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Information on abundance and harvest of Ungava Bay beluga

Information sur l'abondance et la récolte de bélugas dans la baie d'Ungava

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ABSTRACT

Beluga whales (*Delphinapterus leucas*) were historically abundant in Ungava Bay (Nunavik, Quebec), where they are considered to form a distinct summer stock based on their disjoint summer distribution and their fidelity to certain areas. This stock has been depleted by commercial whaling and its recovery has been limited by excessive subsistence hunting. Its current population size is unknown. It is important to determine the maximum harvest that can take place in Ungava Bay in the context of managing both this stock and the Eastern Hudson Bay stock (EHB).

Systematic aerial surveys were flown in 1985, 1993, 2001, and 2008, but no whales were seen within the strip-width of the transects. Based on the 1993 survey, an imprecise upper 90% confidence limit of 150 individuals was proposed. This number, however, was not corrected for availability and does not include the results of previous and subsequent surveys. To provide probabilistic statements about the impact of different harvest levels, we used a Bayesian approach which allowed us to make use of all four surveys with zero-counts. Using the mean group size observed during surveys and the correction factors for animals underwater, the mean estimate of the current population size was 32 individuals (95% CI 0–94). With this estimate, the Potential Biological Removal was equal to 0.16 individuals. Assuming an annual growth rate of 2.7%, the harvest levels for which there is a 5%, 50% and 75% probability of stock increase were 0.95, 0.63, and 0.32 respectively.

The proportions of EHB beluga in harvest samples from the five communities of Ungava Bay as well as Quaqtaq have been estimated at 2% ± 7% in spring, 4% ± 9% in summer, and 28% ± 9% in the fall. These numbers suggest that EHB beluga do not pass by Ungava Bay in great numbers during the spring migration. The high proportion of EHB beluga in the fall is difficult to interpret because samples from Quaqtaq have been pooled with those of communities from inside Ungava Bay. However, satellite telemetry has confirmed that EHB beluga migrate through Ungava Bay during their fall migration. Estimating the proportion of UB beluga at different times of the year is not possible without a dedicated genetic analysis and might be limited by small sample size.

Our results indicate that any harvest from the UB stock poses a threat to its recovery. There is currently a Total Allowable Take of 10 beluga per year in Ungava Bay in the three-year management plan (2011−2013), but 17 beluga were taken there in 2011. The hunt is open from June 24 to August 31, to minimize the amount of EHB beluga killed. However, hunting in Ungava Bay in the summer probably increases the probability of taking UB beluga. A detailed genetic analysis that focuses on Ungava Bay is necessary to better understand the contribution of each stock to the harvest.

RÉSUMÉ

Dans le passé, les bélugas (*Delphinapterus leucas*) étaient présents en grand nombre dans la baie d'Ungava (Nunavik, Québec). Leur distribution estivale et leur fidélité à certains sites permettent de considérer que ces bélugas forment un stock estival distinct. Ce stock a été fortement réduit en abondance par la chasse commerciale et sa récupération a été limitée par une chasse de subsistance excessive. Sa taille actuelle est inconnue. Il est important de déterminer le nombre maximal de bélugas qui peuvent être chassés en baie d'Ungava, afin de gérer à la fois ce stock et celui de l'est de la baie d'Hudson (EBH).

Des relevés aériens systématiques ont eu lieu en baie d'Ungava en 1985, 1993, 2001 et 2008, sans qu'aucun béluga ne soit compté dans les limites des bandes d'observation. En se basant sur le relevé de 1993, le chiffre de 150 individus a été proposé comme limite supérieure de l'intervalle de confiance à 90 %. Toutefois, ce chiffre n'a pas été corrigé pour tenir compte de la disponibilité des bélugas en surface, et n'inclut pas les résultats des relevés précédents et subséquents. Afin de fournir des mesures probabilistes de l'impact de différents niveaux de chasse, nous avons utilisé une approche bayésienne permettant de tirer de l'information des quatre relevés. En supposant une taille moyenne de groupe égale à celle observée lors des observations hors-transects et en appliquant une correction pour les animaux submergés, nous avons obtenu une estimation moyenne de la taille du stock de 32 individus (IC 95 % 0 – 94). Le potentiel biologique de capture (PBR) dérivant de cette estimation est de 0,16 individus. En supposant un taux de croissance annuel de 2,7 %, les niveaux de chasses correspondant à des probabilités de croissance du stock de 25 %, 50 % et 75 % sont respectivement de 0,95, 0,63 et 0,32 individus.

