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Preliminary evaluation of selective hunting and recovery of Eastern Canadian Arctic-West Greenland bowhead whales

Evaluation préliminaire de l'effet de prises sélectives sur le redressement de la population de baleines boréales de l'arctique canadien oriental et du Groënland occidental

L. Dueck and P. Richard

Fisheries and Oceans Canada
501 University Crescent
Winnipeg, MB
R3T 2N6

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ABSTRACT

A deterministic, stage-based population model was constructed to examine the relative impacts of four hypothetical hunting scenarios on the population recovery of the Eastern Canadian Arctic- West Greenland bowhead whale population. The hunting scenarios included "no hunting", an "adult-juvenile" hunt (age and gender in equal numbers), an "adult only" hunt (equal gender ratio), and an "adult female" biased hunt (only adult females). Population characteristics were selected based on a combination of best available information and subsequent assumptions that allow the model to result in some positive growth under "no hunting" and allow a small percentage of animals to survive to 100 years. Theoretical population sizes of 5,000 and 10,000 were examined. An "adult female" biased hunt had the greatest negative (or least positive) effect on population growth, followed by "adult only", "juvenile-adult", and "no hunting". If larger initial population size is assumed, no population decline was observed for any hunting scenarios. The results of the modelling suggest that a risk of decline in the population, even for a female-biased hunt of 10 whales is unlikely. However, without more precise information on survival rates, fecundity, population abundance and population composition, it is not possible to provide specific risk assessments for any given hunting scenario.

RÉSUMÉ

On a élaboré un modèle déterministe de population structurée par stades pour analyser les impacts que peuvent avoir quatre scénarios de chasse sur le rétablissement de la population de baleines boréales de l'est de l'Arctique canadien et de l'ouest du Groenland. Les scénarios de chasse sont : « aucune chasse », une chasse visant les « adultes-juvéniles » (même nombre de captures pour chaque âge et sexe), une chasse aux « adultes seulement » (même nombre de captures pour chaque sexe) et une chasse visant les « femelles adultes » seulement. Les caractéristiques de la population retenues dans le modèle proviennent de la meilleure information disponible et d'hypothèses selon lesquelles les résultats modélisés sont une certaine croissance positive de la population (avec un scénario sans chasse) et la survie, jusqu'à 100 ans, d'un petit pourcentage des animaux. On a analysé des effectifs théoriques de 5 000 et de 10 000 individus. Le scénario de chasse axée sur les « femelles adultes » a eu le plus d'impacts négatifs (ou le moins d'impacts positifs) sur la croissance de la population, suivie de celui de la chasse aux « adultes seulement », de celui de la chasse aux « juvéniles-adultes » et de celui sans chasse. Si l'on suppose que l'effectif initial est plus important, on n'observe aucun déclin démographique avec aucun des scénarios de chasse. Les résultats modélisés semblent démontrer qu'il est peu probable qu'il y ait un risque de déclin de la population, même avec le prélèvement de dix baleines femelles. Cependant, sans information plus précise sur les taux de survie, la fécondité, l'abondance de la population et la composition de la population, il est impossible de formuler des évaluations du risque propres à chacun des scénarios de chasse examinés.

INTRODUCTION

In the eastern Canadian Arctic and Greenland, there is a limited hunt of bowhead whales, but there is interest in increasing the take for Canadian Inuit and West Greenlanders. The IWC recently allocated two strikes per year for West Greenland, with future hunts pending review of further population assessment. In Canada, hunting is co-managed by DFO, the Nunavut Wildlife Management Board, and the Nunavik Marine Region Wildlife Board. Since the renewal of licenced bowhead hunting in the eastern Canada Arctic in 1996, hunting rates within Canada have been based on a two-population hypothesis and 1995 scientific advice of a maximum of one whale per three years for the Foxe Basin/Northern Hudson Bay population and one whale per 13 years for the Baffin Bay/Davis Strait population.

In 2007, scientific advice based on a conservative interpretation of a Potential Biological Removal (PBR) analysis of a single population, with an estimated abundance of 14,400 whales (Dueck *et al.* 2007), indicated that total human-induced removals of up to 18 whales/year were unlikely to jeopardize population recovery (DFO 2008). However, that assessment provided no information on the relative impacts of biases in the hunt structure on population recovery. Evidence suggests that the population is segregated within its range by age and reproductive class (Cosens and Blouw 2003), making it potentially vulnerable to biases in the hunt toward specific age or reproductive classes. Currently, the provisions of the hunt license prohibit hunting of bowhead calves (<25') or whales accompanied by calves, but since it is not possible to determine the gender of unaccompanied animals in the field, a female-biased hunt is possible.

