A note on tuning the *Catch Limit Algorithm* for commercial baleen whaling

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ABSTRACT

The *Catch Limit Algorithm* for commercial baleen whaling developed by the International Whaling Commission converges slowly to a steady depletion (proportion of carrying capacity), and consequently 300 years of management is proposed as horizon for tuning and computer simulation. Long-term depletion is rather insensitive to the parameter currently used for tuning, and an alternative control parameter is suggested for this purpose.

KEYWORDS: WHALING-REVISED CATCHES; MANAGEMENT PROCEDURE

INTRODUCTION

In 1982, the International Whaling Commission (IWC) decided to impose a moratorium or pause in commercial whaling. As part of the 'Comprehensive Assessment' that was part of that decision, the IWC's Scientific Committee began the process of developing a procedure for setting safe catch limits for commercial whaling for baleen whales (Donovan, 1989). The agreed objectives for what was to become the 'Revised Management Procedure (RMP)' were: (i) stability of catch limits which would be desirable for the orderly development of the whaling industry; (ii) acceptable risk that a stock not to be depleted (at a certain level of probability) below some chosen level (e.g. fraction of carrying capacity), so that the risk of extinction is not seriously increased by exploitation; (iii) making possible the highest possible continuing yield from the stock (IWC, 1992a). In this context, the term 'continuing yield' refers to the mean (maximum) yearly harvest in the long term, i.e. when the exploited stock has reached a stationary state. This note considers whether the current simulated management horizon (100 years) is sufficiently long to allow exploited stocks of baleen whales to reach a stationary state. Other simulation studies have shown this not to be the case for a number of scenarios (Aldrin and Huseby, 2007; Butterworth and Punt, 1994). Here, we suggest that 300 years is a more appropriate management horizon and provide a re-examination of the best approach to 'tune' the *Catch Limit Algorithm (CLA)*. The current method seems unfit to tune the median depletion level after 300 years of exploitation to targets less than 70% and here we suggest an alternative tuning method.

To expand upon this, the *CLA* (IWC, 1992b; 1999) is a core component of the RMP that is used, as its name suggests, to calculate levels of anthropogenic removals that meet the stated objectives. The conservation- and yield properties of the *CLA* were and are tuned and investigated under a range of plausible conditions by way of stochastic simulation over a management period of 100 years. In this note, it is argued that under the range of productivity of baleen whale populations that has been considered in past simulation testing of the CLA (with a maximum sustainable yield rate relative to the sexually mature population, $MSYR^{mature}$, being as low as 1%), this horizon is not long enough. With such a low value of $MSYR^{mature}$, the dynamics under many scenarios are too slow for the population of a managed whale stock to even come close to a stationary state after 100 years (Fig. 1). We suggest that the management horizon should rather be 300 years, which is now computationally feasible (it was not when the *CLA* was being developed in the late 1980s and early 1990s) and which allows for a reasonable evaluation of continuing yield and long-term depletion (the ratio of current abundance to the pre-exploitation level, the latter being termed 'carrying capacity' or *K*).

The *CLA* is currently tuned to desired target levels for depletion by the internal posterior percentage point for the catch limit given by a catch control law (see equation 3 below). Since we have found it difficult to tune the *CLA* to target depletion levels much below 0.72 (population size relative to carrying capacity) after 300 years by this method, we will propose that the *CLA* rather should be tuned by varying the steepness of the line determining the internal catch level for estimated depletion above the internal protection level in the catch control law.

This short note first reviews the nature of the *CLA* and then examines issues related to the management horizon and tuning method. It does not contribute directly to the important investigation of conservation properties of the *CLA* and the current management regime, nor does it address the question of how productive baleen whales really are (which is currently under review by the IWC Scientific Committee – see IWC, 2009).

THE CATCH LIMIT ALGORITHM

The *CLA* (IWC, 1999) consists of: a simple internal model for the population dynamics of the whale population in question; a prior distribution for its parameters; a procedure for calculating the posterior distribution from historic catches and available abundance estimates, but with nominal standard errors and correlations on the log scale being quadrupled; and a catch control rule to set catch limits. The input data to the *CLA* consists of a time series of historic annual catches and of absolute abundance estimates

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along with their standard errors and correlations on the logarithmic scale.

The internal population model is the age-aggregated Pella-Tomlinson model

$$P_{t+1} = P_t - C_t + 1.4184\mu P_t\left(1-\left(\frac{P_t}{P_0}\right)^2\right) \quad 0 \le t < T \qquad (1)$$

where P_t and C_t are respectively the number of individuals of age 1+ and the number of individuals removed by whaling (assumed known without error), both at the beginning of year t, and μ is an internal productivity parameter. The catch limit is to be calculated for year T. The population is assumed to be at (internal) carrying capacity P_0 in year 0, which is the first year of recorded catch.

