Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2009/009 / **Document de recherche 2009/009**

Abundance of Eastern Hudson Bay belugas

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

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

Correct citation for this publication:

Hammill, M. O. Kindsley, M. C. S. Lesage and Gosselin, J.-F. 2009. Abundance of Eastern Hudson Bay belugas. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/009. iv + 22 p.

ABSTRACT

In previous assessments a population model incorporating density-dependence as well as information on total catches has been fitted to estimates of beluga whale abundance obtained from aerial surveys. In this assessment, a simple exponential model, incorporating information on catches was also fitted to aerial survey estimates of abundance using Bayesian methods. During initial runs, both approaches gave similar results with an estimated 1985 population of 3,900 obtained using the old model, compared to an estimated 4, 100 obtained using the new model. In 2008, the estimated population has declined to 3,200 and 3,000 using the old and new models respectively. It is recommended that the model fitted using Bayesian methods be used in future assessments because the current population is much reduced from pristine levels, such that the effects of density dependent factors are expected to be limited, and the Bayesian approach presents a more rigorous approach to dealing with uncertainty concerning the dynamics of this population and is based on the full multivariate posterior distribution of the parameter estimates.

Traditionally, eastern Hudson Bay beluga whales have been made up 12%, 21% and 13% of the harvests from the Belcher Islands, Hudson Strait and Ungava Bay respectively. More recent analyses suggest that the proportion of eastern Hudson Bay animals in the spring Hudson Strait harvest is less than the proportion obtained from the fall harvest. Overall, the sample proportion of eastern Hudson Bay animals has declined to 9%. No changes were made to model assumptions because the seasonal distribution of samples collected for DNA analyses did not reflect the seasonal distribution of harvesting.

RÉSUMÉ

Au cours d'évaluations précédentes, un modèle de population intégrant des données fondées sur la densité ainsi que des données sur les captures totales a été adapté aux estimations de l'abondance des bélugas obtenues à partir de relevés aériens. Dans cette évaluation, un modèle exponentiel simple intégrant les données sur les captures a également été adapté aux estimations des relevés aériens de l'abondance en utilisant des méthodes bayésiennes. Dans les premières évaluations, les deux approches ont produit des résultats semblables. Selon l'ancien modèle, la population est estimée à 3 900 individus en 1985, comparativement à une population estimée à 4 100 individus selon le nouveau modèle. En 2008, la population estimée avait diminué pour atteindre 3 200 et 3 000 individus en utilisant respectivement l'ancien modèle et le nouveau. Il est recommandé d'utiliser le modèle adapté à l'aide des méthodes bayésiennes lors de futures évaluations, parce que la population actuelle est beaucoup plus petite par rapport aux niveaux d'origine de la population, de sorte que les effets des facteurs fondés sur la densité devraient être limités et que l'approche bayésienne offre une approche plus rigoureuse pour réduire l'incertitude concernant la dynamique de cette population et qu'est fondée sur la distribution postérieure complète à variables multiples des estimations de paramètres.

Traditionnellement, les bélugas de l'est de la baie d'Hudson représentaient respectivement 12 %, 21 % et 13 % des captures dans les îles Belcher, le détroit d'Hudson et la baie d'Ungava. Des analyses plus récentes donnent à penser que la proportion de bélugas de l'est de la baie d'Hudson lors de la capture du printemps dans le détroit d'Hudson est moindre que la proportion de bélugas capturés à l'automne. Dans l'ensemble, la proportion dans l'échantillon de bélugas de l'est de la baie d'Hudson a diminué de 9 %. Aucun changement n'a été apporté aux hypothèses des modèles parce que la distribution saisonnière des échantillons recueillis aux fins d'analyses de l'ADN n'a pas eu d'incidence sur la distribution saisonnière de la récolte.

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 restrictions 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 and Eastern Hudson Bay (EHB) belugas as 'Endangered' (COSEWIC 2004). Continued subsistence hunting underlines a need to monitor changes in the EHB beluga population.

Previous assessments have used a discrete-time parameterisation of the Pella-Tomlinson model to describe the dynamics of the EHB beluga population and to examine the impacts of different harvests on the future trends in the population. The model was fitted to a series of aerial survey estimates by adjusting the initial population size and a term for animals struck and lost. The model attempted to incorporate some uncertainty around the dynamics of this population by associating the parameters for theta, which describes the shape of the density dependence relationship, the correction factor for animals not visible at the surface and the aerial survey estimates with statistical functions. Samples are repeatedly drawn from these functions, and the model is fitted repeatedly until a suitable number of runs have been completed. This provides a series of struck-and-lost corrections and initial population sizes. Mean values for these variables and their associated uncertainty are incorporated into the model which is then run as a projection model to examine the impacts of future harvests on the trajectories of the population.

The current approach is relatively simple. It is possible to construct more complex stock-dynamic trajectory models that are stage- and sex-structured. These types of models are useful if two conditions are met. The first is that information on the stage- and sex-specific values of the parameters governing stock dynamics should be available, either as extraneous estimates or as informative data. The second is that population structure is expected to change over time, owing to changes in values of stock-dynamic parameters due for example to management measures, changes in exploitation rates, or natural variation. Otherwise, and especially if the available information on stock status consists principally of counts of total numbers, unstructured stock-production models are likely to be just as informative as structured models.

The data available for modelling the dynamics of the Nunavik beluga whale population are sparse and uncertain. The benefits of building complex models are therefore unclear, and model results will inevitably depend on the input of extraneous estimates of necessary parameters. Although the current population model has been useful in providing management advice, the present population is so much lower than historical levels a simple exponential growth model should be appropriate.