While the population is larger than once thought, given the large uncertainties associated with the partial population estimate (i.e., 14,400; 95% CI 4,811-43,105) and potential biases in the hunt, this paper examines theoretical trajectories of the population as a function of various hypothetical hunting scenarios and population characteristics.

METHODS

The software Analytica version 4.1 (Lumina Decision Systems Inc, Los Gatos, CA; www.lumina.com) was used to construct a population model for the evaluation of theoretical population trajectories for a set of hypothetical population characteristics and hunting scenarios. Analytica provides a powerful model building interface, utilizing individual "nodes" to construct an influence diagram that illustrate the interaction of specific features of population characteristics, input scenarios, and mathematical operations, including a range of user-defined outputs. The individual nodes, consisting of simple tables, matrices, or mathematical expressions, can be collapsed into a smaller number of working modules, but are ultimately linked together to provide the user with a user-friendly conceptual framework, much like a flow diagram (see Figure 1).

We constructed a simple deterministic stage-based model, using assumptions about the current population status and characteristics of the population. The model was a non-density dependent, stage structured model, identical to that described by Richard *et al.* (2003), except that inputs to our model were point estimates and therefore non-probabilistic and that there were three size stages: neonate, juvenile and adult.

Most characteristics and vital parameters for this population are not presently well known. Excluding population size, approximations of population characteristics for the eastern Canadian Arctic-West Greenland population are based on knowledge obtained for the Bering-Chukchi-Beaufort Sea (BCB) population. Age and gender composition, age specific survival rates, age at maturation, reproductive rates, population size and growth, are all variables with varying degrees of uncertainty.

Since we could not define vital parameters with any degree of certainty, we selected values for vital parameters where data was available. For parameters where precise data was not available, we chose values that resulted in sufficient resolution in the model runs to distinguish relative differences in the hunt scenarios. The choice of parameters is summarized in Table 1 and the basis for the choice of parameter values are described in more detail below.

Life Stages, Longevity and Age of Sexual Maturity

We defined three life stages for the population: newborn, juvenile and adult. Most calves in the BCB population appear to be weaned at 12 to 14 months (Koski *et al.* 1993). Sexual maturity in the BCB population appears to occur at 14.0-15.9 years for males and ≥ 20 years for females (George *et al.* 1999, Lubetkin *et al.* 2008). Bowheads are now thought capable of life spans well over a hundred years (George *et al.* 1999, George and Bockstoce 2008), although age of reproductive senescence is not known.

For the purposes of the model, the duration of life stages were considered invariant. And since the age of maturation for females defines the onset of calving, we defined the duration of life stages as 1, 19 and 100 years for newborn, juvenile and adult age classes. We assumed that survival probability was constant within each life stage.

Survival

There is no age-based survival information for the EC-WG population. Zeh *et al.* (2002) provide the most recent evaluation of bowhead survival for the BCB population, based on mark-recapture photo-identification data for 13 years between 1981 and 1998. Their analysis, limited to estimates of adult survival, results in estimates of adult survival ranging between 0.95 and 1.0, with a mean of 0.984. There is less information on immature survival, but it has been estimated to be somewhat lower than that of adults in population models of the BCB population (Brandon and Wade 2006, Breiwick *et al.* 1984).

For the initial parameters of the model, we defined adult survival as s_a = 0.984, equal to estimated values for the BCB population, and selected newborn and juvenile survival consistent with $s_c < s_j < s_a$. We considered values for s_c and s_j that would allow for a small proportion of individuals in the population to survive to 100 years. We selected initial parameter values s_a = 0.984, s_j = 0.95, and s_c = 0.50 , allowing for the mathematical probability that about 5% of individuals would live to at least 100 years of age (Table 1). These definitions allowed for modest growth of the population under “no hunting" scenarios, and are likely an overly conservative simulation of reality. However, in the context of the other initial parameters chosen, this selection of survival parameters provided a reasonable distribution of population trajectories for ease of comparison of different hunt scenarios. Less conservative survival parameters were investigated but these resulted in poorer discrimination of population trajectories and are not presented here.

Size and Composition of the Population

There is considerable uncertainty in the estimated size of the EC-WG population. Dueck *et al.* (2007) estimated the abundance at 14,400 but given this estimate may be positively biased and has large uncertainties associated with it, for the purposes of this paper we used initial populations of N_i = 5,000 and N_i = 10,000 (Table 1) to examine the effect of different hunting scenarios.

The age composition of the population is assumed to be at equilibrium in a "no hunting" context and is derived from an initial run of the model. The population stage composition was allowed to stabilize during a run of 500 years and was then used as the initial stage composition in subsequent runs (Table 2). We also assume equal gender ratio at the start of the runs.

