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On determining the Total Allowable Catch for Nunavut odontocete stocks

Sur la détermination des niveaux de capture totale permissibles des stocks d'odontocètes du Nunavut

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ABSTRACT

Most odontocete (narwhal and beluga) population assessments in Nunavut are data-poor, meaning that there is often only one survey of their population size, no trend data, and little information on their population dynamics. As a result, Total Allowable Catches for Nunavut odontocete whales were calculated using the Potential Biological Removal (PBR) method. The PBR results were also compared to simple growth model used to determine the risk probability of decline. In this model, uncertainty distributions were used to model the imprecision of population size and hunting loss rate and to model uncertainty in the population growth rate.

RÉSUMÉ

La plupart des évaluations de populations d'odontocètes (narvals et bélugas) du Nunavut sont basées sur des données déficientes, c'est-à-dire qu'il n'y a souvent qu'un seul relevé de la taille de la population, pas de données sur les tendances et peu d'information sur la dynamique de la population. Par conséquent, le total autorisé des captures des odontocètes du Nunavut a été calculé au moyen de la méthode du taux de prélèvement biologique potentiel (PBP). Les résultats de cette méthode ont aussi été comparés au modèle de croissance simple, afin de mesurer la probabilité de risque de diminution. À l'aide de ce modèle, il a été possible d'utiliser la répartition de l'incertitude, afin de modéliser l'imprécision de la taille de la population et du taux de perte par la chasse, de même que l'incertitude associée au taux de croissance de la population.

INTRODUCTION

Fishery and Aquaculture Management (FAM) requested advice from Science on the total allowable catch (TAC) for all Nunavut stocks of belugas (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*). FAM also requested that that science advice be framed by its draft Precautionary Approach Framework (PAF) (DFO 2007). That framework requires that a stock be classified in one of nine PA zones, defined by its status relative to population reference points and its trend (DFO, 2007). In fact, this requires a sufficiently long time series of assessments of population size, hunting mortality and concurrent population dynamics parameters. This is not feasible for data-poor stocks, stocks for which population dynamic parameters cannot be estimated because there are only one or perhaps two surveys and little data on catch levels or stock-specific measures of fecundity and survival at age. As this is the case for most stocks of odontocete whales of Nunavut, the conservative Potential Biological Removal (PBR) method was used to determine the total allowable catch for these stocks, following the example of the Atlantic Seal Precautionary Approach Framework for data-poor stocks (Hammill and Stenson 2007). Because in the past catch limit advice had been given with simple risk models, we also compared the PBR to results of such a risk model. The benefit of this comparison is that it gives co-managers a rough measure of the risk tolerance that the PBR approach affords to them.

The only exception was in the assessment of the Cumberland Sound beluga stock's TAC. This stock had been assessed previously for DFO's recovery Potential Assessment process for species proposed for listing under the Species at Risk Act. That assessment is reported in an earlier document (DFO, 2005) based on modelling done by Alvarez 2005. The assessment concluded that the present small annual subsistence quota of 41 has a high probability of allowing continued recovery of the population.

METHODS

Definition of stocks

Most Nunavut narwhal stocks (Fig.1) summer in large numbers in bays and channels of the Canadian High Arctic and spend the winter in Baffin Bay and Davis Strait (Born, *et al.*, 1994; Dietz *et al.*, 1995; Dietz *et al.*, 2001; Heide-Jørgensen *et al.*, 2002; Laidre *et al.*, 2005; Richard *et al.*, 1994; Strong, 1988; Heide-Jørgensen *et al.*, 2003). A smaller population summers in Northern Hudson Bay (Richard 1991). Evidence from genetics and contaminant ratios on stock delineation of narwhal summer stocks is weak (de March *et al.*, 2003; de March and Stern, 2003). But, based on tracking results and analogies to beluga population delineation, and for precautionary reasons, the Scientific working group of the Canada/Greenland Joint Commission on the Conservation and Management of Narwhals and Belugas (JCNB) proposed narwhal stock definitions based on summering distribution of narwhals (JWG 2004). These definitions are used to distinguish narwhal stocks here. TAC was estimated for those narwhal stocks which have been surveyed. A few hypothesized stocks such as the Smith Sound, Jones Sound stocks and Parry Island Stock, presumed to be small, could not be assessed here because there were no surveys to provide population estimates for such calculations. Nunavut beluga stocks (Fig.2) are also defined on the basis of their summer distribution

(Harwood *et al.*, 1996; Innes *et al.*, 2002 a,b; Richard *et al.*, 1990; Richard, 2005) except that the Western, Southern and Northern Hudson Bay "stocks" hypothesized to be separate stocks by Richard *et al.* (1990) are treated here as a single stock because of lack of genetic evidence or range segregation based on tracking results to differentiate them (de March, 2001; Richard *et al.*, in prep; Postma, Lianne DFO Winnipeg, pers.comm).