Les proportions de bélugas de l'EBH au sein des échantillons de chasse des cinq communautés de la baie dUngava ainsi que de Quaqtaq ont été estimées à 2 % ± 7 % au printemps, 4 % ± 9 % en été, et 28 % ± 9 % durant l'automne. Ces chiffres suggèrent que les bélugas de l'EBH ne passent pas par la baie d'Ungava en grands nombres au cours de leur migration printanière. La forte proportion de bélugas de l'EBH durant l'automne est plus difficile à interpréter car les échantillons de Quaqtaq ont été combinés à ceux des communautés de l'intérieur de la baie. Cependant, les observations par télémétrie satellite ont confirmé que les bélugas de l'EBH passaient par la baie d'Ungava durant leur migration d'automne. Estimer la proportion de bélugas du stock d'Ungava dans les échantillons de chasse à différentes périodes de l'année n'est pas possible sans une analyse génétique visant spécifiquement à répondre à cette question, et cette analyse serait sans doute limitée par le petit nombre d'échantillons.

Nos résultats indiquent que tout prélèvement dans le stock de la baie d'Ungava menace son potentiel de récupération. Le plan de gestion triennal actuel (2011–2013) autorise une chasse de 10 bélugas par année dans la baie d'Ungava, mais 17 y ont été pris en 2011. La chasse est ouverte du 24 juin au 31 août afin de minimiser les risques de capturer des bélugas de l'EBH. Cependant, cette chasse estivale augmente les probabilités de prendre des bélugas du stock d'Ungava. Une analyse génétique détaillée des échantillons de chasse provenant de la baie est nécessaire pour mieux comprendre les contributions de chaque stock.

INTRODUCTION

Beluga whales (*Delphinapterus leucas*) were historically abundant in Ungava Bay (Nunavik, Quebec), where they were traditionally hunted by Inuit along the shores and in estuaries (Reeves and Mitchell 1989). For management purposes, Ungava Bay beluga (UB) have been considered a distinct summer stock based on their disjoint summer distribution and their apparent fidelity to certain areas (Finley et al. 1982, Reeves and Mitchell 1989). Telemetry, contaminant and genetic data have provided support for this management framework for James, Eastern and Western Hudson Bays (de March and Postma, Richard, Doniol-Valcroze et al. 2011).

A commercial fishery by the Hudson Bay Company (HBC) took place in Ungava Bay from 1867 to 1911. Using information on HBC catches, it is estimated that the Ungava summer stock numbered at least 1,914 whales in the late 1800s (DFO 2005). The commercial fishery is thought to have severely depleted the number of beluga summering in the bay, but observations and catches made in the 1960's and 70's indicates that a few hundreds were still present in the area. Unregulated subsistence harvesting continued until the early 80's when low numbers observed from aerial and land-based surveys raised concerns that the stock was being overexploited (Boulva 1981, Finley et al. 1982). In 1986, a system of quotas was implemented in Ungava Bay, and the Mucalic estuary was closed to hunting (Lesage et al. 2001). The UB stock was designated "endangered" by the committee on the Status of Endangered Wildlife in Canada in 1988.

Although the major summer concentrations of beluga formerly found in southern Ungava Bay are no longer observed, continued sightings and occasional harvesting suggest either that the population persists at some level or that the area is frequented by whales from neighbouring stocks (DFO 2005). The current population size of UB beluga is unknown. Systematic surveys were flown in 1982 by Makivik corporation and in 1985, 1993, 2001, and 2008 by DFO, but no whales were seen within the strip-width of the transects (Smith and Hammill 1986; Hammill et al. 2004, Gosselin et al. 2009). Based on the 1993 survey, an imprecise upper 90% confidence limit of 150 individuals was proposed (Kingsley 2000).

There are several reasons to update this number. First, it was not corrected for availability, i.e., diving animals. This number also does not include the results of previous and subsequent surveys flown in 1986, 2001 and 2008, and it does not provide a statistical distribution from which probabilistic statements about the impact of different harvest levels can be made. For instance, it is not in line with the management frameworks of other stocks, which rely on mean or median estimates of population size.

Current subsistence harvest by Nunavik Inuit is directed towards a mixture of populations during spring, summer and fall. In addition to beluga from the UB stock, Inuit in Ungava Bay occasionally harvest whales from the Eastern Hudson Bay stock (EHB), which was depleted by intensive commercial hunting and has decreased from an estimated pristine population size of 12,500 in the early 1700s to about 3,000 individuals in 2010 (Hammill et al. 2005, Doniol-Valcroze et al. 2011). It is therefore important to determine the maximum harvest that can take place in Ungava Bay in the dual context of managing the UB stock and the EHB stock. Here, we propose to use a Bayesian statistical framework to provide stock estimates from aerial surveys in a format similar to those of the EHB beluga. These estimates can then be used to answer management questions in probabilistic terms of population increase.

METHODS

SURVEY DATA

We used data from systematic aerial surveys flown over Ungava Bay (Fig. 1) in 1985, 1993, 2001 and 2008 (see Smith and Hammill 1986, Kingsley 2000, Gosselin et al. 2009 for details on survey methodology). Following Gosselin et al. (2009), we assumed an effective strip width of 839 m on each side of the aircraft to determine the sampled fraction *f* of the study area. No sightings were made within the strip width of the transects on any of those surveys.