Fecundity

Fecundity is typically defined as the product of first-year survival and calving rate for all adults (Zeh *et al.* 1993, Breiwick and Braham 1990). For the purposes of this model, fecundity is defined by calving rate alone and the survival component is incorporated into the survival definitions of life stages, as described above.

Bowhead calving intervals are thought to range from 3 to 4 years (Koski *et al.* 1993). Assuming equal gender ratio in the population, fecundity is calculated to range from 0.125 to 0.167 for calving intervals of 4 and 3 years respectively. We used both bounding estimates: fecundity f = 0.125 and f = 0.167.

Hunt Structure

Our model examined the outcome for four hunting scenarios, consisting of "no hunting", an "adult only" hunt (equal gender ratio), an "adult-juvenile" hunt (age and gender class in equal numbers), and an "adult female" biased hunt (only adult females). In each scenario except for "no hunting", 10 individuals[1] were removed annually from the population. An "adult only" hunt consisted of the removal of 5 adults of each sex. The "juvenile-adult" hunt consisted of the removal of 2.5 juvenile males, 2.5 juvenile females, 2.5 adult males, and 2.5 adult females. The "adult-female" biased hunt consisted of the removal of 10 adult females.

[1] This number was chosen arbitrarily to illustrate the relative results for hunt scenarios.

RESULTS AND DISCUSSION

There were consistent differences among hunt scenarios (Figures 2-5), indicating that an “adult female” biased hunt has the greatest negative (or least positive) effect on population growth, followed by “adult only”, “juvenile-adult”, and “no hunting” in decreasing order of impact. Positive population growth was observed for all “no hunting” scenarios and most other scenarios. The only negative population growth was observed for scenarios in which fecundity was lowest (f = 0.125, calving interval of four years), calf survival was lowest (50%), and adult mortality was highest (“adult female” hunt) (Fig. 2). A juvenile-only hunt would have the least negative effect on population growth, of any of the examined hunt scenarios, because it doesn’t remove reproductively-active animals from the population.

Under all scenarios where calf survival was increased to 75% or where the calving interval was set to 3 years, positive population growth was observed (Figures 3 and 4), and the results in terms of total numbers and population growth were nearly indistinguishable. Positive growth was even greater when calving interval was reduced to 3 years (Figure 5).

Not surprisingly, larger initial population size always resulted in greater positive effect on population growth. Positive population growth was observed in all scenarios where N_i = 10,000, with the exception of run #1 for an “adult female” hunt.

Population growth rates were constant for all “no hunting” scenarios, reflecting the growth of a population at equilibrium. Population annual growth rate for “no hunting” scenarios ranged from 0.27% to 1.76%. Growth rates for populations when animals were removed (hunted) were lower and exhibited a characteristic initial decrease in growth rate followed by a subsequent increase in growth rate. The difference in the shape of growth rate curves between the “no hunting” and hunting scenarios is due to the fact that the age structure of the population was initially set to equilibrium under a “no hunting” scenario, which is not the same equilibrium as would exist for a hunted population. Model runs where individuals are removed require some finite period for the population to return to another (different) equilibrium, and the observed growth rates for these runs illustrate the adjustments in numbers (and subsequent growth rates) that occur prior to reaching a new equilibrium.

To minimize the impact of hunting on population recovery, bowhead whale hunting in northern Foxe Basin should target only juveniles (≤ 13.5 m or 44.3 feet in total length) because the few adults that spend the summer there are likely to be adult females. Since identifying the sex of adult bowhead whales at sea is difficult, to avoid hunting adult females, juvenile hunting is also the best choice everywhere else in the range of the population.

Adult males landed in Alaska between 1973 and 1989 ranged in length up to 16.2 m or 53.1 feet while adult females landed ranged up to 18.0 m or 59.1 feet (Koski *et al.* 1993). About a quarter of the females measured in those hunts were longer than 16.2 m or 53.1

feet. This suggests that hunting animals larger than 16.2 m or 53.1 feet should be avoided in all areas. While this recommendation will not remove the risk of hunting adult females, it should reduce their frequency in the catch in areas where there are few or no juveniles to target and males and females are in equal proportion.
The population model presented here is sensitive to small changes to population parameters such as stage survival and fecundity. While the results illustrate mostly positive population growth, reductions in fecundity or stage survival could easily result in negative growth of the modelled population. Due to the inherent uncertainty in many of the parameters used, this simple model is thus limited in its' ability to accurately represent the population dynamics of the EC-WG population.