PBR Calculation

The Potential Biological Removal (PBR) is a method which has been shown by many computer simulations to be robust to biases in parameter inputs (Wade, 1998; Palka, 2002). This is the preferred method for stocks that are considered "data-poor", i.e.: where there are insufficient data to make a full assessment (Hammill and Stenson 2007). Often, these stocks only have a single recent survey to assess population size or insufficient or no data to estimate of population dynamic parameters

The PBR method was initially developed in the United States for the regulation of human-induced mortality on marine mammals (Wade 1998). The PBR is a conservative approach that produces a single threshold value. If removals are below the threshold, then the population is likely to increase towards or maintain itself at or above its Maximum Net Productivity Level (MNPL), i.e.: the population size at which the combined size and growth rate of the population produces the largest number of animals per year (largest productivity). PBR is estimated as: $PBR = 0.5 \bullet R_{Max} \bullet N_{Min} \bullet F_{r.}$

N_{Min} is the 20th percentile of the log-normal distribution of the estimated population size, equivalent to the lower 60% confidence limit. R_{Max} is the maximum rate of increase for the population. It is equivalent to λ (mentioned below) minus 1. When unknown for a particular population, R_{Max} is set at a default $R_{Max} = 0.04$ for cetaceans. It is halved ($0.5 \bullet R_{Max}$) to simulate the effect of logistic density dependent growth. F_r is the recovery factor with values set to reduce the base PBR value to improve the probability of recovery. Depending on population's status, F_r is set at 0.1 for a critically low population status, 0.5 for a depleted status (<MNPL) and 1 for a healthy status (Wade and Angliss, 1997).

The conservative PBR approach is a single threshold value so it does not give co-managers an opportunity to choose their risk tolerance to stock decline. But, given the extensive robustness trials of this management approach (Wade 1998, Palka, 2002) on a variety of potential biases in parameter specification, it gives co-managers a greater certainty of achieving their management goal, be it minimizing human-induced mortality for a stock considered critically low in numbers, recovery towards MNPL for a depleted population (<MNPL), or maintaining the population at a high productive level (≥MNPL) for a stock considered healthy.

Co-management for Arctic odontocetes usually is based on annual quotas limiting landed catch rather than total removal. The landed catch is easier to monitor than total removal, i.e.: total harvest mortality. Hunting losses are assessed separately.

The PBR was therefore converted to a landed catch limit (LCL) as shown below.
LCL = PBR / LRC where LRC is the loss rate correction (see below).

Risk Assessment

A simple risk assessment approach has been used in the past for science advice. The impact of harvesting was examined using an exponential growth model: $N_{t+1} = (N_t \cdot \lambda) - H_t$ where N_t is the population size at time t, λ is the rate of increase, and H_t is the annual removal from the population (reported landed catch + hunting losses). Estimates of hunting losses are incorporated as uncertainty distributions, i.e.: Normal (mean, SD), so that the risk probability can be calculated for the landed catch rather than the total removal.

To calculate the risk of decline to a particular decline threshold, we first projected thousands of model populations, assuming fixed population growth rates. Each start population size was drawn from the sampling error distribution of the population estimate, i.e.: in proportion to the lognormal distribution of its estimate. We could then calculate the proportion of those populations that declined by a known percentage over a period of ten years to generate the risk probabilities for various fixed growth rates.

The problem with this approach is that it requires an educated guess about what growth rate is most probable. In fact, while we have imprecise estimates of the population growth rate for some populations, we do not know how fast any particular stock would be able to grow to compensate for hunting removals. It is not sufficiently conservative to reduce the potential risk of serious harm to these data-poor stocks.

A better approach is to treat the lack of estimates of the population growth rate as an uncertain parameter. Thousands of populations are then modelled by drawing a start population from the population estimate's error distribution as well as from a uniform distribution of plausible growth rates between 1.01 to 1.04. Since most of the uncertainty in the risk analysis is related to population size, growth and hunting loss rate, this approach provides co-managers a rough estimate of the risk that they might be taking in choosing a particular catch level. It is used here for comparison with the PBR results to give an indication of the risk tolerance afforded by that approach.