ESTIMATION OF POPULATION SIZE WITH ZERO-COUNTS

Standard strip-width or distance sampling methods to estimate population size are not well adapted to zero-counts. For instance, estimated density and its variance in line-transect techniques are both a direct function of *x*, the total number of groups detected on transect, and thus will always be zero when no groups are detected.

Using the binomial distribution (frequentist approach)

To circumvent this problem, Kingsley (2000) calculated an upper confidence limit on the number of groups by assuming independent binomial sighting probabilities and by answering the question “Given that the sampled fraction was f, how many groups could there be for the chance of seeing none to be less than α%?” This question has an analytical solution if one uses the normal approximation to the binomial distribution. However, this is usually considered acceptable only if *x* or *np* > 5. Otherwise, N can be found by calculating the likelihood of multiple values of n given the number of success *x* = 0. The corresponding cumulative distribution can then be used to find the value of N that corresponds to the desired level of α. With this method, N can only be an integer, but linear interpolation can be used to find intermediate values.

Bayesian approach for one survey

If X ~ Bin(N,P), a Bayesian approach is easy to use to estimate P, but less straightforward to estimate N. One historical difficulty has been the absence of a tractable family of prior distributions, mainly due to the fact that N is an integer (Raftery 1988). Nowadays, the rapid execution of MCMC chains makes it easier to sample from a complex posterior distribution, even without a conjugate prior. Therefore, we can find the posterior distribution of N by giving it a uniform prior and by giving P a value equal to the sampled fraction *f*.

We ran the Bayesian analysis in WinBUGS with 100,000 iterations following a burn-in of 10,000 samples. We used a thinning factor of 10 to remove autocorrelation in the MCMC chains.

Bayesian approach for multiple surveys

The advantage of implementing the Bayesian approach is that it can be easily expanded to the result of multiple surveys. We ran the model again, this time with four successive counts of zero sightings.

To obtain a corrected population estimate, we converted values of N, which represent the number of groups present in the survey area, to the number of individuals by multiplying by 5.6, the average group size in Ungava Bay for all 12 sightings made during the 1993 summer survey, including coastal reconnaissance flights and off-transect observations (Kingsley 2000). Then, we multiply the population estimate by 2.092, the correction factor for beluga underwater (Kingsley and Gauthier 2002).

Potential biological removal
There are several ways we can use these probabilistic population estimates to provide harvest advice (Lonergan 2011). Catch limits defined by the IWC Revised Management Procedure were not used here because they rely on K, the pristine population size, which would introduce another factor of uncertainty in our estimate. We calculated the potential biological removal (PBR), used in the US Marine Mammal Protection Act, which is given by:

$$PBR = N_{min} \times (R_{max}/2) * F_r$$

where PBR is a number of animals considered safely removable from the population without missing the target, N_{min} is a minimum population estimate, R_{max} is the population growth rate at low densities, which is halved to give an estimate of the growth rate at the target population level, and F_R is a recovery factor, with a value between 0.1 and 1, that introduces an extra level of precaution into the results. Values of R_{max} as high as 4% are used for other stocks (e.g., Cumberland Sound, DFO 2005). However, the growth rate of EHB beluga has been estimated at 2.7% (Doniol-Valcroze et al. 2011), even though this depleted population should theoretically be close to R_{max}. Here we use R_{max} = 2.7% as a conservative estimate of Nunavik beluga growth rate. It is usually recommended to set N_{min} at the 20th percentile of the probability distribution of the population estimate. PBR was calculated for several values of the recovery factor (0.1, 0.5, and 1).

To better answer management questions on UB beluga, and to provide advice in a format similar to the EHB stock management approach, we also calculated a probability of stock increase given several harvest levels. We did this by multiplying population estimates by the correction factor for availability, the mean group size and growth rate, and assumed that any harvest below that level would result in stock increase.

RESULTS

POPULATION ESTIMATE

Single survey analysis
Based on previous studies, we gave N a uniform prior distribution between 0 and 100. The resulting posterior distribution had a median of 11 groups and a 95% credibility interval of 1–56 groups. We note that the value of the upper 90% confidence limit was 36 groups, which is very close to the value of 34.3 estimated by Kingsley (2000). In fact, we see that the distributions of N obtained by the two methods (Bayesian and frequentist) are nearly identical (Fig. 2).

Multiple survey estimate
We then ran the same analysis with the four surveys. Counts on transect were zero in all surveys. In this analysis, the resulting posterior distribution was updated from the uniform prior, as well as from the single survey analysis (Fig. 3). The most likely value of N is still 0 groups, but the median is now 2 groups. The mean is 2.7 groups and the 95% CI is 0–12. The lower 20% quantile, which is used in the PBR formula, is 1 group.