However, it is generally accepted that non-harvested cetacean populations have intrinsic growth rates of 3-5% (Wade and Angliss 1997). George *et al.* (2004) estimated the rate of increase for the western Arctic bowhead whale population at 3.4% (95% CI 1.7%-5%). In comparison, the population growth rates produced by the models presented here for a non-hunted population were all less than 1.8% (Figures 2-5), therefore conservative.

Certain model assumptions could positively bias the results, such as population size, population-at-equilibrium, stage durations, and age of senescence. However in terms of population size, at least the smaller initial estimate of 5,000 whales used in the model, is considered a negatively biased estimate of the population size in 2002. Given the long time elapsed since the end of commercial whaling (nearly 100 years), the population has also had considerable time to reach equilibrium.

The stage-based survival rates may be too general to reflect the true nature of survival as a function of age. True survival is not likely to be constant for the entire duration of every life stage. Due to their slow physical growth rate and high age at maturity relative to other marine mammals, very young juveniles are likely to have survival rates closer to that of calves, while older immature animals are likely to have survival rates similar to that of adult animals.

In general, and by most rationales, it appears that the model and the parameters used to describe assumed population status and vital rates are conservative. Most importantly, the model is very conservative in it's representation of population growth. The model suggests that rapid population recovery is more likely with a hunting bias toward juveniles. However, it also seems that a risk of decline in the population, even for an "adult female" biased hunt of 10 whales is unlikely. At the minimum, the population model presented here provides a useful means for examining the relative effects of various hunting scenarios. Without more precise information on survival rates, fecundity, population abundance and population composition that apply to the EC-WG population, we are unable to provide specific risk assessments for any given hunting scenarios.

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Table 1. Summary of the scenarios and parameter values used for population characteristics in the population model of bowhead whales, where f = fecundity, s_c = newborn survival to age 1, s_j = annual juvenile survival, s_a = annual adult survival, and N_i = initial population size. Each of the listed population scenarios were run in combination with four hunting scenarios: "no hunting", "adult-juvenile" (age and gender class in equal numbers), "adult only", and "adult female" (only adult females). In all hunting scenarios where whales were removed, the number removed was 10 per year, and except for the "adult female" hunt scenario, equal proportions of each gender were included in the removals for each hunt scenario.

Model run	*f*	S_c	S_j	S_a	N_i
1a	0.125	0.5	0.95	0.984	5K
1b	0.125	0.5	0.95	0.984	10K
2b	0.167	0.5	0.95	0.984	5K
2a	0.167	0.5	0.95	0.984	10K
3a	0.125	0.75	0.95	0.984	5K
3b	0.125	0.75	0.95	0.984	10K
4a	0.167	0.75	0.95	0.984	5K
4a	0.167	0.75	0.95	0.984	10K

Table 2. Stable stage proportions used for each model run.

Stage \ Run	*1*	*2*	*3*	*4*
Neonate	0.066	0.079	0.058	0.068
Juvenile	0.400	0.445	0.475	0.518
Adult	0.533	0.476	0.467	0.414

