not surprising since this parameter was adjusted to allow the model to fit to the observed aerial survey estimates. The parameter accounts for the number of whales removed from the population. In our treatment of this term, we have considered that this difference results from the failure of hunters to report all animals that have been killed. However, this term will also incorporate emigration from the population and takes into account errors in the estimated proportion of EHB animals in the reported harvest. The sensitivity of the model to this adjustment, points to one area where research is needed, either to improve estimates of the declared harvest or to reduce the number of whales struck and lost. This would also result in an increase in numbers of whales available to communities, without increasing overall harvest rates. Or conversely, a reduction in struck and loss rates could reduce the harvest impact on this population, without necessarily reducing the harvest through lower quotas.

Changes in θ, the shaping parameter of the density-dependent response had little impact on model output because the current population of around 3,100 belugas is quite small compared to our estimated pristine levels of 12,500 (SE=3,400; rounded to the nearest 100) animals.

Under the current management plan overall harvest rates have declined and the model suggests that the rate of decline in the Nunavik beluga population has also slowed. Replacement harvests of around 61 animals are slightly higher than those suggested in previous work (Hammill et al. 2004). If the population is to begin recovery, then harvests must be further reduced. We have not provided harvest guidelines to allow the population to recover, since this will be addressed at the Ottawa workshop in April 2005.

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Table 1. Documented catches from the Little whale River (LWR) and Great Whale River (GWR) commercial fisheries from Reeves and Mitchell (1987b).

Year	LWR harvest	GWR harvest	Total harvest
1854	423		423
1855	707		707
1856	743	4	747
1857	323	1043	1366
1858	16	1007	1023
1859	743	300	1043
1860		1511	1511
1861		30	30
1862		229	229
1863	8	788	796
Total			7875

Table 2. Aerial survey estimates of beluga populations in eastern Hudson Bay. The 1985 survey data were collected only using strip-transect techniques (Smith and Hammill 1986). The 1993 and 2001 surveys flew along the same lines as the 1985 surveys, but data were collected using line-transect techniques (Kingsley 2000; this study). These data were then analysed assuming a strip width of 1000 m on each side of the aircraft. The 1985 survey estimates then were adjusted by multiplying the strip-transect estimates by a line-transect-strip-transect ratio (Mean=1.87, SD=0.268) calculated using the 1993 and 2001 data analysed with DISTANCE and then adding in estuary counts in EHB of 474, 18, 39 and 5 for 1985, 1993, 2001 and 2004 respectively.

	Systematic offshore estimate	Abundance estimate	
Year	Strip-transect $\hat{N}_s$ (SE)	Strip-transect $\hat{N}_s$ (SE)	Distance line-transect (SE)
1985	968 (165)	1442 (165)	*2,294*
1993	688 (205)	706 (205)	1,314 (489)
2001	620 (263)	659 (263)	1,418 (635)
2004			2045 (698)

Minimum Evolution Tree of 94 E-Type Haplotypes

The former H-Type haplotype is descrtibed after the hyphen.