PBR and probability of increase for several harvest scenarios
Using the mean group size observed during surveys of Ungava Bay and the correction factors for animals underwater, the mean estimate of the current population size was 32 individuals (95% CI 0–94). We use $N_{min} = N_{20\%} = 12$ for the calculation of the PBR, which is equal to 0.16 individuals with a recovery factor of 1. The official guidance for using PBR under the MMPA sets the recovery factor to 0.5 for those that are threatened or depleted, and 0.1 for populations listed as endangered. With those values, the PBR would obviously remain under 1 individual.

Assuming an annual growth rate of 2.7%, the harvest levels for which there was a 25%, 50% and 75% probability of stock increase were 0.95, 0.63, and 0.32 respectively (Fig. 4).

DISCUSSION

POPULATION ESTIMATE

Any population estimate based on the absence of sightings has to be considered with caution. The most likely value of population size is zero, but that value is independent of the number of surveys or the coverage fraction and therefore has limited informative value. Conversely, it would be very difficult to demonstrate that there are no beluga in Ungava Bay. For instance, even after dozens of surveys, there would never be a 100% confidence level that this population does not exist anymore. Since some beluga whales are still seen occasionally in Ungava Bay during summer, it seems more likely that the population still exists but in very small numbers, something that is more in line with the median value of our population estimate than with a population of zero.

Our estimate of 32 individuals is very dependent on the value of the average group size. We used the mean size of groups observed in UB during reconnaissance and coastal flights in 1993 (5.6, SE = 2, Kingsley 2000). Alternatively, we could have used the mean size of groups observed by Makivik Corp. in 1982 (2.3, SE = 0.7, Smith and Hamill 1986), which would have resulted in even lower population estimates. However, we note that our estimated population size does not necessarily contradict observations of UB beluga made since 1980. Aerial surveys in July 1980 resulted in sightings of 42 animals, including a group of 24 in the Mucalic river (Finley 1982). Surveys made in 1982 by the Makivik Corporation found 11 whales in the southern part of the bay in July and 12 in August. Coastal and offshore surveys in 1985 resulted in the sightings of less than five whales but aerial surveys in 1993 yielded one sighting of 20 whales in July and one sighting of 19 whales in August. During land-based surveys made in 1993, 8 whales were seen in July off Kangirsuk, and 7 sightings totalling 36 whales were made in July and August in the south part of the bay, including a group of 17 animals (Doidge et al. 1994).

We believe the Bayesian approach allows us to make the best possible use of the limited data. However, there are limitations to how we can use the results. After each survey with zero counts, our estimate of population size gets lower. This does not reflect population trend but rather our refining of the estimate. It is therefore impractical to use these estimates in a population model similar to that of EHB beluga. If we used the results of successive estimates, we would create the impression of a decline. And if we used the same, final estimate for all four surveys, we would create the impression of stability over time, whereas in fact we cannot make any inference about the temporal trend of the population.

This being said, we note that assuming an annual growth rate of 2.7% since the first systematic survey in 1986, the UB stock would have been expected to grow over that time period, thus increasing our probability of detecting whales on the transect lines. The continued absence of sightings may thus suggest that the population is actually smaller than estimated or that little growth has occurred.

Because of strong assumed site fidelity in beluga (Finley et al. 1982, Caron and Smith 1990), it is usually assumed that beluga observed in Ungava Bay, and particularly in river estuaries, during summer belong to the UB stock. However, we cannot exclude the possibility that beluga from other stocks frequent the area and make up some of the sightings or harvest samples.

OTHER SOURCES OF INFORMATION

Historical information and Inuit traditional knowledge

Archeological sites attest that traditional hunting of beluga in Ungava Bay antedated commercial activities by the Hudson Bay Company (HBC). The commercial fishery was at its highest in the bay from 1867 to 1911, with a strong peak during the period 1877–1897 when it is estimated that 1,340–2,000 whales were taken. Using information on catches from the commercial harvest conducted by the HBC and modelling different values for the rate of population increase and the number of animals struck but not recovered or reported, the Ungava Bay population numbered at least 1,914 whales in the late 1800's (DFO 2005).

Observations and catches made in the 60's and 70's indicate that the commercial fishery did not completely eliminate the UB beluga. Reeves and Mitchell (1987) reported a sighting of 400−500 whales in the Mucalic River in August 1962. These numbers are supported by the harvest data from the same period. The harvesting of beluga was encouraged in the 1960's by the Canadian Department of Northern Affairs and National Resources because they were deemed "underexploited" (Currie 1968). Total subsistence catch between 1975 and 1984 was 745 whales. It was only in the early 1980's that the first signs of depletion became obvious. This suggests that the major summer concentrations of beluga formerly found in southern Ungava Bay were depleted by a combination of commercial whaling during the late 19th century and subsistence harvests before and since then (Reeves and Mitchell 1987).