The abundance estimates are assumed to be log-normally distributed with an estimated covariance matrix Σ on the log scale, which is assumed known. Treating the depletion $D_T = P_T/P_0$ as a parameter, and deleting constant factors, the likelihood based on the abundance data at time T is taken to be

$$L(\mu, D_T, \beta) = \exp\left(-\frac{1}{2\tau^2}\left(\underline{a}-\underline{p}-\beta\underline{1}\right)^t \Sigma^{-1}\left(\underline{a}-\underline{p}-\beta\underline{1}\right)\right) \qquad (2)$$

where $\tau = 4$ as discussed below. The underlined terms are vectors of log estimated abundance (a), log abundance (p) and ones, all for years with available abundance estimates. The parameter β is the log of the multiplicative bias in the abundance estimates.

The parameters μ, D_T, $b = exp(\beta)$ are assigned independent uniform prior distributions over the respective intervals (0, 0.05), (0, 1.0) and (0, 5/3). This joint prior distribution is then combined with the likelihood of equation (2) to give a posterior distribution for the three internal parameters. This 'posterior' is in turn used to set the catch limit – the term 'posterior' is used although 'pseudo-posterior' would be more correct since the likelihood in equation (2) is really a pseudo-likelihood.

A distinctive feature of the *CLA* is that abundance data are strongly down-weighted to obtain desired catch stability and conservation properties. In the internal model, all variances and covariances of logarithmic abundance estimates are actually multiplied by $\tau^2 = 16$. The posterior density function of the parameters (μ, D_T, b) over the allowed range is therefore proportional to the function shown in equation (2).

The catch control law provides the internal catch limit L_T as the following function of the internal parameters and the current internal abundance P_T .

$$L_T = 0 \text{ if } D_T \le IPL, \quad L_T = \gamma\mu\left(D_T - IPL\right)P_T \text{ if } D_T > IPL \qquad (3)$$

The internal protection level *IPL* is a further control parameter.

The internal catch limit inherits its posterior distribution from that of (μ, D_T, b). For a chosen probability level α, the catch limit is calculated as the α-quantile of the derived posterior distribution for L. The parameter α has traditionally been used to tune the *CLA* to a desired target population, while the slope parameter γ has been fixed at $\gamma=3$.

In scenarios with deterministic and stationary population dynamics, the posterior distribution for L will asymptote to a degenerate distribution concentrated at one point, provided the information content expands sufficiently. In the so-called 'base case trial' used for tuning the *CLA*, the population dynamics parameters are fixed and the abundance estimates are uncorrelated and have constant coefficients of variation. If n is the number of absolute abundance estimates, there is simply the familiar $n^{-1/2}$ convergence in the joint posterior for (μ, D_T, b), and consequently also in that for L. In the long term, the deterministic population process will converge in probability, and the catch limit will also converge to the replacement yield at the limiting population level.

The size of the catches early in the process will impact the population trajectory, and hence also the later catches and consequently the population level as well. This feedback mechanism has the effect of making the long-term population level depend on the probability parameter α, but only through the size of the early catches. In the limit, the posterior is degenerate, and the value of α has no impact. The limiting depletion is thus only slightly dependent on the traditional tuning parameter. This is further discussed below.

Note that catches are stochastic through the stochasticity of the abundance estimates. This will impact the early part of the process in particular. The stochasticity of the early catches will actually propagate through the feedback mechanism to an element of stochasticity in the limit. This means that the catches and depletion will stabilize over time to a limit, but this limit will vary slightly between simulation runs, even given a specific scenario.

MANAGEMENT HORIZON

The *CLA* has traditionally been tuned to target a specific median depletion after 100 years of managed whaling of an initially unexploited stock (initially this was to allow for the comparison of various candidate *CLAs* e.g. see Kirkwood, 1992), and its performance properties have been investigated by simulating the process over 100 years for a variety of scenarios. It has however been known that 100 years is too little to reach stability when the stock has low productivity; Butterworth and Punt (1994) found for example in the scenario used for tuning that median population level increases from years 100 to 300 of the management period, but then levels off.

Aldrin and Huseby (2007) also found that median population level keep varying, and often increased appreciably, from 100 to 300 years of whaling for a number of scenarios, see for instance the upper left panel of Fig. 1 for the results for the trial used to tune the *CLA* and the upper right panel for another trial. The reader is referred to Aldrin and Huseby (2007) for plots summarising performance in a collection of scenarios.