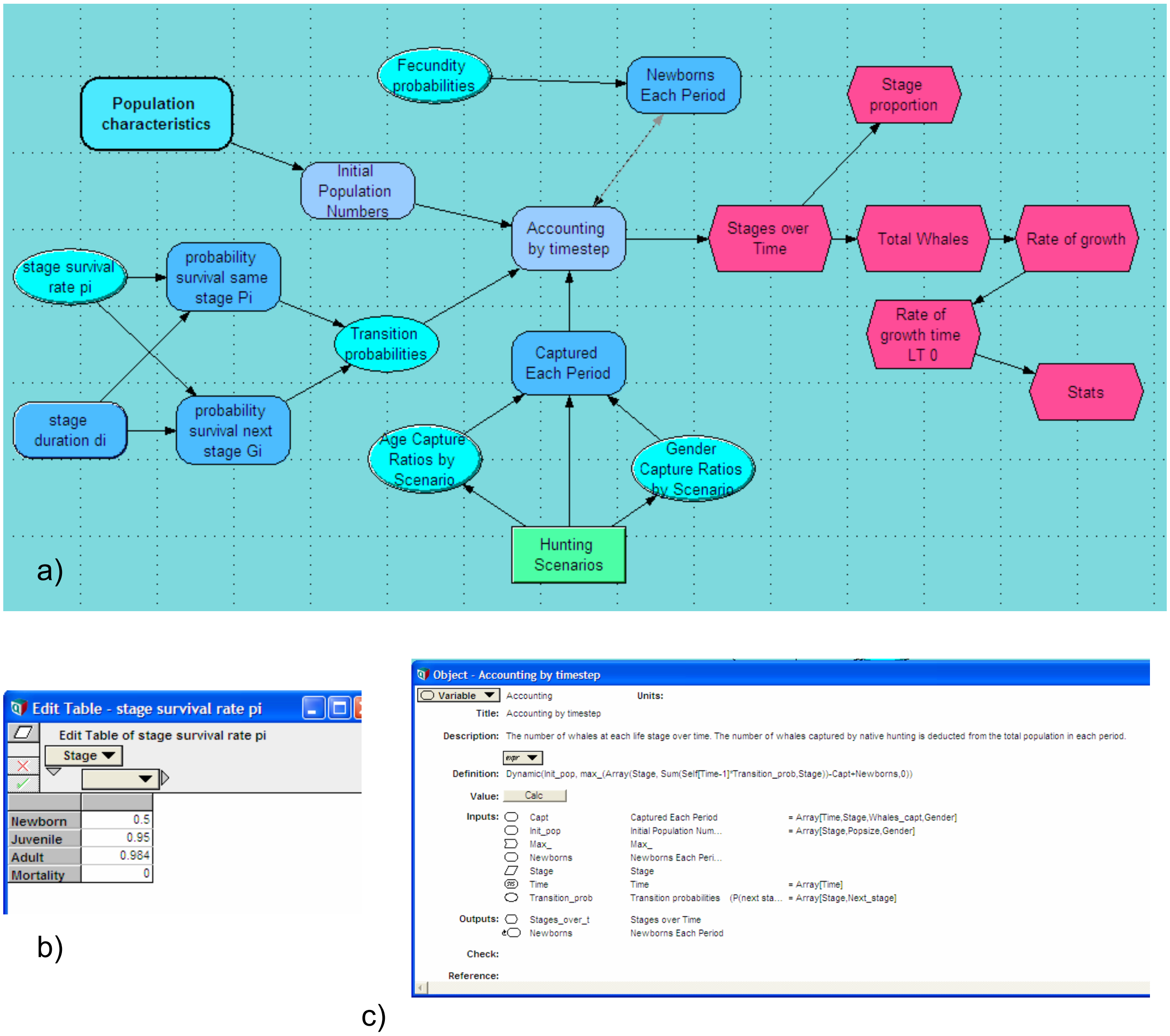

Figure 1. Illustration of a) the graphic model interface, b) an example of a table of survival rates indexed by life stage, and c) the dynamic node calculating the number of whales in each life stage over time.