A simpler model was developed, based on a simple exponential-growth stock dynamic and fitted to the survey estimates using Bayesian methods. Bayesian fitting is well adapted to data-poor situations, allowing the incorporation of existing knowledge of parameter values, even if uncertain, and also accommodating conflicts between different uncertainties. Bayesian methods of fitting models have the advantage of allowing extraneous estimates to be input as prior distributions, while also permitting the data to refine parameter estimates by updating the prior to a different posterior distribution if the data contains information. Furthermore, predictions, and their estimated uncertainties, can be based on the full multivariate posterior distribution of the parameter estimates. This is a significant advantage in the present case where we are fitting to little data and parameter estimates are highly correlated.

Here, we fitted both population models 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

Previous assessment model

The model used in previous assessments (now referred to as ‘old model’) has been described elsewhere (Hammill et al. 2004). Briefly, changes in population size over time were examined using a discrete time parameterisation of the Pella and Tomlinson model (1969) 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.

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 other 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 set at 1.04. 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). The pristine population size, which is considered to represent the population at carrying capacity was set at 12,472 (DFO 2005).

Changes in estimated population size of EHB belugas were determined by minimizing the sum of squares differences between model predictions and the aerial survey estimates (corrected for diving animals), by adjusting the initial population size and *b*, the struck-and-lost parameter (Risk Optimizer, Palisade Corporation, Newfield, NY, USA). Two thousand simulations were fitted to obtain a sample of initial population sizes and struck and lost factors. The expected impacts of continued hunting were examined by entering as a function into the model the estimated mean initial population size and struck and loss values and projecting population trajectories over the next 10 years (@Risk; Palisade Corporation, Newfield, NY, USA).

Model fitted using Bayesian methods

The model fitted using Bayesian methods (referred to as ‘new model’) was built as a simple stock-production model. It was fitted by Bayesian methods, so prior information on, or guesses as to, the values of stock-dynamic parameters were included as prior distributions.

Numbers in each year were a constant multiple of the previous year’s, with removals deducted:

$$N_t = N_{t-1} \cdot \exp(r) \cdot \varepsilon 1_t - R_t$$

The instantaneous rate of growth, *r*, was given a Normal prior with mean 0.03 and standard deviation 0.1, but limited to the range –0.1 – +0.3. Process error terms *ε1* were lognormally distributed with zero mean and uniform variance in log space. The sparse survey data tells us nothing about the process error, and an informative prior was assigned for the precision[1] parameter of the lognormal distribution with CV quartiles at 5.5% and 8.7%.

Removals were calculated as catches corrected for animals struck and lost.

$$R_t = C_t \cdot (1 + SL)$$

where the struck-and-lost correction *SL* was given a moderately informative log-normal prior[2] with quartile points at 0.43 and 0.85.

Survey catchability was assumed to be 1, and survey estimates were linked to population size by a multiplicative error term

$$\ln(S_t) = \ln(N_t) + \varepsilon 2_t$$

where the error terms *ε* were normally distributed with mean zero and the ‘precision’ was given a moderately informative prior, gamma(2.5,0.4) with quartiles approximately equivalent to survey c.v.s of 35% and 55%; approximate symmetrical 95% CI on the c.v. 24%–99% . The relative contribution of the parameters to describing the dynamics of the beluga population were examined by estimating the pD statistic, which if one were thinking in likelihood terms is a measure of the lack of fit of the model. The pD is a diagnostic statistic of Bayesian analysis, corresponding roughly to the ‘effective’ number of parameters being fitted, which can be less than the nominal number depending on the degree to which the model structure creates correlations or other relationships between parameter values or the data is uninformative about parameter values (Spiegelhalter et al. 2002.)

The model was extended into the future for 10 years at 5 different catch levels, producing predictions of stock trajectories expressed both as stock numbers and as the probability of stock decrease since 2008.

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[1] The ‘precision’ parameter for a lognormal distribution is the reciprocal of the variance of the corresponding normal distribution in log space. In real space, it may be looked upon as something like the reciprocal of the square of the coefficient of variation.

[2] A negative binomial model was not used as it is a single-parameter model and variance and mean are tightly related.

The model was coded for BUGS and run on the WinBUGS platform. Typically, trajectory models of this kind produce highly correlated chains in MCMC sampling, so every 200th point was kept from chains of 10 000 000. The model converged easily and ran fast enough.

Data

The data available comprised 5 total-count estimates from aerial surveys flown in 1985, 1993, 2001, 2004 and 2008 and series of annual reports of landed catches (Smith and Hammill 1986; Kingsley 2000; Hammill et al. 2004; Gosselin 2005; Gosselin et al. 2009; Lesage et al. 2009)(Table 1,2). The proportions of those landings that were EHB-summering animals were estimated from genetic analyses and the input catch series correspondingly revised (Table 2). These were set so that the proportion of animals reported landed were: 100% in the Hudson Bay arc area by Nunavik hunters, 12% of Sanikiluaq landings, 21% of Hudson Strait landings and 12.6% of Ungava Bay landings (Hammill et al. 2004). In recent years, the genetic data has shown changes in these proportions (Table 3,4).

Survey counts were corrected for a decline in detection with distance from the survey platform using standard line-transect methods (Gosselin et al. 2009). Corrections were also applied for 'unavailable' animals using: $N_t = N_{survey} / P_0 + N_{estuary}$, where the estimated proportion (P_0) of animals visible from an aerial survey platform is 0.478 (SE 0.0625) (Kingsley and Gauthier 2002). Belugas detected in estuaries ($N_{estuary}$) were assumed to represent total counts:

While estimates of uncertainty were available for each survey estimate, they were incorporated into the fitting process only by guiding the formulation of the prior distribution of the survey error (see above).

RESULTS

The old population model was fitted to the EHB aerial survey estimates from the DISTANCE analyses (Gosselin 2005; Gosselin et al. 2009) (Table 1). 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 old model estimated a struck-and-lost value (b) of 1.82 (SE=0.49), and had a population size of 3,900 (SE=470; rounded to the nearest 100) in 1985 (Fig. 1). The model indicated that the population in 2008 is 3,200 (SE=1,100; rounded to the nearest hundred) (Fig. 1). There is considerable uncertainty associated with these estimates (cv=.34), although the model suggests some improvement compared to the survey cv. The considerable variability is due in part to the uncertainty associated with the surveys (Average cv=.42, range=.14-.74) as well as the uncertainty associated with the shape of the density dependent function and corrections for animals at the surface.