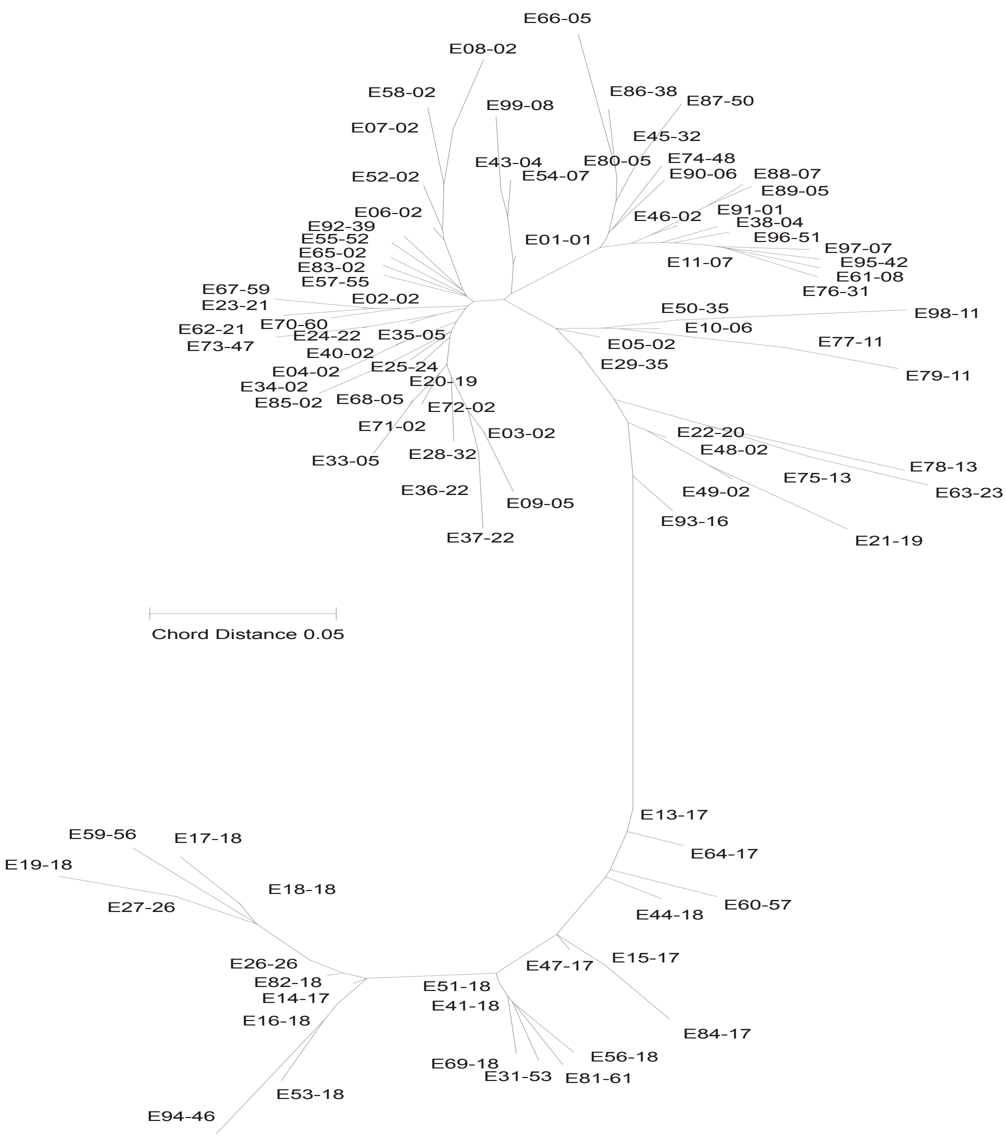
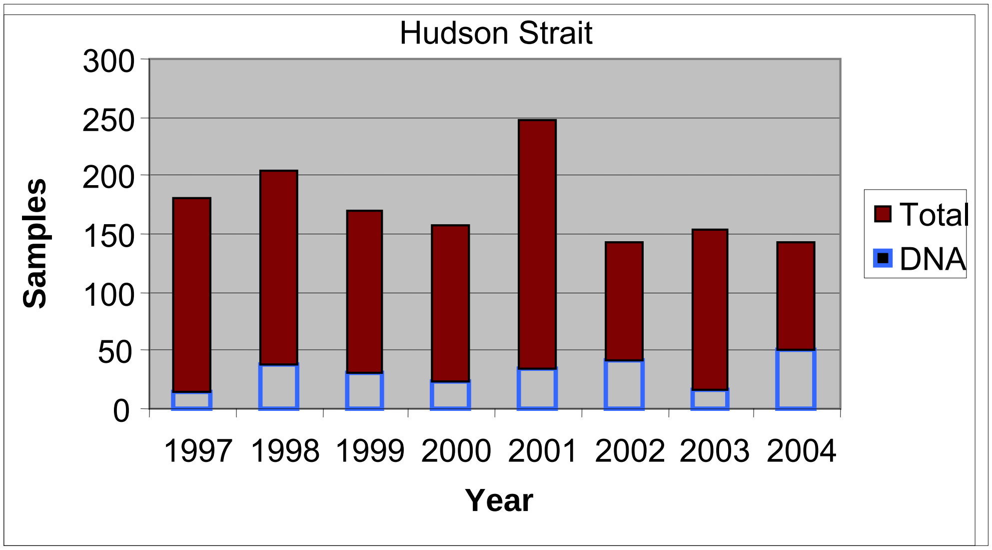


Figure 1. Diagram showing similarities among haplotypes used to distinguish non-EHB beluga (top half) from EHB beluga (bottom half) (Postma, DFO Winnipeg, unpublished).