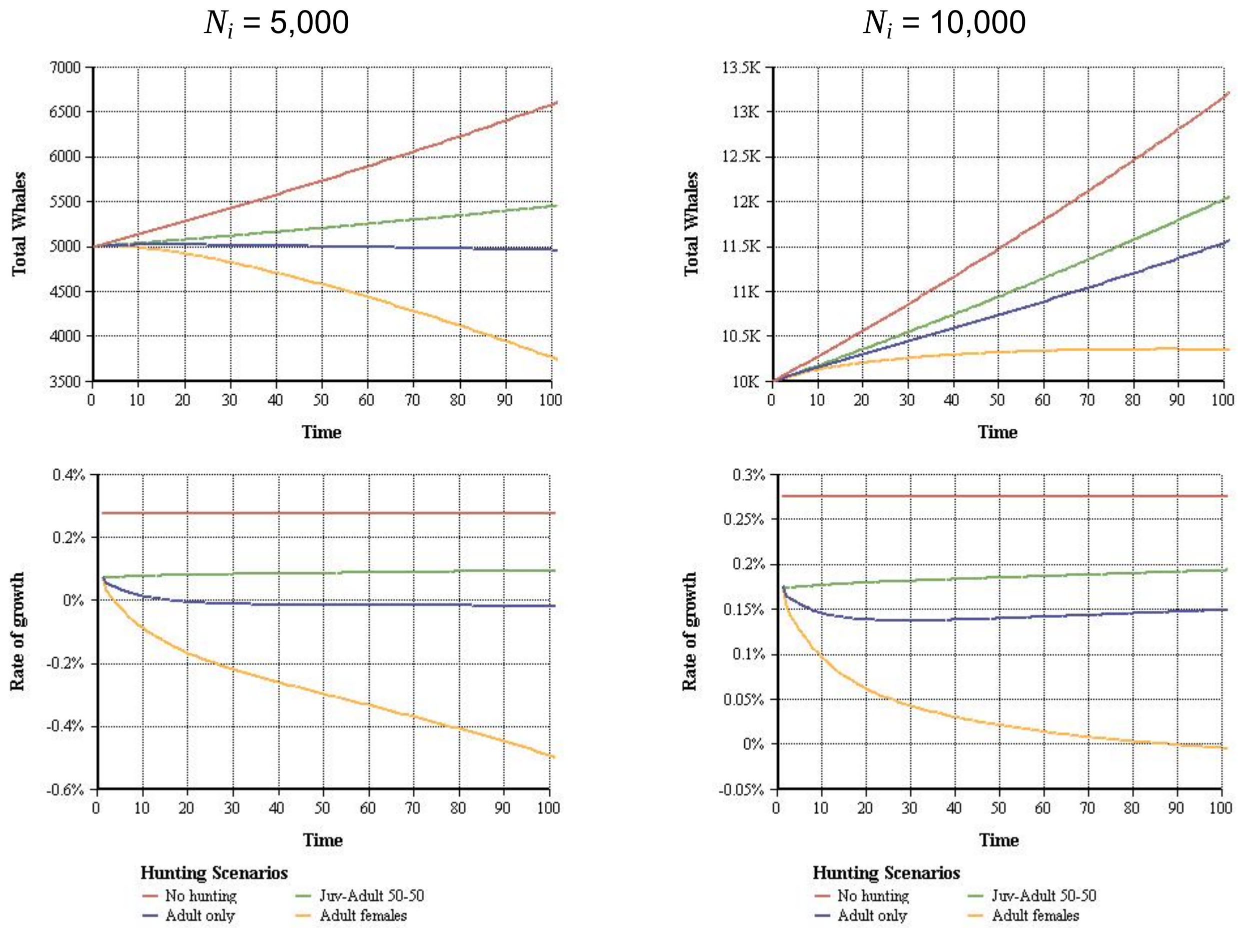

Figure 2. Results of population model run #1 (where fecundity f = 0.125, and survival s_c = 0.50, s_j = 0.95, and s_a = 0.984; see Table 1), depicting hypothetical trajectories for total numbers of whales and population growth rate as a function of time (span = 100 years) for four hunting scenarios. Graphs on left depict results for an initial population size N_i = 5000 whales and those on right for N_i = 10,000.