New model

The Bayesian model used the same survey and harvest data as the old model to provide a comparison between the two approaches (Table 1,2). The model included 5 parameters: precision terms for the survey and the process errors, a growth rate for the underlying exponential-growth model, a correction factor on the landed catch to allow for lost animals, and a starting population value. This model did its best to fit a population trajectory to a sparse and erratic survey series (Fig 2). Harvests of EHB belugas have declined (Fig 2). The initial population in 1985 was 4,100 animals while the 2008 population size was 3,000 whales (Fig. 2). The posterior for the struck and loss term was 1.63, and the growth rate of the population was 3%.

Not surprisingly, some priors were either not, or only slightly, updated, and few were at all precisely estimated, and a pD index showed the model to have only about 2½ 'effective' parameters.

Notably, the informative prior for process error was not updated, and a modified model with deterministic dynamics gave very similar results, even when the forward predictions were considered. A less informative prior on process error, corresponding to quartiles on the CV at about 20% and 41%, was updated in its upper limb, but not much in its lower, the posterior quartiles becoming 16½ and 27%. There were minor changes to posterior distributions of some other parameters: the upper quartile of the survey error became very slightly *wider,* the instantaneous growth rate was less precisely estimated with an inter-quartile range at about 6%/yr instead of 3.75, and the 1985 stock size was also slightly less accurately estimated (Table 5). The probability distribution of the loss correction was not significantly changed. I.e. if we can't trust the stock dynamics, we are slightly less able to estimate other parameters from the survey history; and the predictions of future stock sizes became *much* less certain. The mean deviance was slightly higher with the less informative prior on process error, but the effective number of parameters increased by 1 so the DIC value increased–a less satisfactory model. But such an uninformative prior on process error does not agree with what we believe about beluga stock dynamics, which we regard as subject to relatively small variation[3].

Future harvests will have a probability of the population declining ranging from approximately 30% for a harvest of 25 animals, increasing to over 50% for a harvest of 55 animals (Fig 3,4,5)

<u>Composition of the harvest</u>

Previous assessments have used a harvest composition of EHB animals in the harvest of 21% from Hudson Strait and 13% in the harvest from Ungava Bay. Samples collected since 2004 indicate that the proportion of EHB animals in the Hudson Strait harvest have declined to 9% (Table 3). Although considerable data are lacking on the timing of the hunt for the years prior to 2004, there is a marked difference in the sampled proportion of EHB animals in the fall hunt compared to the spring hunt (Table 4). The number of EHB animals in the summer harvest in the Hudson Strait area remains low. Prior to 2004, 57% of the genetic samples were collected from the fall hunt, whereas since 2004, 66% of the samples are collected from the spring hunt. Sampling from the hunt is not necessarily proportional to reported harvest success, with 31% of the animals killed in the spring in 2008, 48% in 2007, 86% in 2006 and 29% in 2005. In those years 80% of the samples were obtained in the spring in 2007, 100% in 2006 and 83% in 2005.

[3] A model with a *much more* informative prior on process error was tried, but is difficult to fit with MCMC methods: the sampling chains become very highly autocorrelated and uncorrelated subsamples are tedious to collect, and the model with deterministic dynamics was so close to that with the informative prior that further investigation was considered unnecessary.

DISCUSSION

The 'old' 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. 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 five aerial survey estimates. 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 also made certain assumptions about the values and distributions of these parameters 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.

In an earlier assessment, 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. In the old model, the maximum rate of increase is fixed at 4%, so that this term will be adjusted to absorb differences between the maximum rate of increase and the modelled rate of increase. 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.

Both models tracked each other very well. The comparison has shown that there is little to be gained at the current time with a more complex model. Furthermore, using a Bayesian fitting approach, predictions and their estimated uncertainties, can be based on the full multivariate posterior distribution of the parameter estimates. This is a significant advantage in the present case where we are fitting to little data and parameter estimates are highly correlated. Using the new model and the accepted index estimates of abundance from the aerial surveys, the Nunavik beluga whale population declined from an estimated 4,100 in 1985 to about 3,000 animals in 2000. Since 2000, the decline in the population appears to have been halted with the decline in landings that have been observed over the last decade.

As would be expected given that the number of fitted parameters was roughly equal to that of the available observations, parameter estimates were correlated with one another. Leading correlations were between the instantaneous rate of growth, the 1985 numbers, and the correction for loss of struck animals, but the survey c.v. was also positively correlated with the 1985 numbers.

The annual turnover in a beluga population is probably 6–10%, so a *median* process variability of 6–7% is roughly equivalent to 100% of the turnover, and is probably far too large—we do not believe that beluga stock dynamics are highly variable. More informative priors on the process error with smaller medians were tried, but make only very small differences to model estimates of parameters (Table 5) and are somewhat more difficult, and much more tedious, to fit. DIC values showed a steady decrease from a model with large process error to a model with deterministic dynamics (Table 5), which would therefore appear to be preferable.

The sampling program indicates that they proportion of EHB animals in the harvest may be declining. This appears to result form an increasing contribution of animals harvested during the spring, where a lower proportion of animals in the spring hunt belong to the EHB population. It is tempting to apply this lower proportion to the reported harvests from 2004-2008. We did not do this because the proportion of samples from the spring sample does not always match the spring versus fall proportions of the total catch that has been reported from the Hudson strait area . Even though the proportion of animals in the spring hunt of about 9% is much lower than the earlier estimate of 21 %, it is still much higher than would be expected from the relative sizes of the two populations. The WHB population numbers around 57,000 animals compared to 3200 animals form the EHB population. One would expect a proportion of around 5%. Recent harvests dominated by animals killed during the spring would appear to be approaching this value. More work on the timing of migration, linked with sampling might help to improve our understanding of migration and when harvesting should be restricted to limit the harvest of EHB animals.