Recent interviews of Inuit hunters from Kangiqsualujjuaq provide valuable information about migration patterns (K. Breton-Honeyman, unpublished data). Beluga are seen migrating through the Killiniq area at the end of April or beginning of May, depending on when the ice breaks up. Some will enter Ungava Bay while others seem to migrate to Quaqtaq in a straight line. Beluga are usually first seen in George River during June. Large numbers of beluga are seen during the fall migration from October to December. Between these migration peaks, individuals or small groups of whales are observed occasionally in the summer, but some participants in those interviews also acknowledged that there are fewer beluga than in the past.

Genetic identity

The proportion of EHB beluga in harvest samples from the five communities of Ungava Bay as well as Quaqtaq have been estimated by Turgeon et al. (2011) at 4% ± 5% in spring, 6% ± 9% in summer, and 28% ± 9% in the fall. These numbers suggest that EHB beluga do not pass by Ungava Bay in great numbers during the spring migration, possibly because the ice breaks up later in the bay (Galbraith and Larouche 2011), and from a west-east direction (MacLaren Marex Inc. 1979), or that, if they do, their numbers in the harvest are diluted by large numbers of beluga from other summer stocks passing through the area at the same time. It is however difficult to interpret the fall results because samples from Quaqtaq have been pooled with those of communities from inside Ungava Bay in the analysis. Samples from Quaqtaq make up 36 of the 40 fall samples. The high proportion of EHB beluga in the fall is thus characteristic of Quaqtaq, but not necessarily representative of what is available in Ungava Bay, where sample size is not large enough to draw any conclusion.

Estimating the proportion of UB beluga in Ungava Bay at different times of the year is not possible at this point. Indeed, in previous genetic analyses, the UB stock has not been considered as a "source" and therefore no attempt has been made to discriminate between this and other stocks (de March et al. 2003, Turgeon et al. 2011). Sample size in summer for this area is simply not large enough, because of the small population size, regional closure or small allowable catch in Ungava Bay.

Satellite telemetry and land-based sightings

Satellite telemetry showed that EHB beluga migrate through Ungava Bay during their fall migration (Lewis et al. 2009). All 17 whales tagged in Little Whale River between 1993 and 2004 entered Ungava Bay in October or November, where they spent time in the southeastern part of the bay. Tags from eight whales failed after spending 12 to 107 d there. The last transmission from a tag in this area was in late February, indicating that one individual spent a substantial portion of the winter in the bay. The other nine individuals left Ungava Bay between the 1st and 25th of December after staying there for 6 to 55 d (DFO, unpublished data).

Land-based sightings recorded by Inuit hunters from Ungava Bay communities in recent years confirm this pattern: the number of beluga observed in both eastern and western parts of the bay peak first in May-June then in October-November, with fewer whales seen during the summer (Hammill and Lesage 2009). This is in contrast to the 1970's when subsistence hunting in Ungava Bay occurred mostly July-August, indicating recurring presence of beluga during the summer months (Finley 1982).

RECOMMENDATIONS

Given the low estimated population size for Ungava Bay beluga, there is little scope for human-induced mortality for the UB stock. Our results indicate that any harvest from this population poses a threat to recovery. There is currently a Total Allowable Take of 10 beluga per year in Ungava Bay in the three-year management plan (2011−2013), but 17 were taken there in the summer of 2011.

The 2011 hunt was open from June 24 to August 31. The current approach to beluga management aims at minimizing the amount of EHB beluga killed in Ungava Bay. Based on known migration patterns, however, hunting in Ungava Bay in the summer probably increases the probability of taking UB beluga. In the 1996 5-year management plan, no hunting was permitted in the Ungava Bay area between August 1−31 (Lesage et al. 2001). A detailed genetic analysis that focuses on Ungava Bay only (without including Quaqtaq or other Hudson Strait communities) is necessary to better understand the contribution of each stock to the Ungava Bay harvest at different periods of the year.