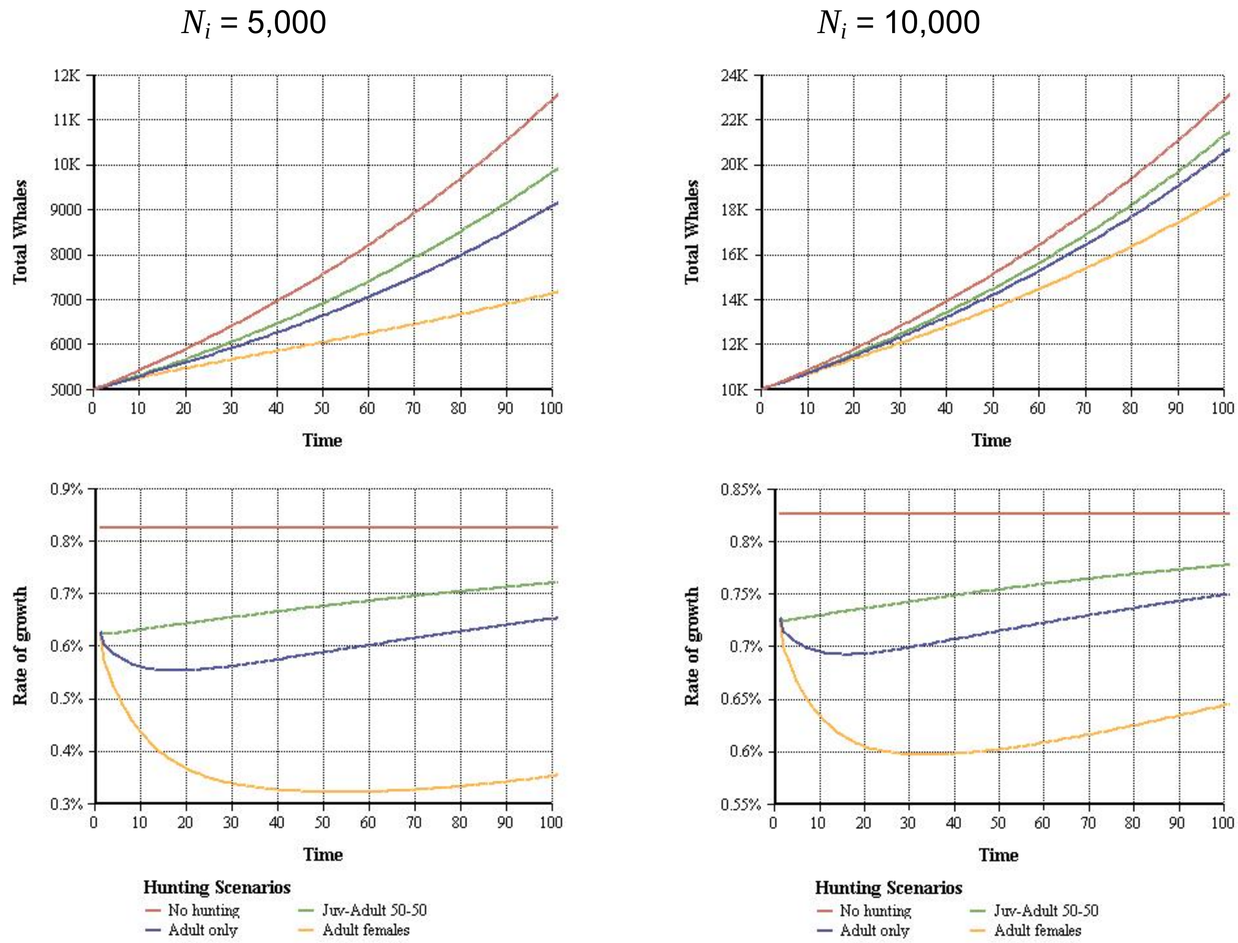

Figure 3. Results of population model run #2 (where fecundity f = 0.167, and survival s_c = 0.50, s_j = 0.95, and s_a = 0.984; see Table 1), depicting hypothetical trajectories for total numbers of whales and population growth rate as a function of time (span = 100 years) for four hunting scenarios. Graphs on left depict results for an initial population size N_i of 5000 whales and those on right for population size N_i of 10,000.