Model inputs

Stock size

High Artic narwhals (*Monodon monoceros*) were recently surveyed in Eclipse Sound, Admiralty Inlet, Prince Regent Inlet, Barrow Strait, Gulf of Boothia, and in fiords and bays along the eastern coast of Baffin island during the month of August of 2002 to 2004 (Richard *et al.*, in prep.[*]). An earlier survey in 1996 covered Prince Regent Inlet, Peel Sound, Barrow Strait. It covered the summer range of the "Somerset" sub-stock better than the more recent surveys and gave a more precise estimate of its numbers (Innes *et al.*, 2002a). That population estimate was used for modelling that particular stock.

Estimates of narwhal and beluga stock numbers are given in Table 1. They are based on the most recent published surveys or, as in the case of the Somerset narwhal, the best coverage of the stock's summer range.

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Table 1: Population estimates used for beluga and narwhal Allowable Landed catch estimates.

Population	Estimate	SE	CV	References
Nunavut narwhal stocks				
Somerset Narwhal	45358	15875	35%	Innes *et al.* 2002
Admiralty Narwhal	5362*	2681*	50%	Richard *et al.*, in prep.
Eclipse Narwhal	20225*	7285*	36%	“
East Baffin Narwhal	10073*	3123*	31%	“
N Hudson Bay Narwhal	5053	2009	40%	Bourassa, 2003; Richard *et al.*, unpubl. data
Nunavut beluga stocks				
W+N+S Hudson Bay Beluga	63122	12429	20%	Richard 2005; Richard and Barber 1990
Eastern High Arctic*-Baffin Bay Beluga	21213*	5303*	25%	Innes *et al.* 2002
E Beaufort Sea Beluga	41803	7577	18%	Harwood *et al.* 1996; Kingsley and Gauthier 2002*

Rate of increase

The dynamics of narwhal populations are uncertain, so the range of rates of increase used in the model runs are based on the dynamics of its closest relative, beluga, and of other odontocetes. It has been estimated that maximum intrinsic rates of increase of odontocetes are probably between 1.03 -1.06 (Doidge, 1990; Kingsley, 1989; Reilly and Barlow, 1986; Richard *et al.*, 2001; Wade, 1998). In this analysis, population growth rates are not known but they are unlikely to be in the upper range of these maxima since none of those populations are likely to be small enough to grow at the upper end of that range. The range of rates of increase for beluga and narwhals used in these analyses was therefore set at 1.01-1.04. This range was modelled as a Uniform (1.01, 1.04).

Hunting loss rate conversion

Hunting losses are not known for all populations of these species and for all areas where they are hunted. In some Nunavut communities with a community-based management system, killed-lost and wounded-lost narwhal numbers have been documented. Nevertheless, the number of animals wounded and lost which actually die as a result of their wound is unknown.

From those narwhal hunts, a hunting loss rate correction (LRC) of landed catch was calculated as follows: LRC = HM / LC where HM is the estimated total hunting mortality, or the sum of the landed catch and hunting loss, and LC is the Landed Catch (Appendix I). The estimated hunting loss was calculated as: $HM = (HM_{min} + HM_{max})/2$ where HM_{min} is the number of animals landed plus the ones reported sunk & lost, and

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HM_{max} is HM_{min} + the number reported wounded & escaped. In effect, the HM estimate assumes that half of the animals wounded & escaped die later of their wounds. This is an untested assumption but a reasonable one in absence of data on that proportion. Belugas and narwhals are sometimes seen with well-healed gunshot wounds, indicating that not all animals that escape a hunt die of their wounds. On the other hand, days or weeks after hunts, animals are sometimes found dead, indicating that other animals escape the hunts with wounds that lead to their eventual death.

The loss rate correction was averaged over the different communities monitored (Appendix I) and modelled as an uncertain parameter expressed as a Normal distribution (mean: 1.28, SD: 0.15) left-truncated at 1. A similar correction was calculated for beluga stocks from community-based loss rate reporting in Kimmirut, Iqaluit and Pangnirtung (Appendix II). In the case of belugas, the reported loss rate correction for that stock was modelled as Normal (1.18, 0.7) truncated at 1.

RESULTS AND DISCUSSION

The 20% percentile of the population estimate (Nmin) was used to calculate PBR and the corresponding Total Allowable Landed Catch (TALC), which is the PBR minus losses (Table 2). Given the lack of significant trend for most stocks (Richard, unpubl. data), a recovery factor (F_r) of 1 was used in all these calculations. The exception is Admiralty Inlet where there is an apparent decline in numbers from earlier estimates. For that stock, a recovery factor of 0.5 was used.