We did not attempt to model the dynamics of the Ungava Bay populations. Repeated surveys have failed to detect any beluga whales while on transect. In some surveys, beluga whales have been seen while off transect (Smith and Hammill 1986; Kingsley 2000), as well as other cetaceans (bowhead, minke whales, dolphins), harp seals and polar bears (Gosselin et al. 2009) have been observed. With the current survey design and effort, it is unlikely that beluga whales would be detected on transect if the surface population is ≤ 200 animals. Reports from hunters and from aircraft continue to report observations of beluga in the Mucalic River area and near Tasiujaq, but observations remain low (Hammill and Lesage, 2009). Therefore, it is not recommended to allow hunting in the Ungava Bay area during the summer. The hunt in spring and fall in this area continues to report that some EHB animals are taken in the harvest. Unlike the Hudson Strait harvest, there does not seem to be any trend in the proportion over time and the proportion of EHB animals in the Ungava Bay harvest remains around 14-15%.

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 or stopped. Both models indicate a maximum harvest of around 65 EHB animals per year if no decline in the population is to occur, provided that all assumptions associated with the model are correct. The old model suggests that a slightly higher harvest might be possible, but this model fixed the rate of increase at 0.04, which is 30% higher than the fitted value of 0.03 obtained with the Bayesian model. The value of r=0.03, estimated by the model falls within the range of 0.02-0.04 normally considered for beluga and other cetaceans with similar life histories. We would expect that EHB beluga should have a higher maximum rate of increase, probably closer to the maximum of 0.04. The difference may result from the limited survey data and the considerable variability associated with the survey data, the composition of the harvest and struck and loss estimates. However, the continued high harvest of female animals may also contribute to reducing this factor. If the population is to begin recovery, then harvests must be further reduced. The rate of recovery will be determined by how much harvest levels are limited.

ACKNOWLEDGEMENTS

We thank the Nunavik hunters for providing the skin samples and reports on their catches. We also thank Lianne Postma and Denise Tenkula for the DNA analyses. This work was supported by Species at Risk funding to the Department of Fisheries and Oceans, the Interdepartmental Recovery Fund (Environment Canada) and the Centre of Expertise for Marine Mammalogy (CEMAM) support for the aerial surveys.

REFERENCES

BARLOW, J. and P. BOVENG. 1991. Modeling age specific mortality for marine mammal populations. Mar. Mamm. Sci. 7: 50-65.

BURNS, J.J. AND G.A. SEAMAN. 1985. Biology and ecology. Pt II of Investigations of belukha whales in coastal waters of western and northern Alaska. Final report to OCSEAP, Contract NA 81 RAC 00049. Alaska Department of Fish and Game, Fairbanks, Alaska. 129 pp.

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

DFO, 2005. Recovery Assessment Report on Cumberland Sound, Ungava Bay, Eastern Hudson Bay, and St. Lawrence Beluga Populations (*delphinapterus leucas*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/036.

DOIDGE, D.W. 1990. Age and stage based analysis of the population dynamics of beluga whales, *Delphinapterus leucas,* with particular reference to the northern Quebec population. Ph.D. thesis, McGill University, Montreal. 190 pp.

GOSSELIN, J.-F. 2005. Population indices of beluga in James Bay, eastern Hudson Bay, and Ungava Bay, in 2004. Can. Sci. Advis. Sec. Res. Doc. 2005/011. Available at http://www.dfo-mpo.gc.ca/csas.

GOSSELIN, J-F. LESAGE, V. et HAMMILL, MO. 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 p.

HAMMILL, M.O., V. LESAGE, J.-F. GOSSELIN , H. BOURDAGES, B. G.E. DE MARCH and M.C.S. KINGSLEY. 2004. Changes in abundance of northern Quebec (Nunavik) beluga. Arctic 57:183-195.

HAMMILL, M. O. and LESAGE, V. 2009. Seasonal movements and abundance of beluga in northern Quebec (Nunavik) based on weekly sightings information. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/010. iv + 13 p.

INNES, S. AND R.E.A. STEWART. 2002. Population size and yield of Baffin Bay beluga (*Delphinapterus leucas*) stocks. NAMMCO Scientific Publications 4:225-238.

KAYSUYA, T., D.E. SERGEANT, and K. TANAKA. 1988. Re-examination of life history parameters of long-finned pilot whales in Newfoundland waters. Sci. Rep. Whales Res. Inst. 39: 103-119.

KINGSLEY, M.C.S. 1989. Population dynamics of the narwhal (*Monodon monoceros*): an initial assessment (Odontoceti: Monodontidae). J. Zool., Lond. 219: 201-208.

KINGSLEY, M.C.S. 2000. Numbers and distribution of belugas in Hudson Bay, James Bay and Ungava Bay in Canada during the summer of 1993. Fish. Bull. 98: 736-747.

KINGSLEY, M.C.S. and I. GAUTHIER. 2002. Visibility of St Lawrence belugas to aerial photography, estimated by direct observation. NAMMCO Scientific Publications Vol. 4: 259-270.

KINGSLEY, M.C.S., P. RICHARD, and S. INNES. 1995. The effect of management options on the dynamics of beluga populations. Unpubl. MS, prepared for the Northern Quebec and Native Affairs Division, Fisheries and Oceans Canada, Quebec Region. 21 pp.

LESAGE, V. BAILLARGEON, D., TURGEON, S. and DOIDGE, DW. 2009. Harvest statistics for beluga in Nunavik, 2005–2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/007. iv + 25 p.

PELLA, J.J. AND P.K. THOMLINSON. 1969. A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission 13:420-496.

REEVES, R.R., and E. MITCHELL. 1989. Status of white whales, *Delphinapterus leucas*, in Ungava Bay and eastern Hudson Bay. Can. Field-Nat. 103: 220-239.