N_i = 5,000 N_i = 10,000

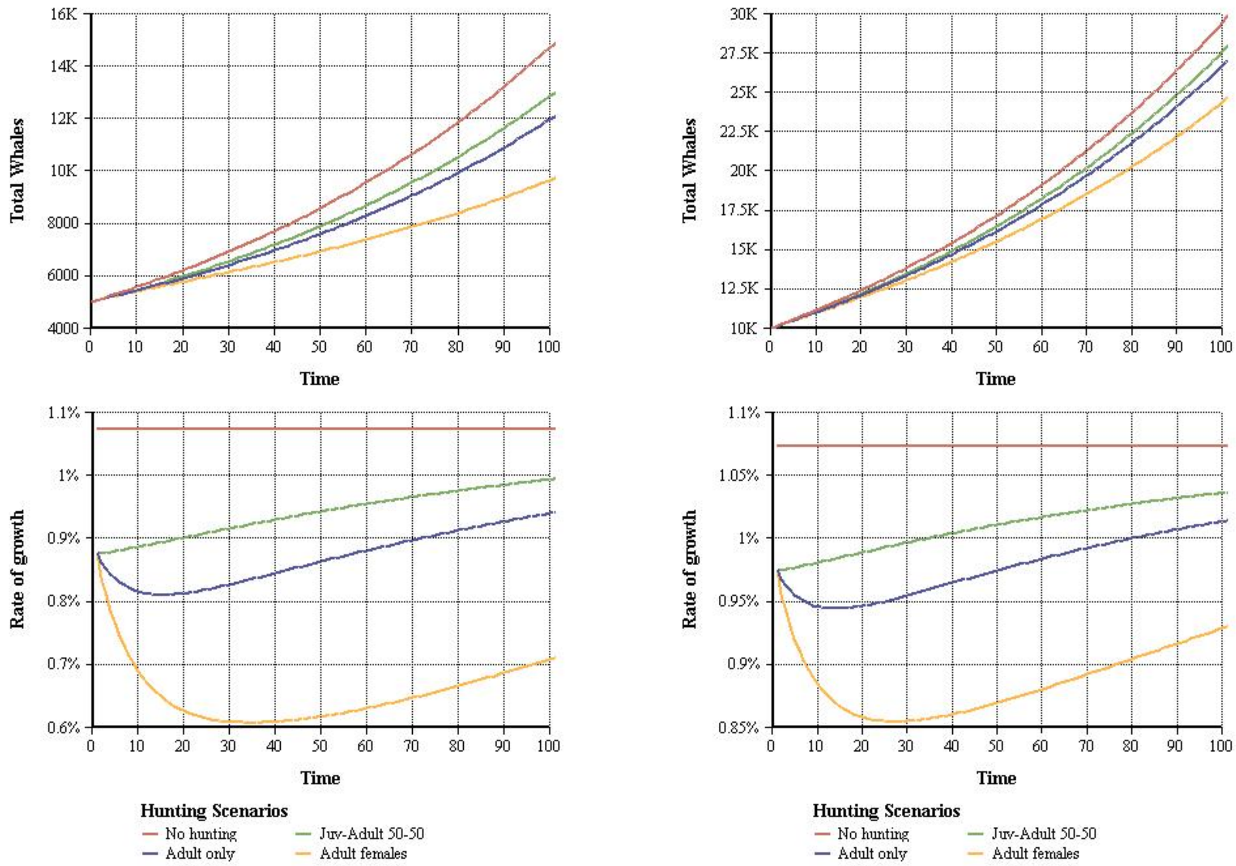

Figure 4. Results of population model run #3 (where fecundity f = 0.125, and survival s_c = 0.75, s_j = 0.95, and s_a = 0.984; see Table 1), depicting hypothetical trajectories for total numbers of whales and population growth rate as a function of time (span = 100 years) for four hunting scenarios. Graphs on left depict results for an initial population size N_i of 5000 whales and those on right for population size N_i of 10,000.

N_i = 5,000 N_i = 10,000

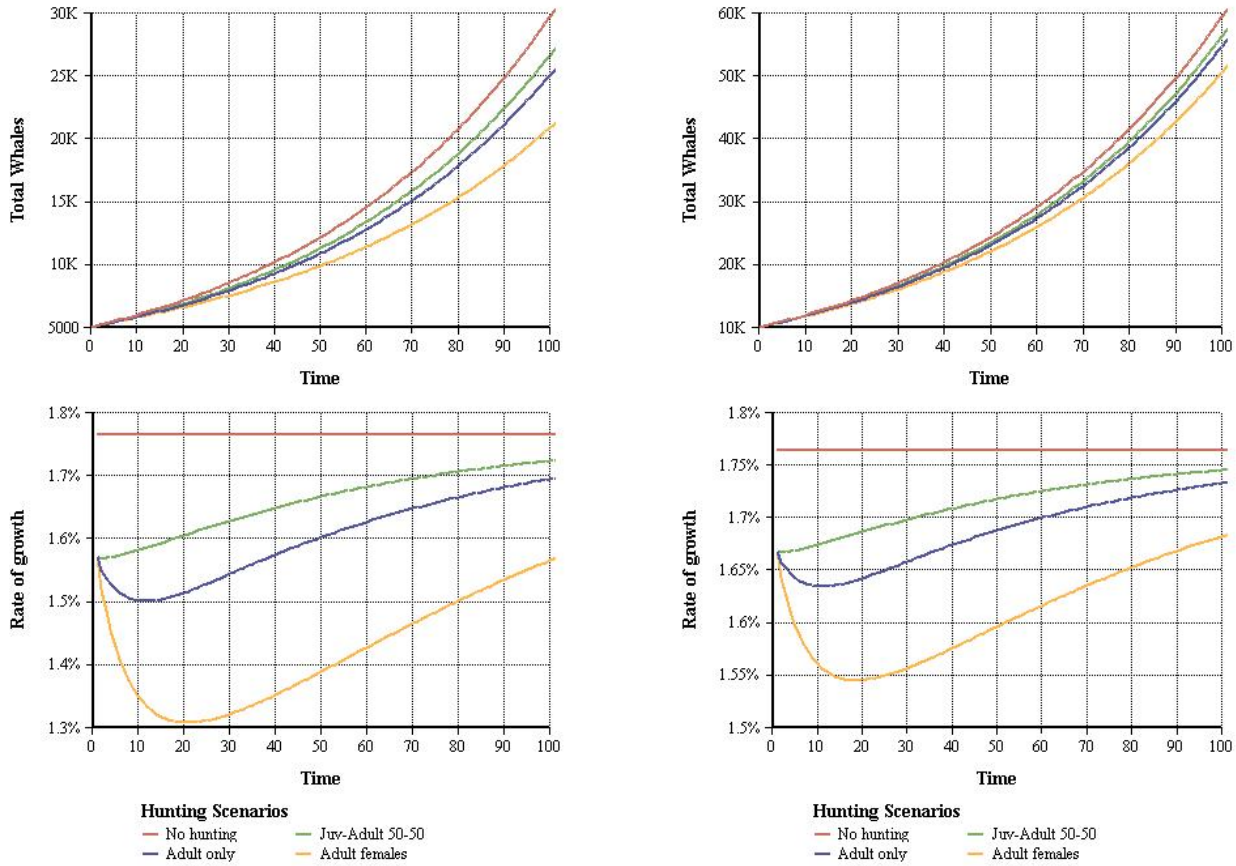

Figure 5. Results of population model run #4 (where fecundity f = 0.167, and survival s_c = 0.75, s_j = 0.95, and s_a = 0.984; see Table 1), depicting hypothetical trajectories for total numbers of whales and population growth rate as a function of time (span = 100 years) for four hunting scenarios. Graphs on left depict results for an initial population size N_i of 5000 whales and those on right for population size N_i of 10,000.