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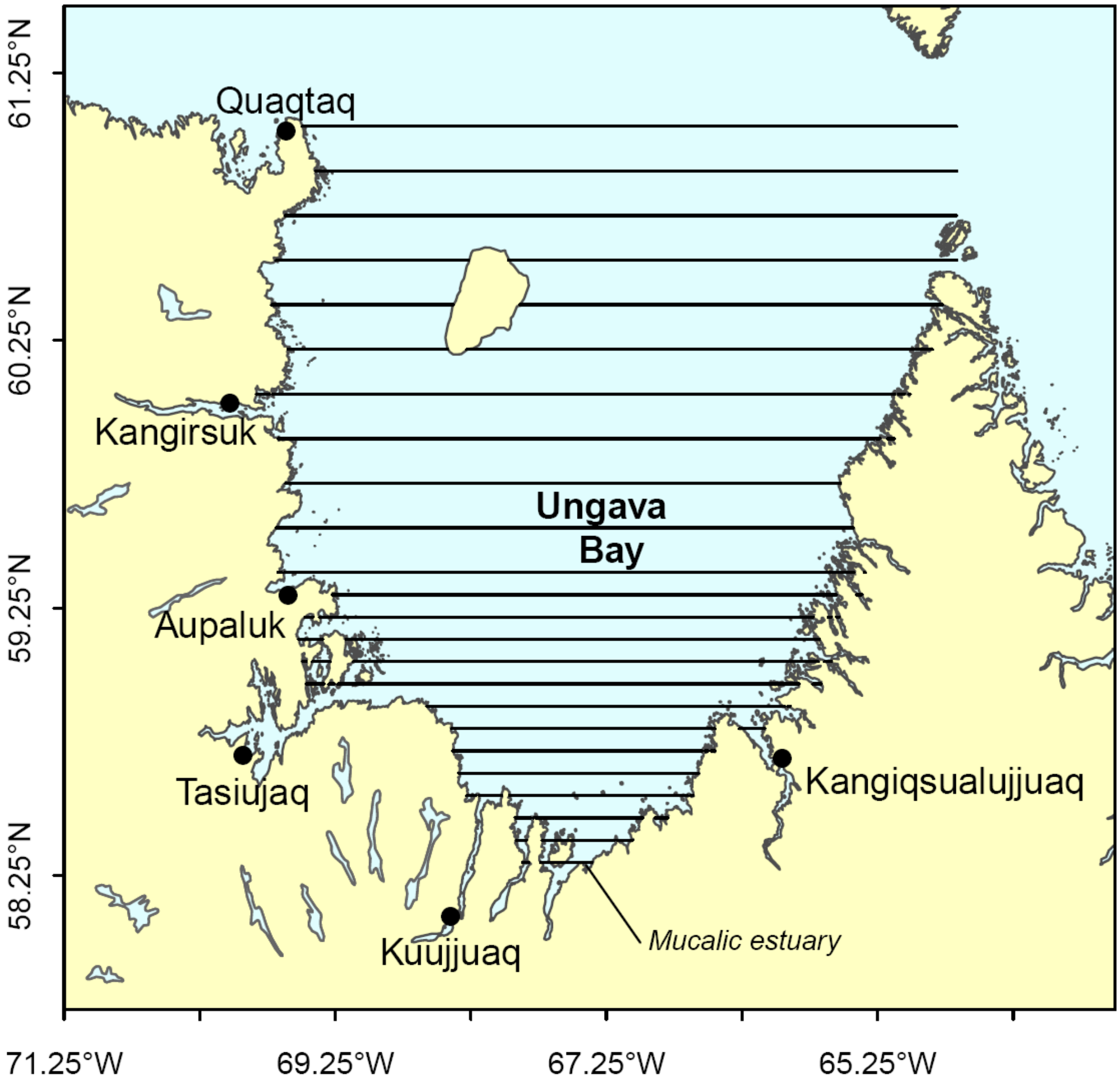

Figure 1. Map of Ungava Bay showing the transect lines of aerial surveys flown in 1985, 1993, 2001 and 2008.