SERGEANT, D.E. 1973. Biology of white whales (*Delphinapterus leucas*) in western Hudson Bay. J. Fish. Res. Brd Can. 30: 1065-1090.

SMITH, T.G. and M.O. HAMMILL. 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.

SPIEGELHALTER, D.J., N.G. BEST, B.P CARLIN, and A. VAN DER LINDE. 2002. Bayesian Measures Of Model Complexity And Fit (With Discussion). Journal Of The Royal Statistical Society, Series B. 64(4):583-616

Table 1. Final aerial survey estimates of beluga populations in eastern Hudson Bay. The 1985 survey data were adjusted to account for differences between strip-transect and line-transect methods (Hammill et al. 2004). Aerial survey estimates correcting for estuary animals by adding in estuary counts in EHB of 474, 18, 39 , 5 and 0, for 1985, 1993, 2001, 2004 and 2008 respectively.

Year	Distance line-transect (SE)	Estimate corrected for diving animals
1985	*2,294*	4279 (620)
1993	1,314 (489)	2727 (1,012)
2001	1,418 (635)	2922 (1,368)
2004	2045 (698)	4269 (1,499)
2008[1]	1,265 (570)	2646 (1,959)

[1] The initial 2008 index estimate presented at the meeting and used to run the old model was 1,446 (868), which resulted in a corrected estimate of 3,025 (2,238).

Table 2. Number of eastern Hudson Bay animals removed from the population assuming that following herd composition for EHB (100%), Sanikiluaq (12.6%), Hudson Strait (21%), and Ungava Bay (12.6%).

Year	Harvest	Year	Harvest	Year	Harvest
1985	84	1996	101	2007	59
1986	69	1997	98	2008	53
1987	81	1998	102	2009	70
1988	76	1999	106		
1989	144	2000	104		
1990	77	2001	129		
1991	144	2002	49		
1992	99	2003	54		
1993	105	2004	43		
1994	128	2005	41		
1995	103	2006	29		

Table 3. Proportion of EHB animals in harvest from Hudson Strait.

Hudson Strait	EHB	non-EHB	Total	Average %EHB
1997	3	11	14	21.4
1998	15	27	42	35.7
1999	4	32	36	11.1
2000	14	17	31	45.2
2001	11	44	55	20
2002	2	38	40	5
2003	5	46	51	9.8
Average				21.1
Stdev				14.6
2004	41	8	33	19,5
2005	28	1	26	3,6
2006	30	2	28	6,7
2007	34	2	32	5,9
Average				8,9
Stdev				7,2
Global Average				10.1
Global Stdev				7.5

Ungava Bay	EHB	non-EHB	Total	%EHB
1997	2	7	9	22.2
1998	0	4	4	0.0
1999	1	12	13	7.7
2000	0	10	10	0.0
2001	1	11	12	8.3
2002	3	5	8	37.5
2003	3	21	24	12.5
Average				12.6
Stdev				13.4
2005	9	1	8	11,1
2006	2	18	20	10,0
2007	2	6	8	25,0
Average				15,4
Stdev				8,4
Global Average				15.4
Global Stdev				8.4

Table 4. Seasonal changes in the number of EHB (%) beluga whales in the Hudson Strait catch.

Pre-2004	EHB	Non-EHB	Total	Percent
Fall	21	101	122	17.2
Spring	5	54	59	9.2
Summer	2	30	32	6.0
2004 and later				
Fall	7	17	24	29.2
Spring	4	83	87	4.6
Summer	1	18	19	5.3

Table 5: Quartiles of *prior* and posterior distributions of parameters of a stock-production model of the dynamics of the eastern Hudson Bay beluga stock, showing the effect of changing the prior distribution of process error.

	Process Error														
	none			small			moderate 1			moderate 2			large		
Quantile	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%	25%	50%	75%
Start number ('00) (prior)	*47.5*	*91.2*	*142.1*	*48.2*	*93.1*	*143.0*	*46.9*	*91.0*	*142.3*	*46.4*	*91.4*	*141.5*	*47.1*	*90.8*	*141.6*
(posterior)	33.9	41.2	50.7	34.0	41.5	51.1	34.4	42.2	52.6	34.7	42.7	52.9	35.9	44.9	56.8
Growth rate (%/yr)	*-2.6*	*4.9*	*12.4*	*-2.5*	*4.9*	*12.6*	*-2.5*	*4.9*	*12.6*	*-2.5*	*5.1*	*12.5*	*-2.5*	*5.0*	*12.5*
(posterior)	1.4	3.0	4.8	1.2	3.0	4.9	0.9	3.0	5.1	0.8	3.0	5.2	-0.4	2.9	6.3
Lost (per landed,%)	*43.3*	*60.9*	*84.7*	*43.1*	*60.7*	*84.9*	*43.1*	*60.3*	*85.1*	*43.1*	*60.7*	*85.0*	*43.3*	*60.9*	*85.2*
(posterior)	41.1	56.7	78.8	40.9	57.0	78.8	41.0	57.1	78.7	40.7	57.0	79.1	41.0	57.2	79.1
Survey c.v. (%)	*35*	*43*	*55*	*35*	*43*	*55*	*35*	*43*	*55*	*35*	*43*	*55*	*35*	*43*	*55*
(posterior)	31	37	45	32	37	45	32	37	45	31	37	45	32	38	46
Process c.v. (%)	*0.0*	*0.0*	*0.0*	*2.2*	*2.9*	*4.1*	*5.5*	*6.8*	*8.7*	*6.7*	*8.3*	*10.6*	*17.3*	*21.3*	*27.3*
(posterior)	0.0	0.0	0.0	2.2	2.9	4.0	5.4	6.7	8.4	6.6	8.1	10.2	16.2	19.5	24.0
Est. numbers, 2008 ('00)	26.7	32.3	38.9	26.6	32.3	39.0	26.4	32.2	39.2	26.3	32.2	39.2	25.2	31.5	39.5
Est. numbers, 2018 @ 45/yr	24.0	35.5	51.1	23.4	35.6	52.2	22.0	35.0	54.5	21.3	34.9	55.2	15.6	33.6	68.9