The recommended total allowable landed catch, i.e.: PBR-losses, is similar to the risk analysis landed catch that has a 0.05 risk probability of causing a declining trend of up to10% in ten years (Table 2). The results vary between the PBR – loss being just above or just below the risk analyses TALC.

Table 2: Recommended Allowable Landed Catch estimates obtained by the PBR – loss method. Shown for comparison are results from the risk analysis (greyed-out). A recovery factor of 1 was used, except in the case of Admiralty Inlet where it was set to 0.5. [*] *Note: A TALC of 41 for Cumberland Sound belugas was assessed in a previous science advice document (DFO 2005).*

				Total Allowable Landed Catch (TALC)	**Risk Analysis**
Population	**N_{min}**	**Loss rate correction (SD)**	**PBR***	**PBR minus losses**	**TALC for Prob(change ≥ -10%) = 0.05**
Nunavut narwhal stocks					
Somerset Narwhal	34068	1.28 (0.15)	681	532	598
Admiralty Narwhal	3602*	1.28 (0.15)	36	28	51
Eclipse Narwhal	15074*	1.28 (0.15)	301	236*	235*
East Baffin Narwhal	7805*	1.28 (0.15)	156	122	126*
N Hudson Bay Narwhal	3660	1.28 (0.15)	73	57	56
Nunavut beluga stocks					
W+N+S Hudson Bay Beluga	53563	1.18 (0.07)	1071	908	991
Eastern High Arctic*-Baffin Bay Beluga	17241*	1.18 (0.07)	345*	292*	315*
East Beaufort Sea Beluga	35930	1.18 (0.07)	719	609	668

A decline of 10% is a significant decline for populations that probably do not grow faster than 1% - 4% per year. Co-managers would more than likely want to minimize the risk of such a decline by setting TALC that have a very low risk probability (e.g.:~ 0.05) because, if such a decline did take place, it would force them to further reduce the TALC in the future to allow the population to recover. The recommended TALC or PBR minus losses provides a limit which has a low risk of causing such a decline.

The above results are sensitive to input parameters. The survey estimates have wide variances (CV, Table 1) and the population growth rate is assumed to be in the range of 1.01-1.04. It is difficult to improve on the precision of the survey estimates because of the wide summer range of these animals and their non-random or uniform distribution in that summer range. That distribution is often variable between years and even over a particular summer season, making stratified survey designs difficult to implement.

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In the future, more surveys of these stocks may help to estimate trend and population dynamic parameters for these stocks. These recommended allowable landed catch could also be revised for any particular stock if there is good evidence that hunting losses have been significantly reduced. In the mean time, management advice is best to be conservative to ensure long-term sustainability.

These PBR estimates are total allowable landed catch recommendations for each stock irrespective of where a stock is hunted. In many cases, stocks are hunted as they migrate between winter and summer range. They may also be taken in their winter range. In future allocation of these TACs, care should be taken to estimate the numbers of animals from each stock which are taken in other areas of Nunavut than their summering range or by hunters in regions adjacent to Nunavut (e.g.: N.W.T., Greenland, Nunavik).

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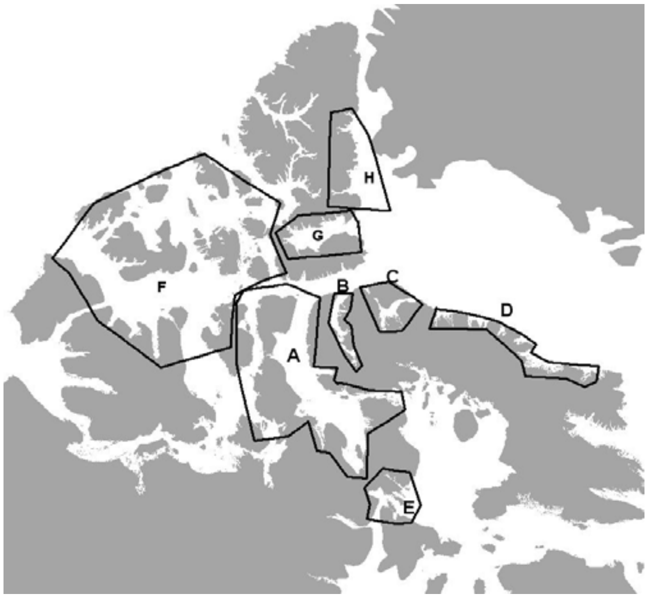

Fig 1: Approximate summer range of Nunavut narwhal stocks discussed in document: A- Somerset, B- Admiralty, C- Eclipse, D- East Baffin, E- Northern Hudson Bay, F – Parry Island, G- Jones Sound, H – Smith Sound.