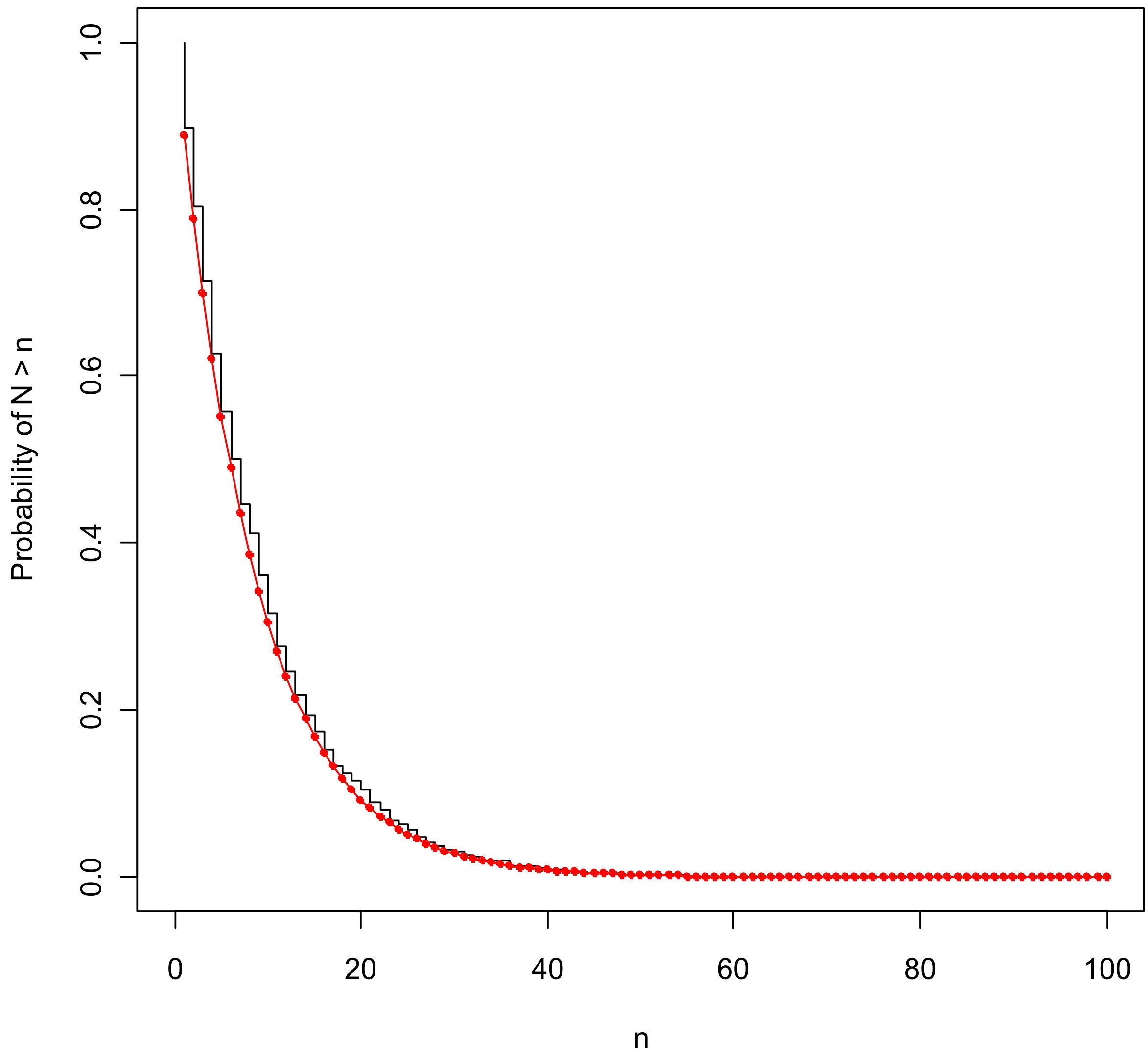

Figure 2. Probabilities of N the number of groups in Ungava being higher than the range of values on the x-axis, given that no groups were actually observed on transect lines during one survey. Black line: cumulative curve of the posterior distribution of N from a Bayesian analysis. Red line: cumulative distribution of the likelihood of multiple values of N from a classical binomial approach (as in Kingsley 2000).

