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Assessment of the recovery potential of the eastern Canadian Arctic bowhead whale population by deterministic projections with a modified logistic growth model.

Évaluation du potentiel de rétablissement de la population de baleines boréales de l'est de l'Arctique canadien à l'aide de projection déterministes réalisées au moyen d'un modèle de croissance sigmoïde modifié

Larry Dueck and Pierre Richard

Fisheries and Oceans Canada
Central and Arctic Region
501 University Crescent
Winnipeg, Manitoba, R3T 2N6

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ABSTRACT

A deterministic growth model employing a logistic growth function was used to simulate the population growth of the eastern Arctic bowhead whale population. Parameters in the model included R_{max} (the natural intrinsic rate of increase of the population), K (the estimated carrying capacity of the ecosystem), Ψ (a shaping parameter that modifies the population growth rate as the population approaches theoretical carrying capacity), and C (human induced causes of mortality). A total of 612 scenarios were examined, based on the combinations of different levels for the parameters described above. The levels were selected to encompass the range of uncertainty in modeling the growth of the population as well as including harvest levels ranging from low or none, to levels that resulted in a decline in the population. The results of the model provide insight into the potential for recovery of the bowhead whale population in the eastern Arctic. Under the assumptions of the model, under moderate levels of human-induced mortality, all scenarios would lead to recovery of the population. The results provide a useful measure of comparison for stochastic modeling exercises incorporating error into growth parameters.

RÉSUMÉ

Un modèle de croissance déterministe utilisant une fonction de croissance sigmoïde a servi à simuler la croissance d’une population de baleines boréales de l’est de l’Arctique. Les paramètres du modèle comprenaient R_{max} (le taux intrinsèque naturel d’augmentation de la population), K (la capacité de charge estimative de l’écosystème), Ψ (un paramètre de modelage qui modifie le taux de croissance de la population à mesure que celle-ci se rapproche de la capacité de charge théorique) et C (les causes de mortalité anthropiques). Au total, 612 scénarios ont été examinés, issus de combinaisons de différents niveaux des paramètres décrits ci-dessus. Les niveaux ont été choisis de manière à inclure toute la gamme d’incertitudes dans la modélisation de la croissance de la population, ainsi qu’une échelle de niveaux de captures allant de faibles ou inexistantes jusqu’à un taux qui entraîne une diminution de la population. Les résultats du modèle donnent une idée des possibilités de rétablissement de la population de baleines boréales dans l’est de l’Arctique. Compte tenu des hypothèses du modèle, à des niveaux moyens de mortalité anthropique, tous les scénarios entraînent le rétablissement de la population. Les résultats fournissent une mesure utile de comparaison pour les exercices de modélisation stochastique intégrant une erreur dans les paramètres de croissance.

INTRODUCTION

In 2005, COSEWIC recommended that bowhead populations of the eastern Canadian Arctic be listed as “threatened”. Accepting this designation under Canada’s Species at Risk Act (SARA) requires DFO to assess the recovery potential and to develop recovery goals for these animals under a “Recovery Strategy”. One of the objectives of the Recovery Strategy is to identify and assess recovery targets such as recovered population size, acceptable time to recovery, and allowable harm (e.g. harvests) under such a strategy.

This paper describes the results of a deterministic growth model exercise used to examine potential population growth and years-to-recovery (YTR) for bowhead whales of the eastern Canadian Arctic. The exercise employs various scenarios for growth of the population based on different levels of presumed pre-exploitation population size, harvest rates, and various population growth parameters.

In their assessment of bowhead whales, COSEWIC designated two populations in the eastern Canadian Arctic. Recent information indicates that there is no evidence to support the idea of two populations. Genetic analyses provides no basis for discriminating populations (Postma *et al.* 2006) and tracking data indicates that bowhead whales from various parts of the eastern Canadian Arctic and Greenland range widely and share both common summering and wintering areas (Dueck *et al.* 2006, Heide Jørgensen *et al.* 2003, 2006). The exercise described here thus assumes that bowhead whales in the region belong to one population.

METHODS

A deterministic growth model was used to calculate future population size for bowhead whales in the eastern Canadian Arctic. The model uses a logistic growth function without an error term, described by the formula

$$N_{t+1} = N_t + N_t\, R_{max}\, [1 - (N_t/K)^{\Psi}] - C_t$$

where:

N_t = abundance at time t;
R_{max} = the maximum intrinsic rate of increase of the population;
K = the pre-exploitation population size, assumed to be the carrying capacity;
Ψ = a shaping parameter that modifies the population growth rate as the population approaches theoretical carrying capacity, effectively defining at what population size productivity is maximum;
C_t = the removal rate due to harvest and struck and loss

A total of 612 scenarios were examined, based on the combinations of different levels for the parameters described above. The levels were selected to encompass the range of uncertainty in modeling the growth of the population as well as including harvest levels ranging from low or none, to levels that would be sure to cause a decline in the population.