The simulation period was set somewhat arbitrarily to 100 years in the early phase of developing the *CLA*. Computing capacity was relatively limited before 1990, and a longer simulation period was found too expensive in computer time. Simulation time does actually grow way faster than linear with period length. With current computing power, we consider that a longer simulation period is feasible and suggest 300 years to be a reasonable compromise between the desire to investigate the long-term performance properties of the *CLA* and the need to keep computing costs within reasonable limits.

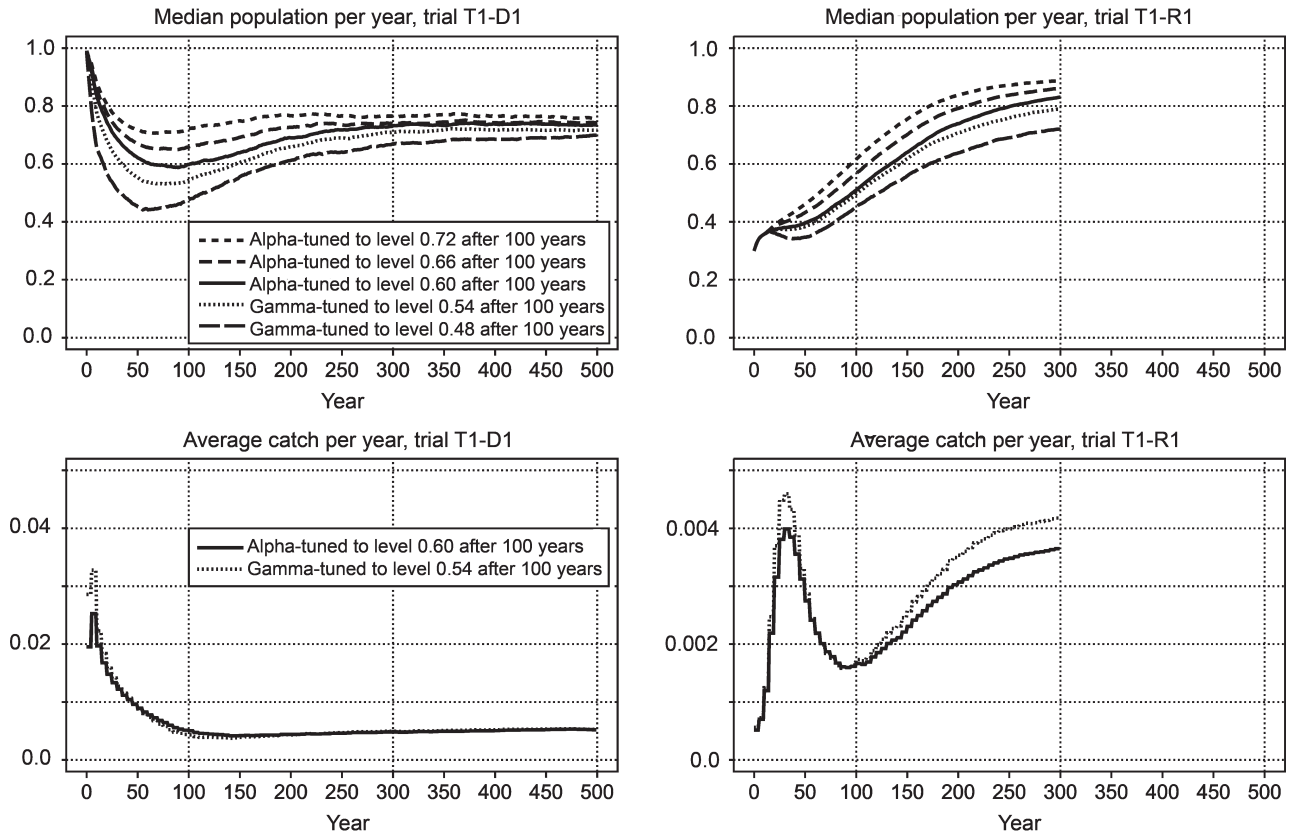

Fig. 1. Median depletion for five different tuning levels and average catch for two tuning levels. Left panels: Trial T1-D1 used for tuning, which commences with an abundance of 99% of the carrying capacity and $MSYR^{mature}$ = 1%. Right panels: Trial T1-R1, which commences with an abundance of 30% of the carrying capacity and $MSYR^{mature}$ = 1%. The results are based on 400 replicate simulations in each case.

