AWMP-LITE (Version 5.0)

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ABSTRACT

AWMP-Lite (Givens *et al*., 2006) is updated so that it can be used as the basis for future projections for multi-stock trials for the Bering-Chukchi-Beaufort Seas stock of bowhead whales in which *Strike Limits* are set using the Grand Unified Procedure (GUP). The results for a single-stock implementation of AWMP-Lite are compared to those from the common control program for trials BE01 and BE09. The results suggest that the behaviour of GUP is very similar for the common control program and AWMP-Lite, suggesting that AWMP-Lite is sufficient to form the basis for an evaluation of GUP for multi-stock scenarios.

INTRODUCTION

AWMP-Lite (Givens *et al*., 2006) is a package developed in Visual Basic for Applications that can be used to implement two-stock hypotheses for the Bering-Chukchi-Beaufort (B-C-B) Seas stock of bowhead whales. AWMP-Lite is tailored to the specific case of the B-C-B bowhead whales, but could be modified fairly straightforwardly to handle aboriginal whaling operations for other species / stocks. A key objective of the original development of AWMP-Lite was to assess whether it was possible for hypotheses regarding possible stock-structuring of the B-C-B bowhead whales to be implemented in a manner such that they are consistent with the abundance data for these whales. However, the projection component of the original version of AWMP-Lite was restricted to projections based on constant catch.

Unless revised as a result of the current *Implementation Review*, future *Strike Limits* for the B-C-B bowhead whales will be based on the Grand Unified Procedure (GUP) selected by the Commission in 2002 (IWC, 2003a). The GUP is a feedback management procedure that uses abundance estimates and historical catches to determine *Strike Limits*. Its performance, in terms of satisfying the conflicting objectives of resource conservation and need satisfaction, could therefore be quite different from that of a constant catch strategy.

The objective of this paper is to extend AWMP-Lite so that it can be used as the basis for future projections for the Bering-Chukchi-Beaufort Seas stock of bowhead whales in which *Strike Limits* are set using the GUP. The revised AWMP-Lite is then used to evaluate the performance of the GUP for trials similar to those for *Evaluation Trials* BE01 and BE09 to determine whether the qualitative (and quantitative) performance of GUP is robust to whether the trials are based on an age- and sex-structured population dynamics model (that implemented in the common control program) or on an age-aggregated population dynamics model (the population dynamics model that underlies AWMP-Lite).

BASIC POPULATION DYNAMICS

The population dynamics model is based on the assumption that there are two stocks that have the same intrinsic rate of growth[1] and whose dynamics are governed by the logistic (Schaefer) model, i.e.:

$$\begin{aligned} N^1_{t+1} &= N^1_t + \tfrac{r}{z} N^1_t (1-(N^1_t/K^1)^z) - C^1_t \\ N^2_{t+1} &= N^2_t + \tfrac{r}{z} N^2_t (1-(N^2_t/K^2)^z) - C^2_t \end{aligned} \tag{1}$$

where N^i_t is the number of stock *i* animals at the start of year *t*;
K^i is the carrying capacity of stock *i* ($N^i_{1848} = K^i$);
r is the intrinsic rate of growth (assumed to be independent of stock);
z is the degree of compensation (the Pella-Tomlinson shape parameter); and
C^i_t is the catch during year *t* from stock *i*.

[1] The model could be extended straightfiorwardly to handle the case in which each stock has a different intrinsic rate of growth.

For this model, therefore, *MSYL* is the solution of the equation $1=(z+1)MSYL^z$ and *MSYR* is $r/(1+z)$. The catch by stock is determined by apportioning the catches by spatio-temporal stratum, taking account of mixing (i.e. exposure to harvesting) matrices, according to:

$$C_t^i = \sum_s \sum_A C_t^{A,s} \frac{X_t^{A,s,i} N_t^i}{X_t^{A,s,2} N_t^2 + X_t^{A,s,1} N_t^1} \tag{2}$$

where $C_t^{A,s}$ is the catch in spatial stratum *A* during season *s* of year *t*; and

$X_t^{A,s,i}$ is the relative exposure of stock *i* to harvesting in area *A* during season *s* of year *t* (i.e., the proportion of stock *i* animals in area *A* during season *s* of year *t*).

Note that equation 2 implies that the harvest during the year is sufficiently small that there is no need to remove catches in seasons 1, 2, ..,*s*-1 before determining the split among stocks of the catch during season *s*. The $X_t^{A,s,i}$ (over all *A*, *s*, and *i*) constitute the elements of a mixing matrix. The mixing matrices are permitted to vary over time, *t*, usually in multi-year blocks which are referred to 'exposure eras'.