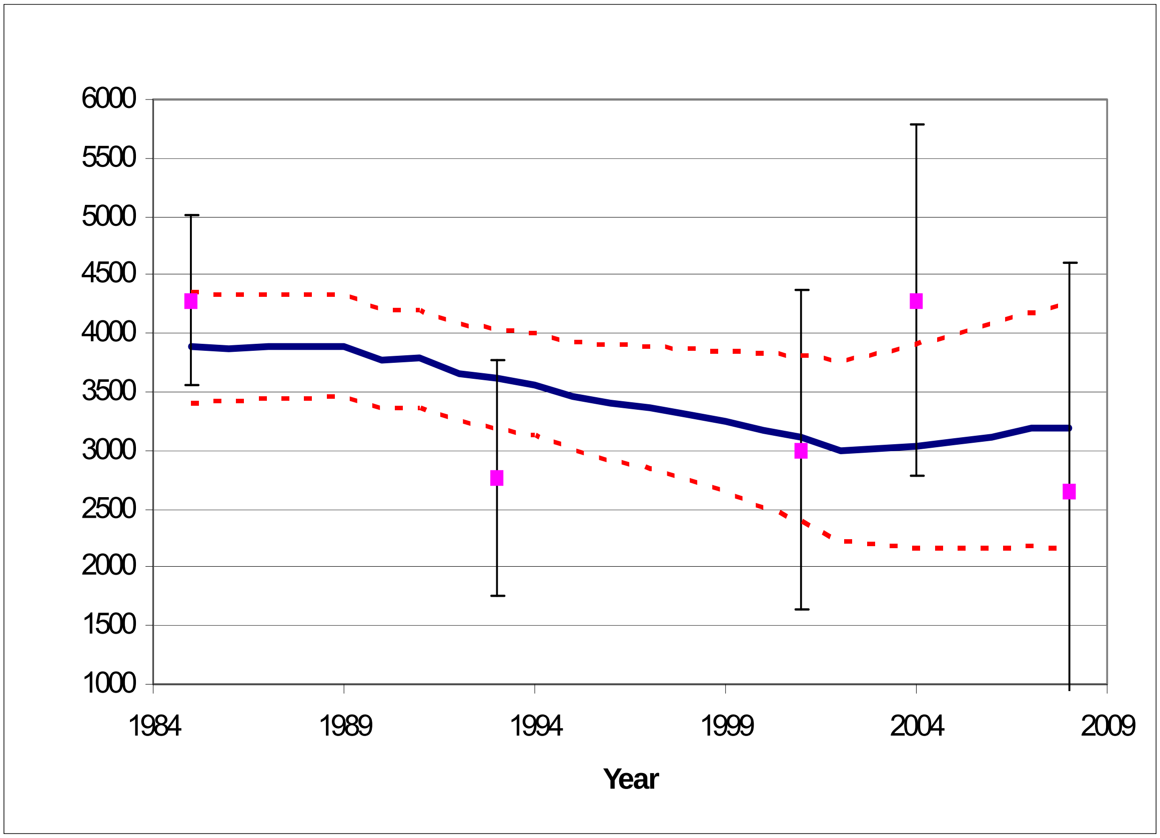

Figure 1. Aerial survey and model estimates (± SE) of eastern Hudson bay beluga abundance fitted to aerial survey estimates corrected for animals at the surface.