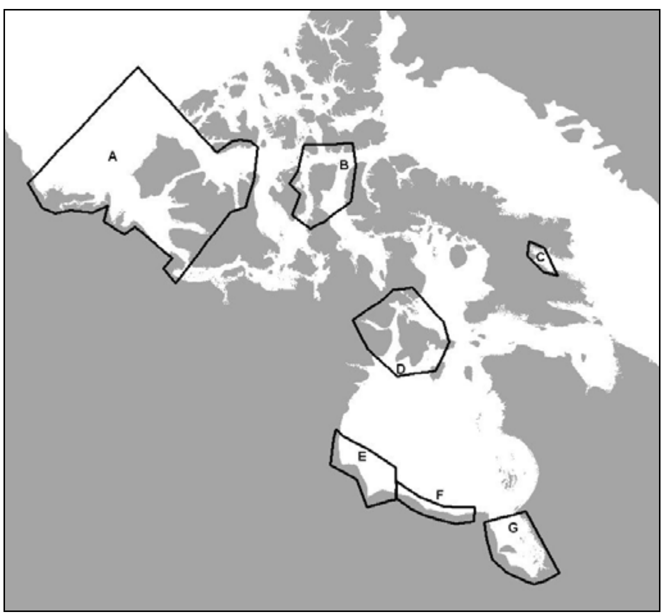

Fig 2: Approximate summer range of Nunavut beluga stocks discussed in document: A- East Beaufort Sea, B- Baffin Bay, C- Cumberland Sound, D- Northern Hudson Bay, E- Western Hudson Bay, F- Southern Hudson Bay. It is possible the James Bay population (G) is occasionally hunted by Sanikiluaq hunters in winter, but this has not been confirmed.*

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Appendix I: Calculation of narwhal standard hunting loss rate correction. Numbers landed, wounded and escaped, and sunk and lost are provided by FAM and are based on reports from communities.

NARWHALS Community	Year	Quota?	Landed	Wounded & Escaped	Sunk & Lost	Hunting Mortality MIN	Hunting Mortality MAX	Estimated Total Kill	Loss rate correction Total / landed
Pond Inlet	1999	NQ	130	14	16	146	160	153	1.18
	2000	NQ	166	21	10	176	197	187	1.12
	2001	NQ	63	5	27	90	95	93	1.47
	2002	108	92	1	13	105	106	106	1.15
Qikiqtarjuaq	1999	NQ	81	30	25	106	136	121	1.49
	2000	NQ	137	79	40	177	256	217	1.58
	2001	NQ	89	8	9	98	106	102	1.15
	2002	81	81	40	16	97	137	117	1.44
	2004	90	96	12	9	105	117	111	1.16
Repulse Bay	1999	NQ	156	68	30	186	254	220	1.41
	2000	NQ	49	9	5	54	63	59	1.19
	2001	NQ	100	38	21	121	159	140	1.40
	2002	72	57	0	8	65	65	65	1.14
	2003	72	30	0	5	35	35	35	1.17
	2005	72	72	25	3	75	100	88	1.22
Arctic Bay	2001	NQ	134	20	4	138	158	148	1.10
	2003	130	129	14	22	151	165	158	1.22
	2004	130	122	22	33	155	177	166	1.36
Kugaaruk	2001	NQ	41	18	8	49	67	58	1.41
	2003	25	24	4	2	26	30	28	1.17
								mean	1.28
								stdev	0.15
								min	1.10
								max	1.58

Appendix II: Calculation of beluga standard hunting loss correction rate. Numbers landed, wounded and escaped, and sunk and lost are provided by FAM and are based on reports from communities.

BELUGAS Community	Year	Quota?	Landed	Wounded & Escaped	Sunk & Lost	Hunting Mortality MIN	Hunting Mortality MAX	Estimated Total Kill
Iqaluit	1999	70	23	5	75	98	87	1.24
	2000	22	0	4	26	26	26	1.18
	2001	45	3	12	57	60	59	1.30
	2002	35	8	5	40	48	44	1.26
Kimmirut	1999	19	1	2	21	22	22	1.13
	2000	27	2	2	29	31	30	1.11
	2002	38	0	5	43	43	43	1.13
Pangnirtung	2002	41	2	3	44	46	45	1.10
	2003	46	1	8	54	55	55	1.18
							mean	1.18
							stdev	0.07
							min	1.10
							max	1.30