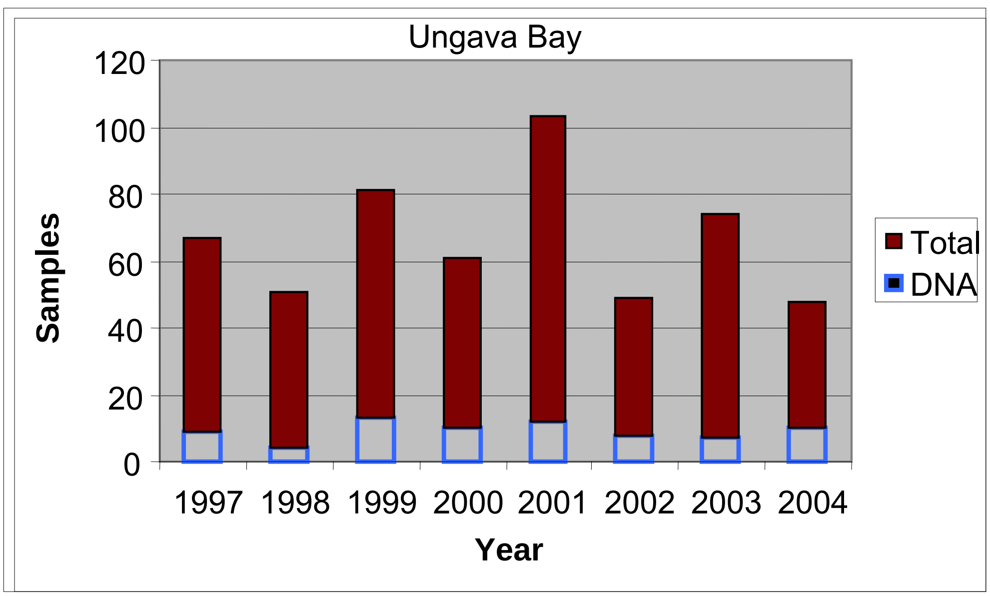
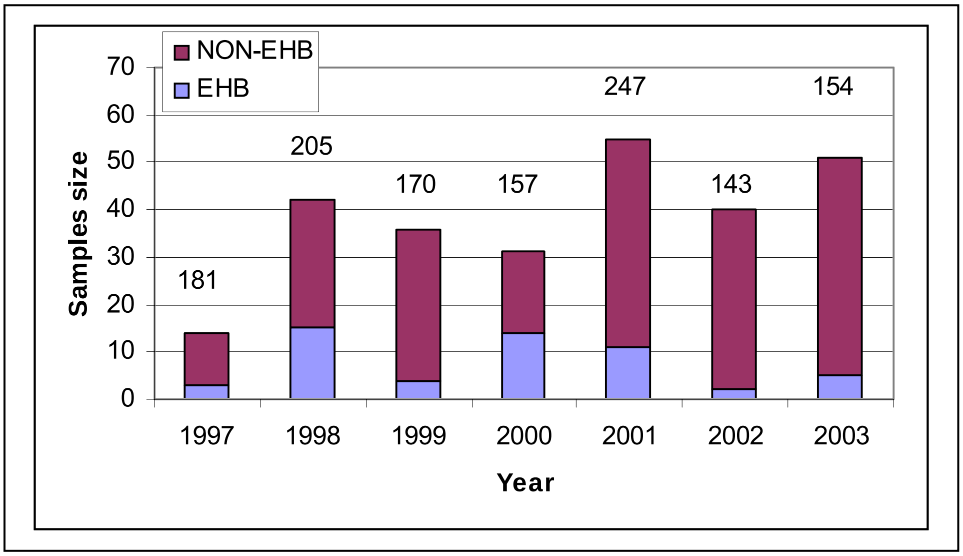


Figure 2. Number of DNA samples available and number of animals reported harvested in Hudson Strait (top) and from Ungava Bay (bottom).