The initial abundance of the population (N_t) was derived from the most recent aerial surveys available (Cosens *et al.* 2006). The best estimate for a single population of bowhead whales in Canada was determined to be 7309 (corrected for diving whales, CV = 0.45), based on counts obtained in August 2002 for Prince Regent Inlet, Gulf of Boothia and Eclipse Sound. This estimate is considered conservative since it is a partial estimate of the population. Not included in this estimate are whales known to be present during August in the areas of Foxe Basin, Hudson Bay, eastern Baffin Island coastal area, Admiralty Inlet and Peel Sound (Cosens *et al.* 2006). In order to add a measure of conservatism, the 60% LCL of the survey estimate was used as the initial population abundance.

In absence of estimates of the maximum net productivity rate (R_{max}), a default value for cetaceans is 4% in PBR assessments (Wade and Angliss 1997). The most recent estimate of the rate of increase determined for the western Arctic bowhead whale population is 3.4% (95% CI 1.7%-5%) and was suggested by the authors that this may be the biological maximum for the species (George *et al.* 2004). In our trials, four levels of population growth (R_{max}) were used (0.1, 0.2, 0.3, and 0.4), corresponding to a range of growth rates from very low to the default maximum for cetaceans.

Available estimates of the original population size of bowhead whales in the eastern Canadian Arctic are based on direct calculations from catch histories. Calculations based on whales taken in the Davis Strait and Baffin Bay region resulted in an estimate of 11,780 whales prior to exploitation in that region (Woodby and Botkin 1993). Similarly, about 580 whales are estimated to have existed in Hudson Bay prior to exploitation (Woodby and Botkin 1993). Combining the two estimates results in a total of about 12,300. In COSEWIC's status report on bowhead whales, they indicate the Hudson Bay population (excluding the Foxe Basin segment) was estimated to number 440-470 whales, and the Davis Strait-Baffin Bay population was estimated to number 12,000 whales prior to the onset of commercial whaling, but provide no references for the source of these numbers. Three levels for the pre-whaling population abundance were used (assumed to be comparable to carrying capacity), based on 60% confidence limits around the estimate of 12,300 (using a Normal distribution with CV of 30% (Alvarez 2006). This meant that original populations of 9000, 12300 and 15000 were examined. Recovery was assumed to have occurred when the population reached 70% of the given original population size.

Three values for the shaping factor Ψ were selected, roughly corresponding to the range considered feasible for the ratio of maximum net productivity level to K

(MNPL/K) for marine mammals (Taylor and De Master 1993). The Ψ parameters of 1, 4.2 and 18.18 produced logistic growth functions where MNPL was achieved at 0.5K, 0.675K and 0.85K.

A range of removal levels (catch + struck and loss) was chosen to reflect the full range of possible harvests, including no harvest, as well as levels certainly exceeding current demands, so as to examine the effects of high harvest levels. Removal levels were selected beginning at zero and increasing incrementally by one up to 10, by 5 to 30 and by 10 up to a maximum harvest of 50 animals.

RESULTS

The results of the modeling exercise are presented in Table 1. All scenarios lead to recovery of the eastern Arctic bowhead whale population (70% of pre-exploitation levels) if harvest levels ≤ 15 animals. The longest time to recovery under this harvest level scenario is 261 years.

For Ψ ≥ 4.2, the results indicate that the population is likely to grow to recovery within 100 years at harvest levels ≤ 10, even at a low population growth rates (R = 0.01) and for any K selected. Recovery using this level of Ψ would occur within a few decades if R ≥ 0.02, even for high harvest levels.

For Ψ = 1 and K ≥ 12,300, recovery is possible within 100 years for harvest levels ≤ 15 and growth rates ≥ 0.02, but YTR would be > 100 years if R = 0.01, even with no harvest.

The eastern Arctic bowhead whale population is predicted to go into decline for certain selected population growth parameters. A decline is predicted for Ψ = 4.2, R = 0.01 and a harvest levels of 50 animals, if the original population size is ≤ 12,300. For Ψ = 1, population abundance is also predicted to decline in some cases if R is low and harvest levels > 20.

DISCUSSION

The deterministic growth modeling exercise provides a variety of population growth scenarios, from conservative to optimistic. The exercise is useful in allowing comparison of the relative effects of varying the levels of input parameters affecting the growth of the population and on the estimated years-to-recovery.