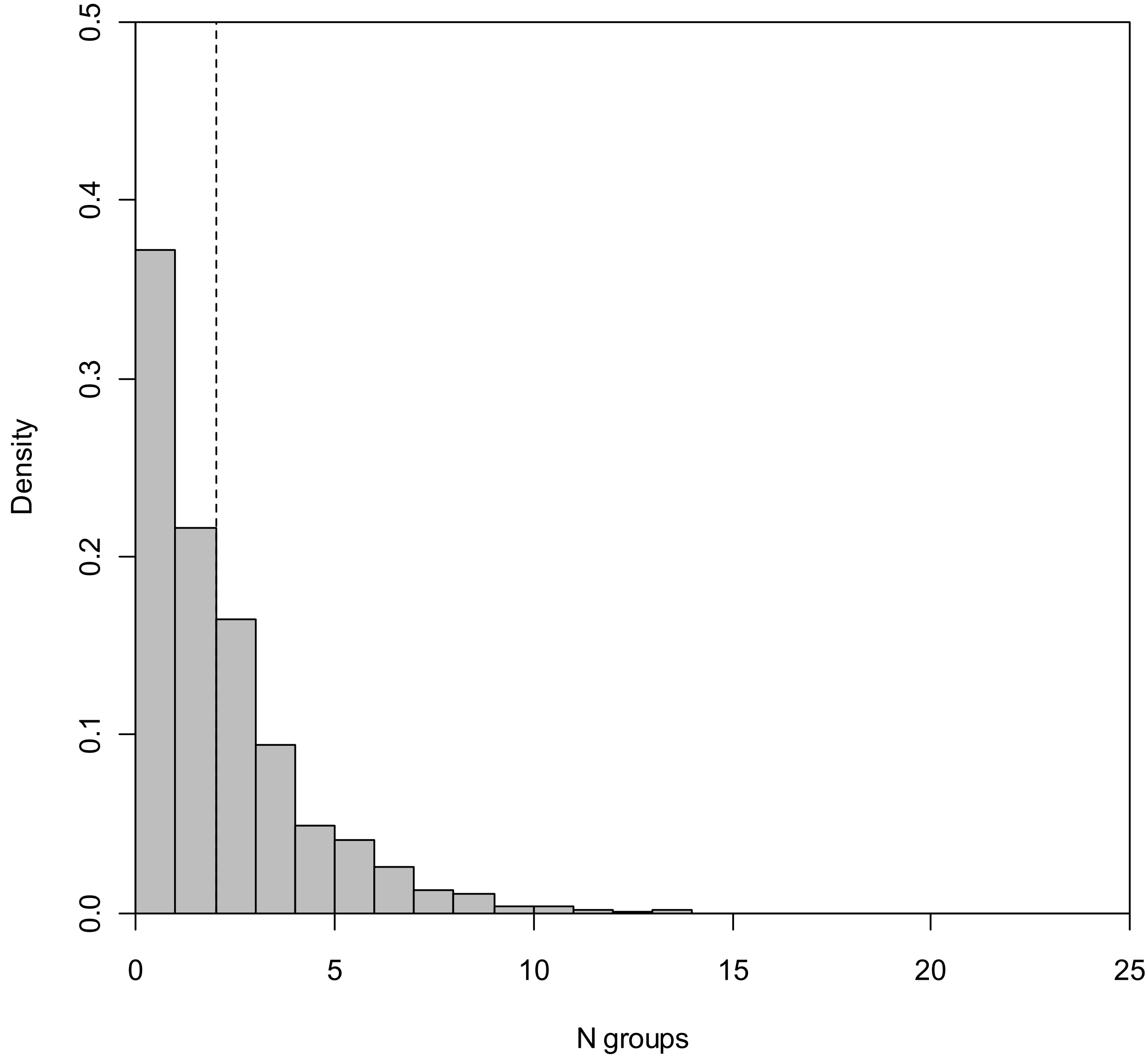

Figure 3. Posterior distribution of the number of beluga groups in Ungava Bay, based on four surveys with zero counts. Dashed line: median.

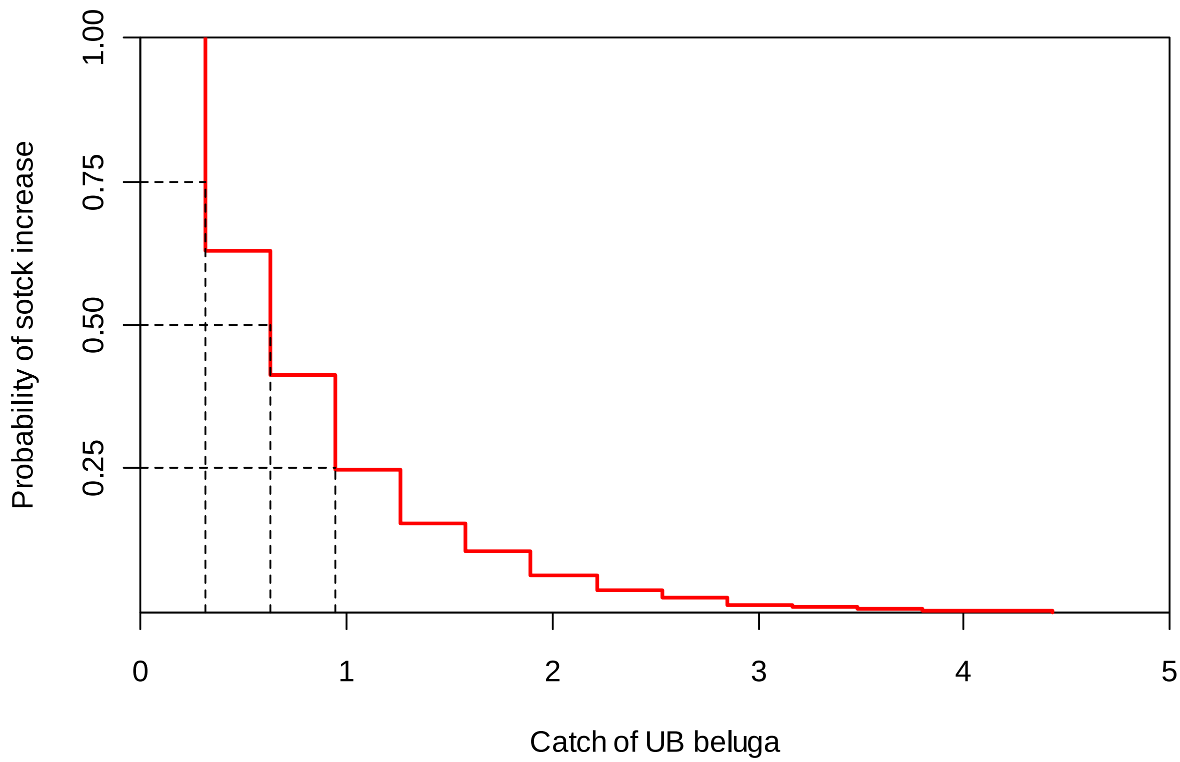

Figure 4. Probability of stock increase as a function of UB beluga harvest per year, assuming a mean group size of 5.6, a correction factor of 2.092 and a growth rate of 2.7%.These figures do not include struck-and-lost whales. Dashed lines indicate values corresponding to 75%, 50% and 25% probabilities of stock increase.