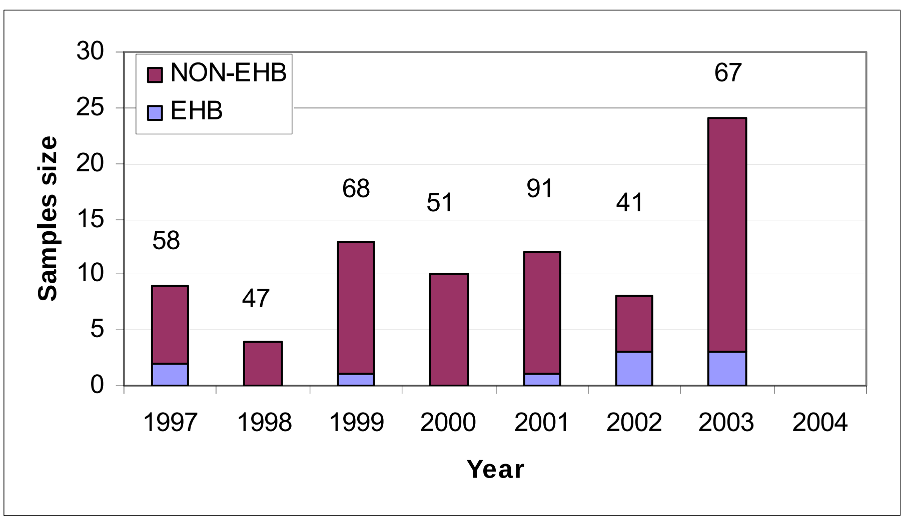


Figure 3. Number of EHB and non-EHB animals in samples obtained from hunters. Total reported harvests for the region are reported above columns. Top panel is for Hudson Strait, bottom panel refers to Ungava Bay.

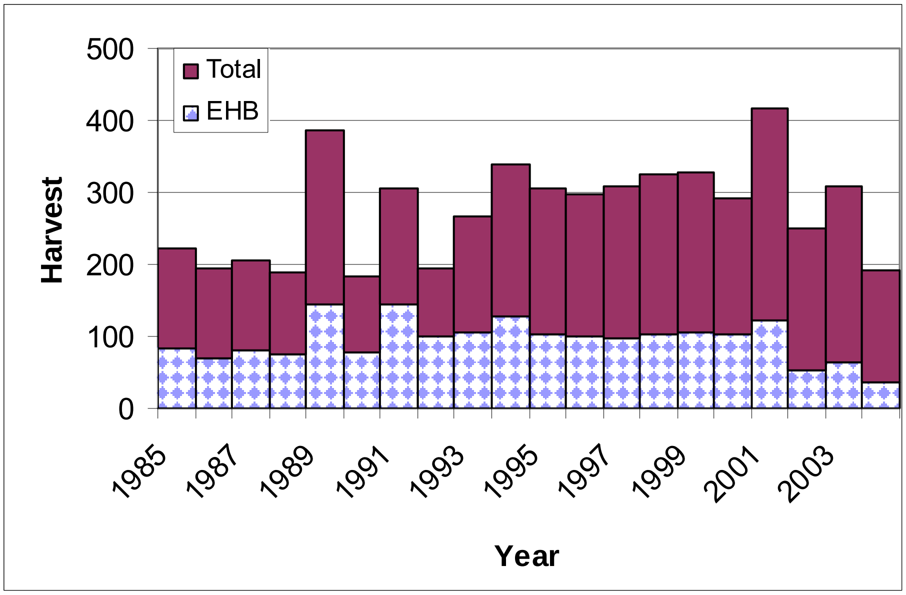


Figure 4. Total harvests and estimated number of EHB beluga harvested by Nunavik and Nunavut hunters, based on harvest statistics.