Assuming that the population growth of the eastern Arctic population of bowhead whales is accurately defined by some combination of the range of input parameters tested in the model, we conclude that the population is very likely to reach recovery (70 % of pre-exploitation population size) with moderate harvest levels (eg.: ≤ 20). Using parameter options that are considered to be the most biologically reasonable (e.g. $\Psi = 4.2$, $R_{max} \geq 0.02$), recovery is likely to occur within a few decades if harvests are moderate, and well within 100 years at harvest levels up to 50 animals per year.

The target for recovery of 70% of the historic (pre-commercial whaling) population size is considered to be consistent with patterns of natural variability for many species with life histories characteristics of cetaceans. It is important to note that the bowhead whale population will be in a condition when they would no longer be at risk of extinction well before this target is reached

The conclusions described above hold under the assumption that the population is described appropriately by a logistic model with the parameters in the range used in the present analysis. This model assumes that environmental conditions will not change substantially due to climate change or catastrophic events, and that there are no other significant sources of mortality not accounted for.

The model used here is a logistic growth model without variance in the vital rates. A better model to predict growth would be a stochastic model that incorporates variance. Such a model would require assumptions about vital rates that are largely unknown for bowhead whales currently. However, large (K-selected) mammals tend to have relatively small variation in vital rates and they tend to be serially correlated. Bowhead whales, which are able to store vast quantities of energy to endure periods of poor environmental conditions (George *et al.* 1999) exhibit the characteristics of animals with stable vital rates. Until a more realistic stochastic model is completed, the deterministic logistic growth model described here provides an approximation of the expected growth of the population. In turn, the results of a stochastic model can be interpreted in reference to the deterministic exercise.

REFERENCES

Alvarez, C. 2006, Evaluating the effect of alternate harvest scenarios on the recovery of bowhead whales, *Balaena mysticetus*, in the eastern Canadian Arctic. Contract report N. F2402-050202 to the Department of Fisheries and Oceans, C&A region, Stock Assessment Division. 26 p.

Cosens, S.E., H. Cleator and P. Richard. 2006. Results of aerial surveys of bowhead whales (*Balaena mysticetus*) in the eastern Canadian Arctic in 2002, 2003 and 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/052.

Dueck, L.P., M.P. Hiede-Jørgensen, M.V. Jensen and L.D. Postma. 2006. Update on investigations of bowhead whale (*Balaena mysticetus*) movements in the eastern Arctic, 2003-2005, based on satellite-linked telemetry. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/050.

George, J.C., J. Bada, J. Zeh, L. Scott, S.E. Brown, T. O'Hara and R. Suydam. 1999. Age and growth estimates of bowhead whales (Balaena mysticetus) via aspartic acid racemization. Canadian Journal of Zoology 77: 571-580.

George, J.C. "Craig", J. Zeh, R. Suydam, and C. Clark. 2004. Abundance and population trend (1978-2001) of the western Arctic bowhead whales surveyed near Barrow, Alaska. Marine Mammals Science 20:755-773.

Heide-Jørgensen, M.P., K.L. Laidre, Ø. Wiig, M.V. Jensen, L. Dueck, L.D. Maiers, H.C. Schmidt and R.C. Hobbs. 2003. From Greenland to Canada in ten days: tracks of bowhead whales, *Balaena mysticetus*, across Baffin Bay. Arctic 56: 21-31.

Heide-Jørgensen, M.P., K.L. Laidre, M.V. Jensen, L. Dueck, L.D. Postma. 2006. Dissolving stock discreteness with satellite tracking: bowhead whales in Baffin Bay. Marine Mammal Science 22: 34-45.

Postma, L.D., L.P. Dueck, M.P. Heide-Jørgensen, and S.E. Cosens. 2006. Molecular genetic support of a single population of bowhead whales (*Balaena mysticetus*) in eastern Canadian Arctic and western Greenland waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/051.

Taylor, B.L. and D.P. De Master. 1993. Implications of non-linear density dependence. Marine Mammal Science 9: 360-371.

Wade, P.R. and R. Angliss. 1997. Guidelines for assessing marine mammal stocks: report of the GAMMS workshop April 3-5, 1996, Seattle, Washington. U.S. Dep. Commerc., NOAA Tech. Memo. NMFS-OPR-12, 93 pp.

Woodby, D.A. and D.B. Botkin. 1993. Stock sizes prior to commercial whaling, pp. 387-407 in *The Bowhead Whale*, edited by J.J. Burns, J.J. Montague and C.J. Cowles. The Society of Marine Mammalogy Special Publication No. 2. Allen Press Inc., Lawrence, KS.