The historical catches are specified by 'catch allocation era' (a block of years) along with the breakdown of the catch among areas within each season. The catches by spatial-temporal stratum can be computed using this information and the total catch by year.

PARAMETER ESTIMATION

The values for the parameters of the population dynamics model are: a) the intrinsic rate of growth, b) the stock-specific carrying capacities, and c) the values for the mixing and catch allocation matrices. The first and third of these quantities are pre-specified by the user while the values for the stock-specific carrying capacities are estimated by minimizing an objective function that contains contributions from: a) abundance estimates for Stock 1 obtained based on surveys conducted in area A' and during season s', b) a pre-specified value for the abundance of Stock 2 in 2002, and c) a prior for the abundance of Stock 1 in 1993. The objective function minimized to find the values for the "free" parameters of AWMP-Lite is therefore:

$$-0.5(\ell n\mathbf{N}^{obs} - \ell n(\mathbf{X}^{A',s',1}\mathbf{N}^1))^T \mathbf{\Sigma}^{-1}(\ell n\mathbf{N}^{obs} - \ell n(\mathbf{X}^{A',s',1}\mathbf{N}^1)) + \Omega(N_{2002}^2 - V)^2 + \tfrac{0.5}{1300^2}(X_{1993}^{A',s',1} N_{1993}^1 - 7800)^2 \tag{3}$$

where $\mathbf{N}^{obs}$ is the vector (over year index *t*) of observed abundance estimates;

$\mathbf{X}^{A's'1}$ is the vector (over *t*) of exposures in the survey years;

$\mathbf{N}^1$ is the vector (over *t*) of simulated abundances in the survey years;

Σ is the variance-covariance matrix for the observed log-abundances, as given by Zeh and Punt (2005) and replicated here as Table 1; and

Ω is the weight assigned so that the abundance of Stock 2 mimics the pre-specified value for this abundance, *V*, closely.

Unlike the common control program, AWMP-Lite does not consider uncertainty in the values for the parameters of the operating model.

DATA GENERATION

The historic (*t*<2003) abundance estimates (and their *CV*s) are provided to the *SLA* and are taken to be those in Table 1 (note that these estimates differ from those provided the *SLA* by the common control program (see table 3 of IWC (2003b)). An estimate of absolute abundance together with an estimate of its CV is generated, and is provided to the *SLA*, for the year *t*=2006 and then once every *F* years during the management period (where *F*=10). The *CV* of the abundance estimate (CV_{true}) may be different from the expected value of the *CV* provided to the *SLA*.

The survey estimate, $\hat{S}$, may be written as:

$$\hat{S}_t = B_A P^* \beta^2 Y_t w_t \quad (4)$$

where B_A is the bias (set equal to 1 for the purposes of this paper);

P^* is the reference population level (the pristine 1+ population size of Stock 1 in area A' during season s');

P_t is the current 1+ population size of Stock 1 in area A' during season s' of year t ($= X_t^{A',s',1} N_t^1$);

Y_t is a lognormal random variable:

$$Y_t = e^{\phi_t} \qquad \phi_t \sim N[0; \ell n(1+\alpha^2)] \quad (5)$$

w_t is a Poisson random variable, independent of Y_t, with $E(w_t) = P_t / (P^* \beta^2)$.

The *SLA* is provided with an estimate of *CV* for each sightings estimate, $CV_{est,t}$. The value for the estimate of $CV_{est,t}$ is given by:

$$\hat{C}V_{est,t} = \sigma_t \sqrt{(\chi_n^2 / n)} \qquad \sigma_t^2 = \ell n(1 + E(CV_{est,t}^2)) \quad (6)$$

where $E(CV_{est,t}^2)$ is the actual *CV* for the abundance estimate for year *t*:

$$E(CV_{est,t}^2) = \theta^2 (a^2 + b^2 / (w_t \beta^2)) \quad (7)$$

θ is the parameter that determines the relationship between the parameters *a* and *b* and the expected value of the observed *CV*:

$$\theta = CV_{est} / \sqrt{a + b / 0.6} \quad (8)$$

χ_n^2 is a random number from a χ^2 distribution with *n* (=19; the value assumed for the single stock trials for the RMP) degrees of freedom;

a^2, b^2 are constants and equal to 0.02 and 0.012 respectively;