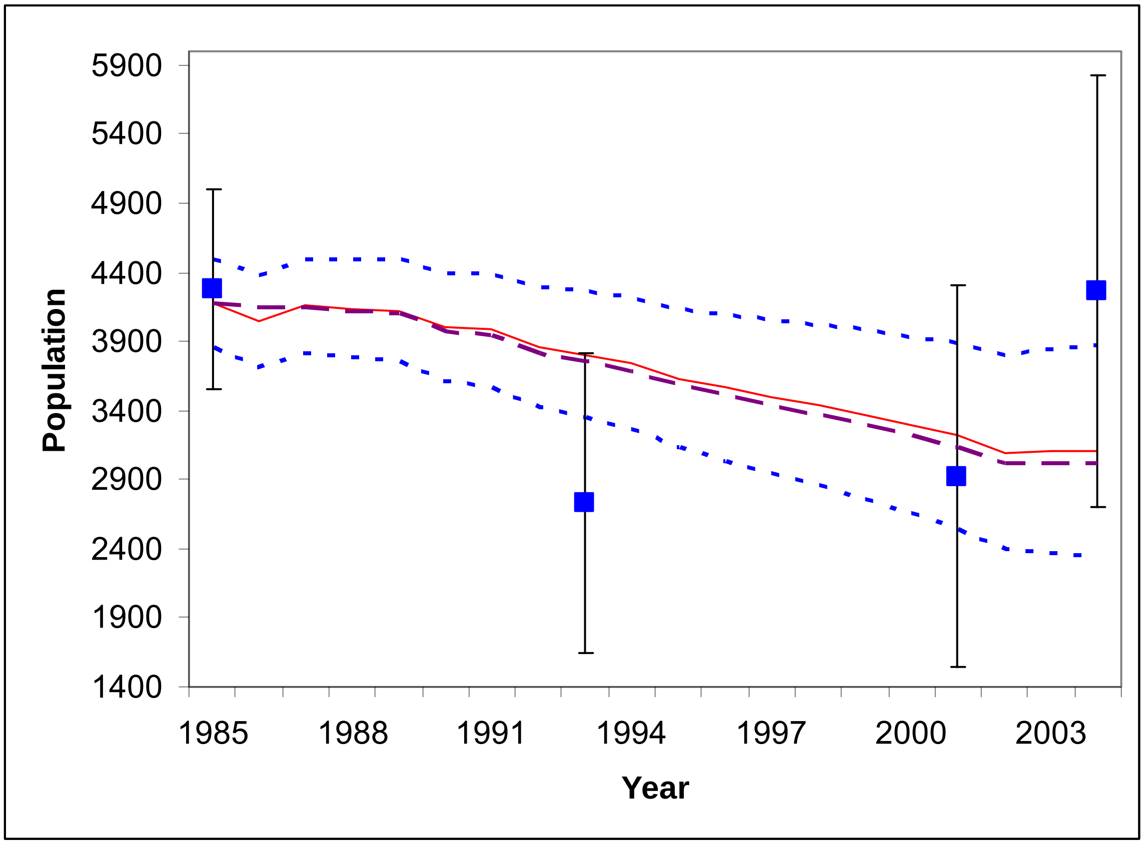


Figure 5. Aerial survey estimates corrected for diving animals and predicted trajectory (mean ± SE) of EHB beluga population from 1985 to 2004. Using two estimates of pristine population size N_{1854}=7,785 (dashed line) and N_{1854} =12,500 (solid line, mean ±SE). Points with error bars represent aerial survey estimates ±1SE).