Table 1. Results of deterministic growth model, using varying levels of original population size (K), population growth rate (R), shaping parameter (Ψ), and harvest levels to determine YTR (years to recovery), where YTR was defined as the population level that reached 70% of the original population size (see text for description of model formula and selection of parameters)

Ψ = 18.18, MNPL = 0.85K

For K = 15000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	73	37	25	19
1	74	37	25	19
2	75	37	25	19
3	76	38	25	19
4	77	38	25	19
5	79	38	26	19
6	80	39	26	19
7	81	39	26	19
8	82	39	26	19
9	84	39	26	20
10	85	40	26	20
15	93	41	27	20
20	102	43	27	20
25	113	45	28	21
30	128	47	29	21
40	179	51	31	22
50	403	57	32	23

For K = 12300

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	53	27	18	14
1	54	27	18	14
2	55	27	18	14
3	56	28	18	14
4	57	28	19	14
5	58	28	19	14
6	58	28	19	14
7	59	28	19	14
8	60	29	19	14
9	62	29	19	14
10	63	29	19	14
15	69	30	20	15
20	77	32	20	15
25	86	33	21	15
30	99	35	21	16
40	145	39	23	16
50	361	44	24	17

For K = 9000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	22	11	8	6
1	22	11	8	6
2	23	11	8	6
3	23	11	8	6
4	23	12	8	6
5	24	12	8	6
6	24	12	8	6
7	25	12	8	6
8	25	12	8	6
9	26	12	8	6
10	26	12	8	6
15	29	13	8	6
20	33	13	9	6
25	39	14	9	7
30	46	15	9	7
40	75	17	10	7
50	259	20	11	7

Ψ = 4.2, MNPL = 0.65K

For K = 15,000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	79	40	27	20
1	80	40	27	20
2	81	40	27	20
3	82	41	27	20
4	84	41	27	21
5	85	41	27	21
6	86	42	28	21
7	88	42	28	21
8	89	42	28	21
9	91	43	28	21
10	92	43	28	21
15	101	45	29	21
20	112	47	30	22
25	126	49	30	22
30	143	51	31	23
40	204	56	33	24
50	535	63	35	25

For K = 12,300

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	58	30	20	15
1	59	30	20	15
2	60	30	20	15
3	61	30	20	15
4	63	31	20	15
5	64	31	20	15
6	65	31	21	15
7	66	31	21	16
8	67	32	21	16
9	69	32	21	16
10	70	32	21	16
15	78	34	22	16
20	87	35	22	16
25	100	37	23	17
30	117	39	24	17
40	181	44	25	18
50	decline	50	27	19

For K = 9,000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	25	13	9	7
1	26	13	9	7
2	26	13	9	7
3	27	13	9	7
4	28	13	9	7
5	28	14	9	7
6	29	14	9	7
7	30	14	9	7
8	30	14	9	7
9	31	14	9	7
10	32	14	9	7
15	37	15	10	7
20	43	16	10	7
25	52	17	11	8
30	66	19	11	8
40	147	22	12	8
50	decline	26	13	9

Ψ = 1.0, MNPL = 0.5K

For K = 15,000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	152	76	51	38
1	156	77	51	39
2	161	78	52	39
3	165	79	52	39
4	171	80	53	39
5	176	82	53	40
6	182	83	54	40
7	188	84	54	40
8	195	86	55	40
9	203	87	55	41
10	210	88	56	41
15	261	96	59	43
20	346	105	62	44
25	512	117	66	46
30	>1000	131	70	48
40	decline	173	81	53
50	decline	256	95	59

For K = 12,300

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	120	60	40	30
1	124	61	41	30
2	128	62	41	31
3	133	63	42	31
4	138	64	42	31
5	144	66	43	32
6	150	67	43	32
7	157	68	44	32
8	164	69	44	32
9	172	71	45	33
10	181	72	45	33
15	245	80	48	35
20	379	91	52	36
25	943	104	56	38
30	decline	123	61	40
40	decline	190	73	46
50	decline	471	93	52

For K = 9,000

Harvest level	Years to recovery R = 0.01	R = 0.02	R = 0.03	R = 0.04
0	58	29	20	15
1	61	30	20	15
2	65	31	20	15
3	68	32	21	15
4	72	32	21	16
5	77	33	21	16
6	82	34	22	16
7	88	35	22	16
8	95	36	23	16
9	103	37	23	17
10	113	39	23	17
15	214	46	26	18
20	>1000	57	29	19
25	decline	74	33	21
30	decline	107	38	23
40	decline	>1000	55	28
50	decline	decline	104	37