α^2, β^2 are constants given by:

$$\alpha^2 = \theta^2 a + \eta 0.1 \,; \; \beta^2 = \theta^2 b + \eta 0.013 \quad (9)$$

η determines the relationship between the observed and actual *CV*s:

$$\eta = [(CV^{true})^2 - (CV^{est})^2] 0.6 / 0.73 \quad (10)$$

EXAMPLE APPLICATIONS

The example applications of this paper are based on single-stock trials BE01 and BE09 for the B-C-B bowhead whales (see IWC 2003b and Table 2 for details). The value of the parameter *z* (Equation 1) is set equal to 2.39 so that *MSYL*=0.6K for AWMP-Lite ($MSYL_{1+}$=0.6K for trials BE01 and BE09). Note that, unlike AWMP-Lite, allowance is made for time-varying historical survey bias when trial BE01 is conditioned based on the common control program (see Table 2).

The results for trials BE01 and BE09 from AWMP-Lite and the common control program are shown in Figures 1 and 2. These figures show the time-trajectories of 1+ population size and catch for each of the 100 simulations. The catch and (particularly) the population size trajectories based on the common control program are more variable than those based on AWMP-Lite. This is, however, not unexpected given that AWMP-Lite ignores parameter uncertainty while each of the 100 simulations based on the common control program are based on a random draw from a Bayesian posterior distribution for the parameters of the operating model (see IWC 2003b for details). Nevertheless, the behaviour of GUP is very similar for the common control program and AWMP-Lite, suggesting that AWMP-Lite is sufficient to form the basis for an evaluation of GUP for multi-stock scenarios. The performance of the GUP for any multi-stock trials could assessed in terms of conservation performance and need satisfaction with reference to the 'equivalent' single stock trials (sense IWC (2007)).

OTHER COMMENTS

Linking AWMP-Lite and GUP involved developing a standalone program to implement GUP. The results for the BE trials in which GUP is a standalone program and in which it is integrated into the common control program are identical, suggesting that the standalone program performs correctly. Moreover, a standalone version of GUP is needed if the GUP is to be to used calculate actual *Strike Limits* for the B-C-B bowhead whales. However, the G-G *SLA* (Givens 2003), which forms part of the GUP, requires the values for parameters that are calculated based on earlier calls to the GUP. Although not a concern from a testing point of view, consideration should be given to developing a totally standalone version of the GUP – that such a version of the GUP produces identical results to the present version would, course, need to be checked.

ACKNOWLEDGEMENTS

Doug Butterworth (UCT) is thanked for his comments on an earlier version of this document.

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Table 1
Estimates, *CV*s (actually standard errors of the logarithms), and the correlation matrix for the logarithms of the indices of abundance for the B-C-B bowhead stock. The values in this Table are based on the estimation procedure described in Zeh and Punt (2005).

Year	Estimate	CV	Correlation matrix										
1978	4765	0.305	1										
1980	3885	0.343	0.118	1.000									
1981	4467	0.273	0.056	0.050	1.000								
1982	7395	0.281	0.094	0.084	0.035	1.000							
1983	6573	0.345	0.117	0.104	0.049	0.084	1.000						
1985	5762	0.253	0.070	0.062	0.020	0.078	0.062	1.000					
1986	8917	0.215	0.072	0.064	0.017	0.092	0.064	0.113	1.000				
1987	5298	0.327	0.124	0.110	0.052	0.088	0.110	0.065	0.067	1.000			
1988	6928	0.120	0.028	0.025	0.013	0.017	0.024	0.009	0.007	0.026	1.000		
1993	8167	0.071	0.001	0.001	0.001	0.000	0.001	-0.001	-0.002	0.001	0.000	1.000	
2001	10545	0.128	0.008	0.007	0.005	0.001	0.007	-0.004	-0.008	0.008	0.003	0.000	1.000

Table 2.
Specifications for two of the *Evaluation Trials* for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. Survey interval = 10years; differences from the base case are shown in bold.