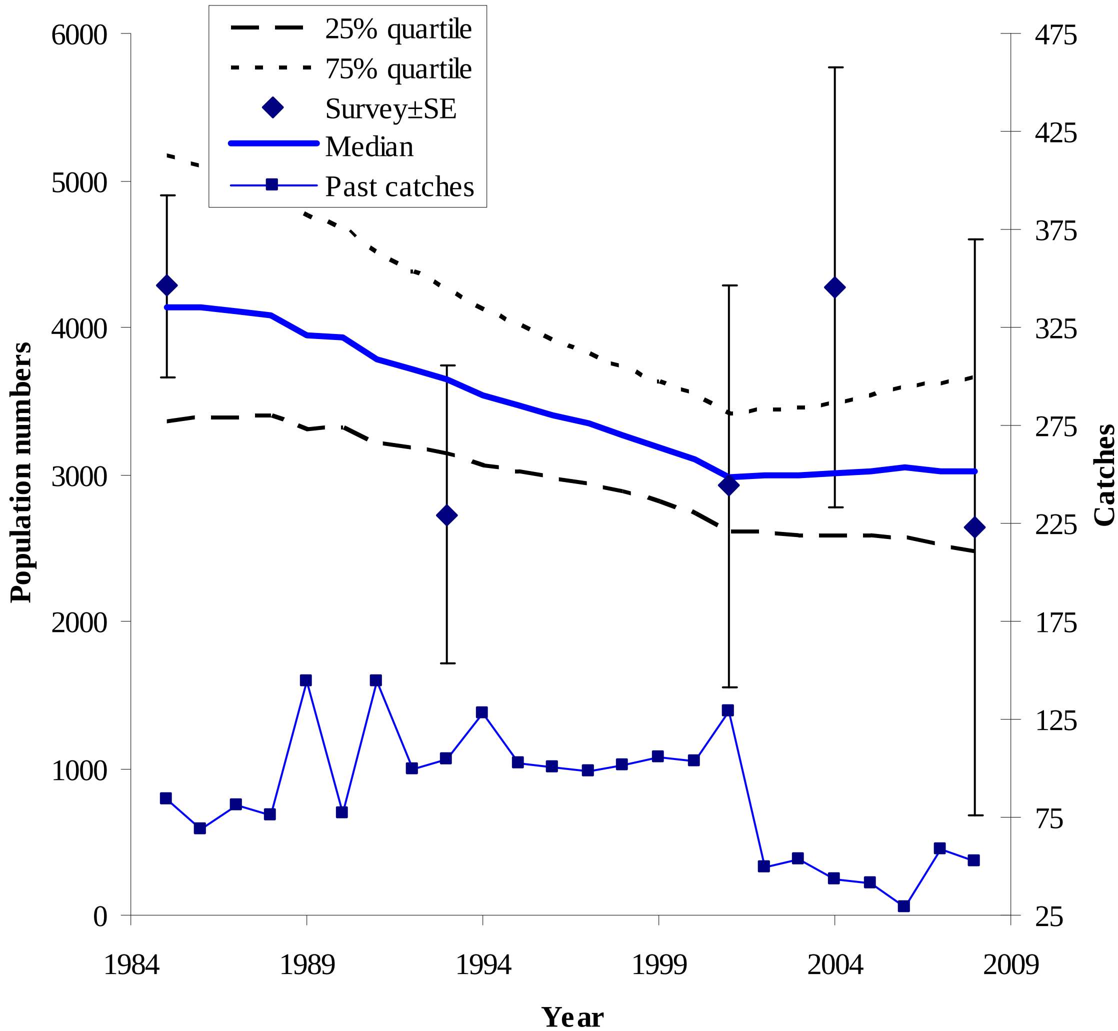

Figure 2: Eastern Hudson Bay belugas: quartiles of fitted past and predicted future stock trajectories from a stock-production model fitted to initial survey and catch data by Bayesian methods, for comparisons in model results with the old model (Figure 1). The bottom line represents harvests of EHB animals (y-axis on right side).

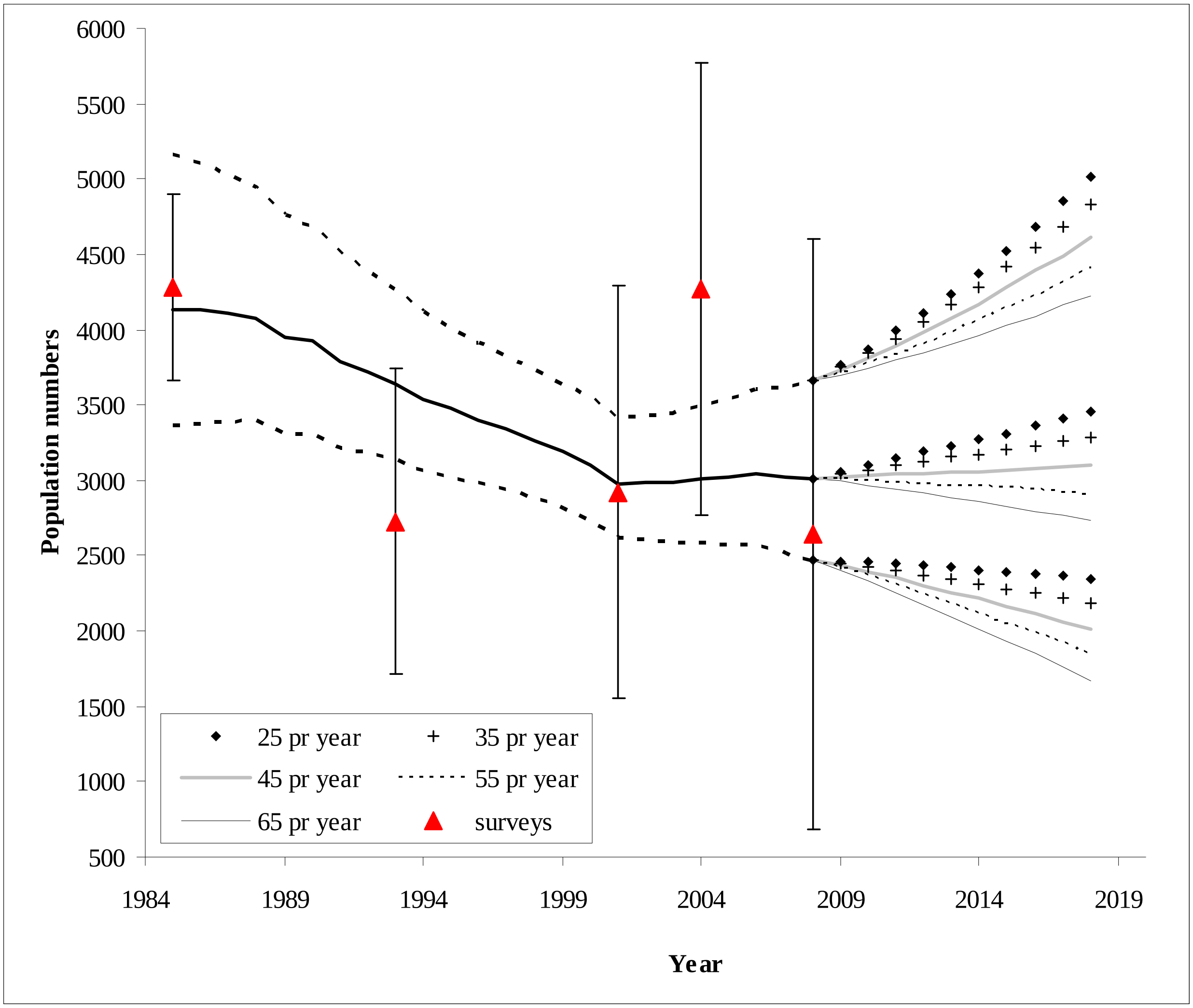

Figure 3: Eastern Hudson Bay belugas: Median (solid line) and 25% and 75% quartiles (dotted lines) of fitted past and predicted future stock trajectories from a stock-production model fitted to survey and catch data by Bayesian methods; (highly informative prior on process error.) The different points represent expected trajectories under different harvest levels of EHB animals only.