Table 1

Median depletion by tuning method and by years of management. The tuning is by α in the three upper rows, and then by γ. 400 replicate simulations were run in each case.

α	γ	Year 100	Year 300	Year 500
0.4015	3	0.72	0.76	0.76
0.4629	3	0.66	0.74	0.74
0.5222	3	0.60	0.73	0.73
0.5	4.7157	0.54	0.71	0.72
0.5	9.3443	0.48	0.67	0.70

TUNING METHOD

From Fig. 1 and Table 1, it is clear that tuning to target depletion in the range of interest (0.66-0.72) after 300 years is difficult when this is attempted by varying α. The long-term population level is actually rather insensitive to the value of α between 0.4 and 0.5. Values of this tuning parameter above 0.5 are inappropriate, since then the catch limit increases with the spread of the posterior distribution for *L*, i.e. less certainty results in greater catches contrary to the precautionary approach.

There are two other parameters that could be used for tuning, namely the internal protection level *IPL* and the scaling parameter γ, see equation (3). *IPL* is not considered as a viable option as a tuning parameter since it was determined by the Commission that *IPL* = 0.54 (IWC, 1992a).

This leaves γ as the candidate for tuning parameter. This slope parameter simply scales the non-zero catch limits, and should therefore enable tuning to any desired limiting depletion level.

The lower panels of Fig. 1 show the average catch per year for two tuning levels, one tuned by α and one by γ, for the two trials. Table 2 shows other summary statistics for the same trials and tuning levels.

DISCUSSION

As one management objective, the Commission (IWC, 1992a) agreed that whaling ought to be managed on a long term basis. In this note we consider that 100 years of management is too short for the process to come close to a stationary state at the lower end of what is presently assumed to be the range of productivity in baleen whales, and that a management horizon of 300 years is more appropriate. We further suggest an alternative method of tuning the catch limit algorithm to obtain (long term) continuing yield of a size leading to the stock approximating around 70% of carrying capacity in the tuning scenario.

The plausible range of productivity in baleen whales is currently under investigation (IWC, 2009). This note does not contribute to that investigation. Aldrin and Huseby (2007), found that the risk of extinction of a single stock is not seriously increased by exploitation when managed by the *CLA* with α=0.5, γ=4.7157. In the trials considered (with 400 replicate runs in each), they found no cases where extinction occurred over 300 years of management. They found the low 5% quantile for population size after 100 years of management to be at least 24% of *K* for all trials considered where at least one whale was harvested, reported catches were at least 50% of true catch and survey bias was at most +50%. This happened in a trial where the initial population was 30% of *K*. In trials with episodic 'events' (i.e. a major depletion of a population in a single year), the

Table 2

Median and 5% percentile depletion at year 100 and 300, and 5% percentile of lowest population size and average catch in years 1-100 and 101-300, for two tuning levels and two trials. Their unit is K (carrying capacity). 400 replicate simulations were run in each case.

			Median depletion		5% percentile depletion		5% percentile of lowest population		Average catch per 100 years	
Trial	α	γ	Year 100	Year 300	Year 100	Year 300	Years 1-100	Years 101-300	Years 1-100	Years 101-300
T1D1	0.5222	3	0.60	0.73	0.46	0.54	0.45	0.41	1.10	0.45
	0.5	4.7157	0.54	0.71	0.39	0.53	0.37	0.35	1.19	0.44
T1R1	0.5222	3	0.51	0.83	0.42	0.73	0.30	0.42	0.23	0.29
	0.5	4.7157	0.49	0.78	0.39	0.67	0.30	0.39	0.24	0.33

population was however driven to near extinction in a few replicate simulations regardless of tuning levels. This happened also in a trial where *K* being doubled over the first 100 years for some levels of tuning. They did in fact run all the trials required at that time (IWC, 2007) to demonstrate whether a candidate procedure is an improvement compared to the current version of the RMP. Many of these trials assumed low productivity, with $MSYR^{mature}$ = 1%. It has been agreed by the IWC Scientific Committee that discussion of Aldrin and Huseby (2007) would await completion on the review of values for MSYR to be considered in the context of the RMP (IWC, 2008a; 2008b). We suggest that the version of the *CLA*, α=0.5, γ=4.7157, should be a candidate for consideration when the plausible range for productivity in baleen whales has been settled.

ACKNOWLEDGEMENTS

This work has been funded by the Norwegian Ministry of Fisheries and Coastal Affairs and by the Research Council of Norway project 'Modern Application driven Statistical Challenges (186951/I30)'. We thank Doug Butterworth for his valuable contributions to this work.

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Date received: October 2008
Date accepted: January 2009