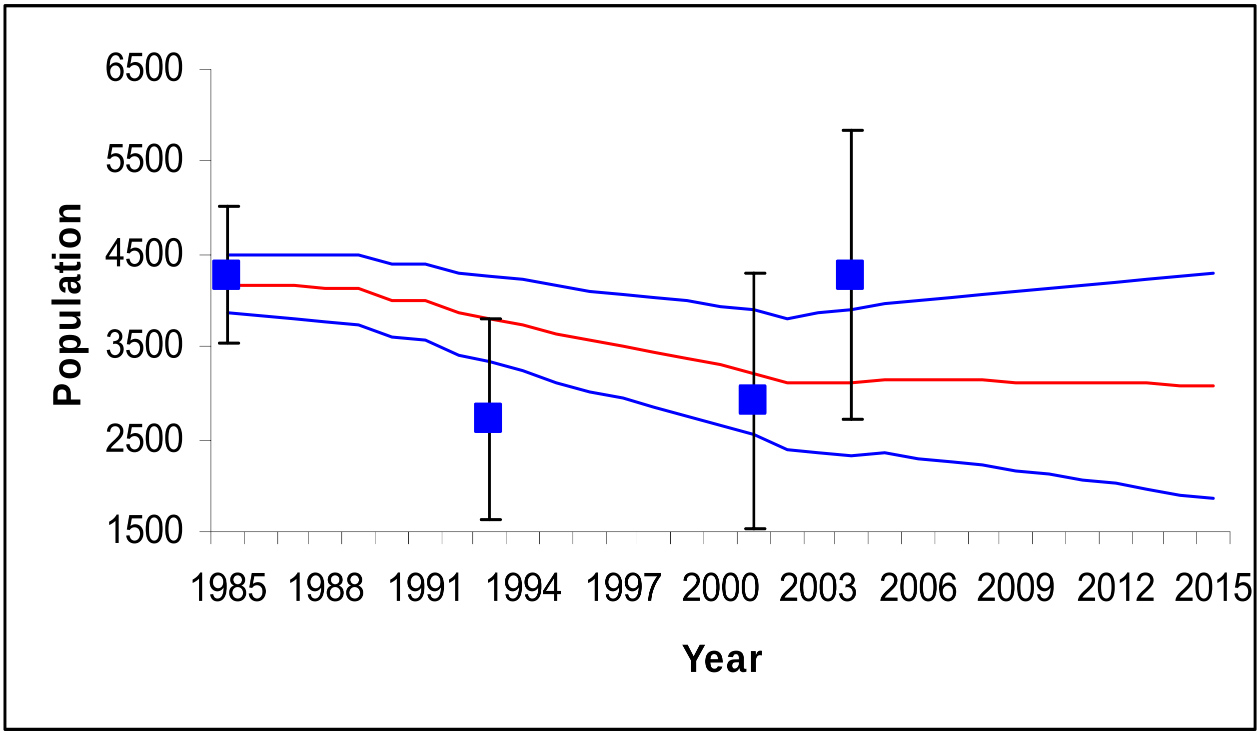


Figure 6. Aerial survey estimates, fitted model and predicted trajectory of EHB beluga population with a reported harvest of 61 EHB whales.

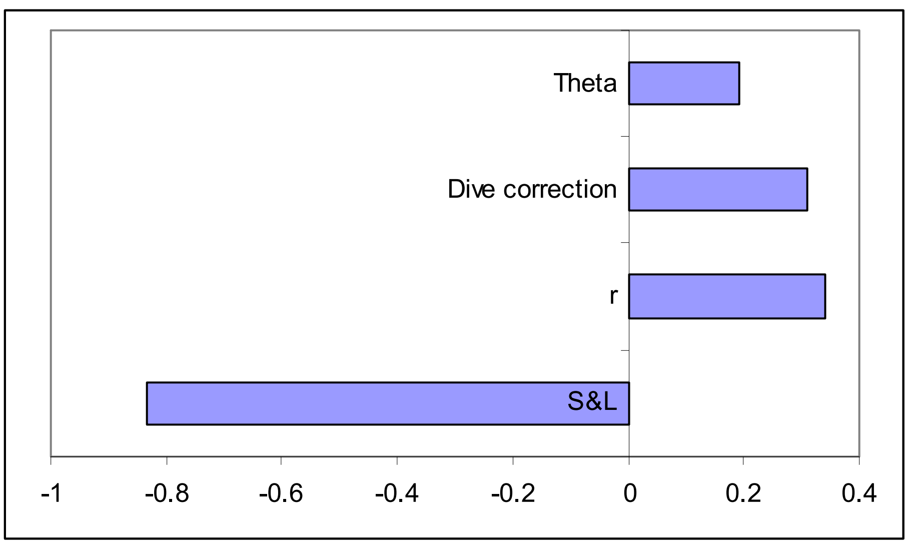


Figure 7. Sensitivity of model output to model parameters for rate of increase (r), the density dependent function (theta), the factor to correct survey estimates for whales below the surface (Dive correction), and the number of whales killed but not reported (S&L).