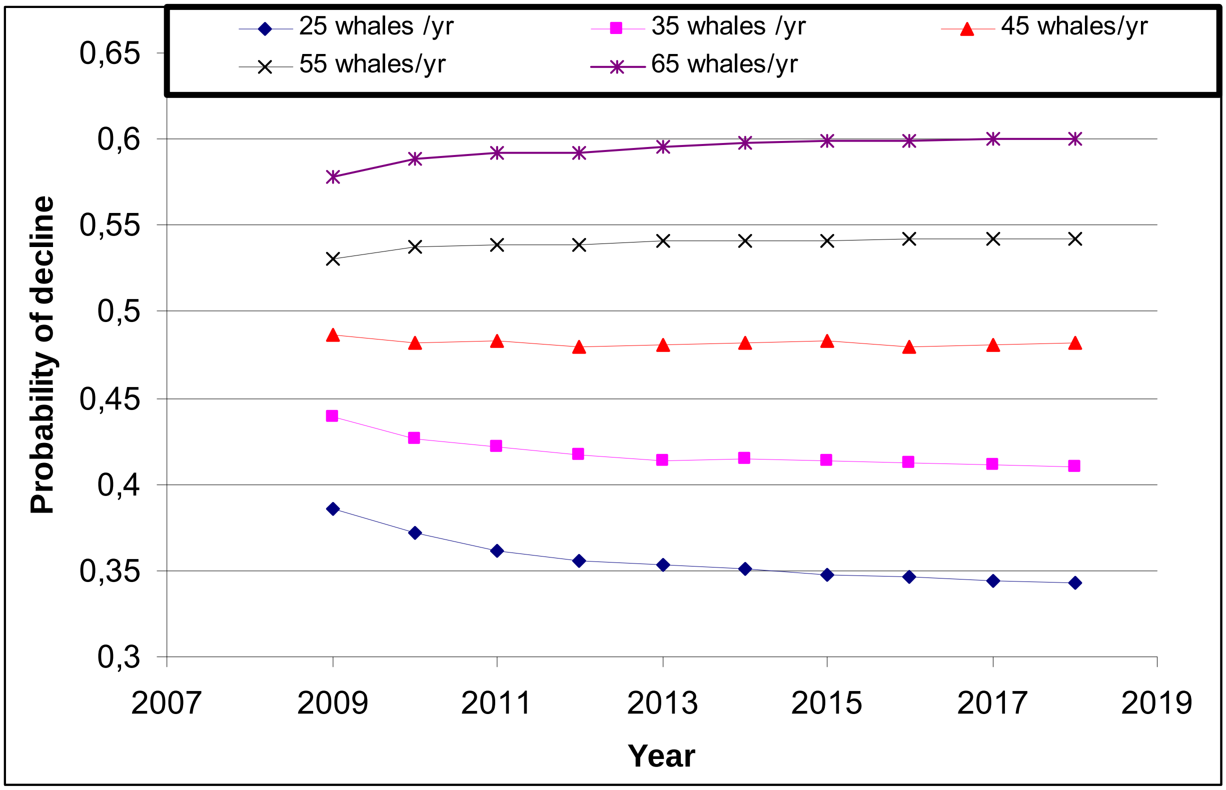

Figure 4. Eastern Hudson Bay belugas. Probability of a population decline under different annual landings, estimated by a Bayesian stock-production model with a highly informative prior on process error.

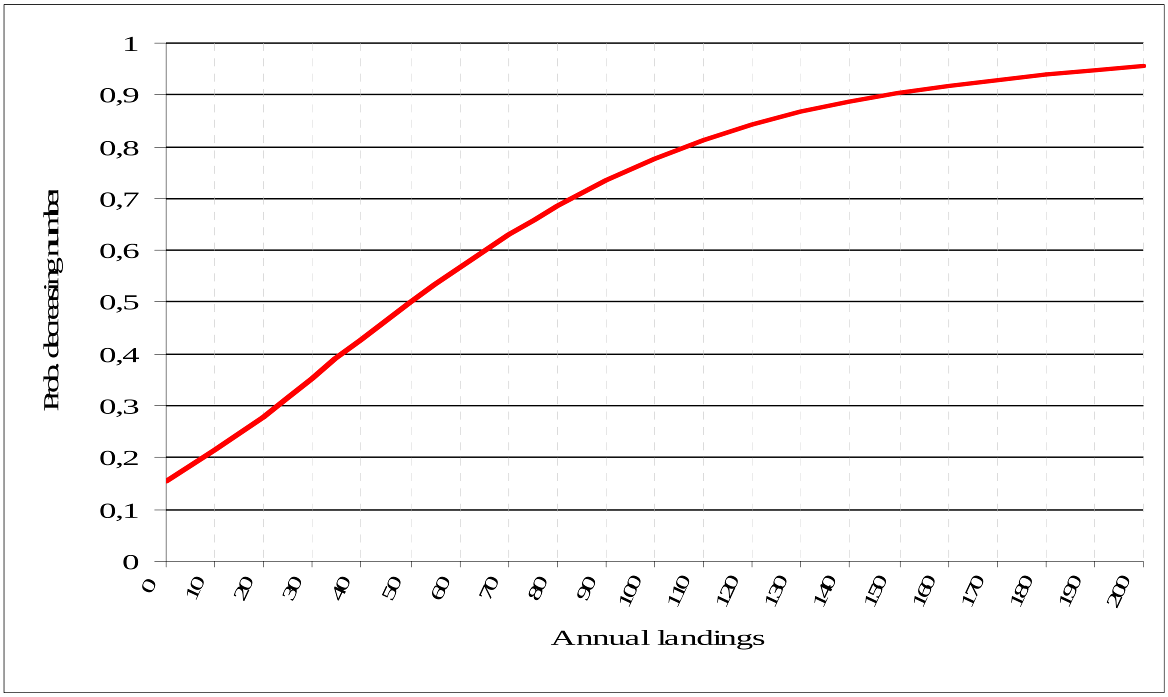

Figure 5: Eastern Hudson Bay belugas. Probability of stock decrease at different catch levels estimated by a Bayesian stock-production model assuming deterministic stock dynamics.