Trial No.	Description	$MSYR_{1+}$	$MSYL_{1+}$	Final need	Historical survey bias	Future survey bias	Survey CV (true, est)
BE01	Base case	2.5%	0.6	134	1	1	0.25, 0.25
BE09	$MSYR_{1+}$ = 1%	**1%**	0.6	134	**0.67 → 1**	1	0.25, 0.25

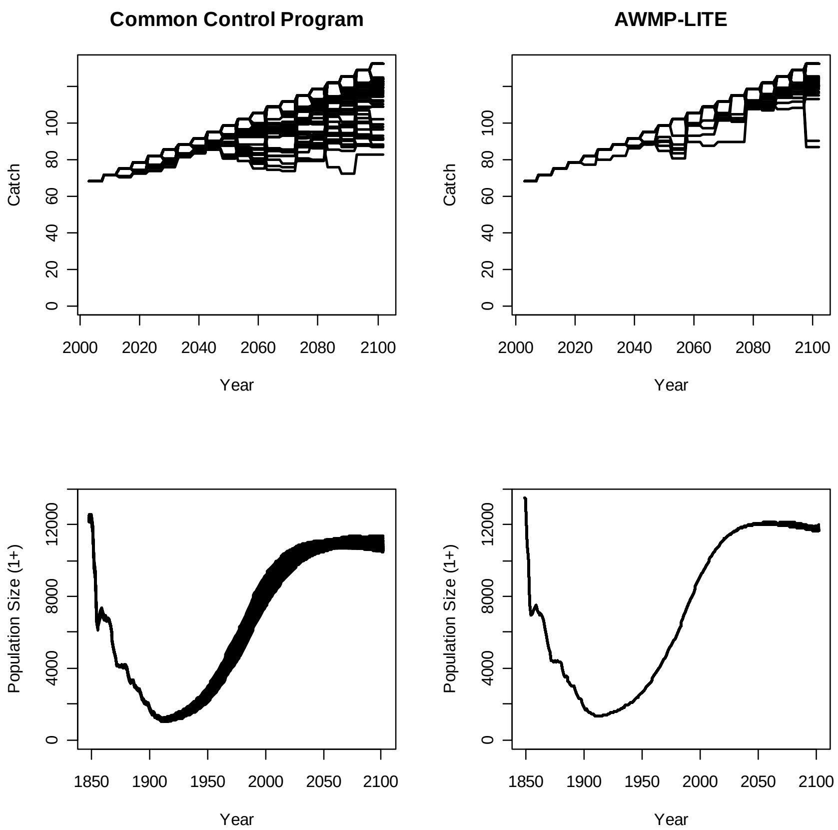

Figure 1. Population size and catch trajectories for trial BE01 based on the common control program and AWMP-Lite.

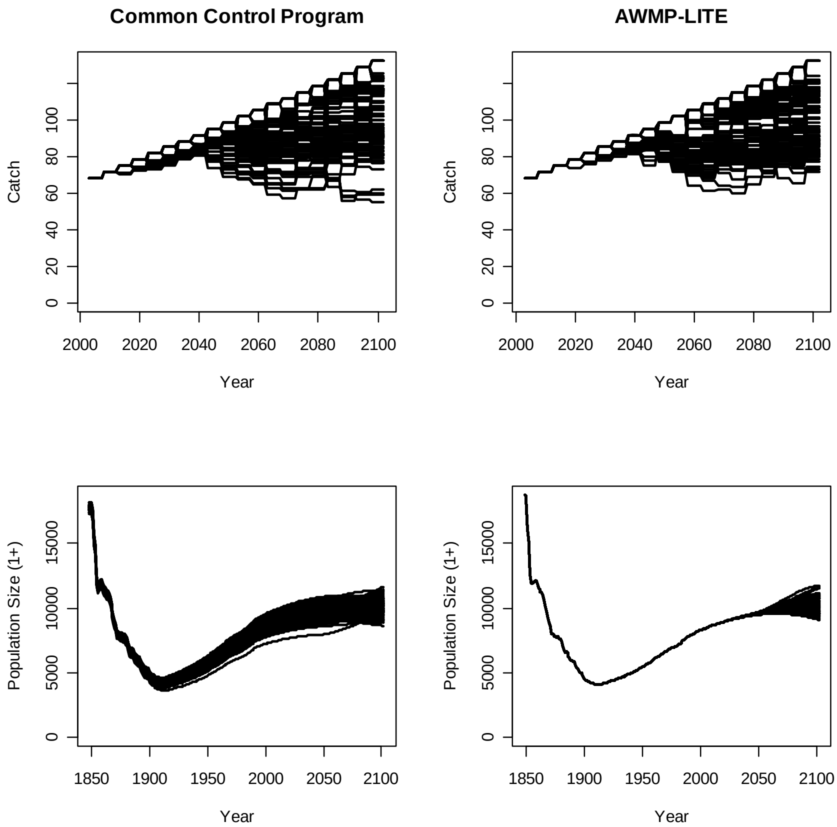

Figure 2. Population size and catch trajectories for trial BE09 based on the common control program and AWMP-Lite.