An Assessment of Plausibility of Sub-Stock Scenarios on Western North Pacific Minke Whales Using the Historical CPUE series

ABSTRACT

The aim of this article is to investigate the plausibility of different stock structure scenarios on western North Pacific minke whales proposed in *Implementation Simulation Trials* (IST) of *Revised Management Procedure* (RMP). To provide an independent assessment of the plausibility, we used CPUE time series data, which were not used in IST. Using a simple Bayesian population dynamics model, we showed that the posterior confidence interval (CI) of the depletion rate contained that of initial depletion statistics of Stock Scenario A wholly. On the other hand, the confidence intervals of Stock Scenarios C and D were not included in the CI derived from the model. As a result, we conclude that the plausibility of Stock Scenarios C and D is much lower than that of Stock Scenario A on the assumption that CPUE is proportional to population abundance. The conclusion is supported even under square root nonlinearity of the relationship between CPUE and abundance.

1. INTRODUCTION

Implementation Simulation Trials (IST) of western North Pacific minke whales have four 'baseline' trials based on different stock structure scenarios, in which Baselines A and B have fewer stocks or simpler stock structure than Baselines C and D. Baseline A is the scenario with three stocks, J, O, and W, in which W-stock occurs sporadically in sub-area 9. Baseline A was derived from analysis of mt-DNA data by Japanese scientists. Baseline B is the same as Baseline A with no W-stock. Baseline C is the scenario with four stocks, J, Ow, Oe, and W, where the existence of Ow and Oe stocks was inferred by the boundary rank method. Baseline D is the scenario with three stocks, J, O, and W, where O and W-stocks are mixing among the whole sub-areas of western North Pacific. We hereafter refer to the stock structure scenario associated with each Baseline as 'Hypothesis'. See the details on pages 118-119 of JCRM 6 (Supplement) (IWC, 2004).

Hypotheses C and D predict the considerable decline of O or Ow stock in terms of initial depletion statistics of IST (IWC, 2004). For example, in the C1-J1 O trial, the 90% confidence interval of initial depletion is [0.25, 0.42] with the median value, 0.33. Kawahara (2003) pointed out that plausibility of Hypotheses C and D was lower than that of Hypotheses A and B using the historical catch per unit effort (CPUE) time series data, which were not used in IST and the result therefore was an assessment of plausibility of the different stock structure hypotheses independent from IST. In this article, we provide a more refined assessment of the CPUE time series data, especially in terms of statistical inference.

2. MATERIALS AND METHODS

2.1. The Data

Basic datasets are same as Kawahara (2003). Although Kawahara (2003) showed main results using the uncorrected CPUE time series data, we use the CPUE time series data with the effort data corrected for vessel tonnage effects. The corrected effort might overcompensate for the changes in efficiency (Kawahara, 2003). However, for our purpose, overcompensation is less problematic than undercompensation.

As in Kawahara (2003), we use the CPUE series from three periods 1955-1964 (Period 1), 1968-1977 (Period 2), and 1977-1987 (Period 3). Periods 1 and 2 series were corrected for the total vessel tonnage while Period 3 series was not corrected. Because there was no big change in the vessel tonnage between 1977 and 1987, this may be not so much problematic. We use three CPUE time series with Areas 3, 4, and 7 data derived from Anderson and Weaver (1991) as the independent time series data of Period 3. The plots of the CPUE time series data for each Period are shown in Fig. 1.

2.2. Model

A state-space model enables us to deal with natural variability underlying the annual population dynamics transitions (process error) and uncertainty in the observed abundance indices due to measurement and sampling error (observation error) distinguishably (Meyer and Millar, 1999). We use a state-space model to incorporate the intrinsic uncertainty as much as we can appropriately.

For the state equation, we use a population dynamics model with a simple exponential increasing rate:

$$N_{t+1} = N_t \exp(\lambda_t)$$

where $\lambda_t \sim N(\bar{\lambda}, \tau^2)$, in which $\bar{\lambda}$ is the mean increasing rate of population. It is possible to avoid making any extra assumptions using the simple model like this.

The observation equations are given by

$$I_{i,a,t} = q_i N_t \exp(\sigma_{i,a,t})$$

where q_i is the fishing efficiency of Period i, a denotes the corresponding area (a = 3,4,7 for Period 3. If Period is 1 or 2, a is omitted), and $\sigma_{i,a,t} \sim N(0, \nu_{i,a}^2)$.

We use a Bayesian approach to infer parameters because the Bayesian approach can easily handle nonlinearities of state and observation equations and realistic distributional assumption of each parameter (Meyer and Millar, 1999).

As prior distributions of each parameter, we use the following ones:

$\log(N_{1955}) \sim \mathrm{U}(8, 11)$ (This corresponds to $N_{1955} \in [3,000, 60,000]$),

$\bar{\lambda} \sim \mathrm{N}(0, 10^6)$,

$\log(q_i) \sim \mathrm{U}(-20, 20)$,

$1/\nu_{i,a}^2 \sim \mathrm{Ga}(0.001, 0.001)$,

$1/\tau^2 \sim \text{Ga}(0.001, 0.001)$,

where we use approximately noninformative priors for the parameters except for $\log(N_{1955})$ and uniform distributions for the logarithms of scale parameters according to the custom of Bayesian population dynamics models (Punt and Hilborn, 1997; McAllister and Kirkwood, 1998). For $\log(N_{1955})$, we use a mildly informative prior distribution to stabilize estimation. The informative prior is set within 3,000 to 60,000 with reference to the existing information (IWC, 2004; Butterworth, 1996; Hakamada, 2004). Note nevertheless that as there is no scale information input to these analyses, because all the CPUE series are treated as relative indices and there are no catches or survey estimates of abundance used, the specific choice of the prior for $\log(N_{1955})$ will hardly affect results.

The inference is carried out using WinBUGS (Spiegelhalter et al., 2003), which produces the posterior samples using the Gibbs sampler (Gelfand and Smith, 1990). We use the 5 MCMC sequences with different initial parameter values to diagnose the convergence and the MCMC simulation for each sequence is repeated 35,000 times. We remove the first 5,000 iterations as the burn-in samples.

The posterior distribution of depletion $D_{2000} = N_{2000}/N_{1955}$ is compared with the initial depletion statistics of IST. We use N_{1955} as the initial population size, while IST used the catch statistics prior to 1955. However, the catches prior to 1955 would have made little impact on the population abundance, so the comparison whould not be much affected by the model not covering the pre-1955 period, as is evident from inspection of IST trajectories shown in IWC (2004). We use the results of O trials with $\text{MSYR}_{\text{mature}} = 1\%$ for comparison, since they are one of Basecase trials of North Pacific minke whales IST and have a big impact on the performance statistics for the O stock (IWC, 2004). In addition, we carry out two sensitivity tests, where one is done by removing the Period 1 CPUE dataset, which is considered the least reliable among three periods, and another is done by assuming the CPUE time series is proportional to the square root of population size to take into account the case that the changes in CPUE are proportionally smaller than changes in abundance. We call the former test the 'DR' trial, and the latter test the 'NP' trial (DR = Data Reduction, NP = Non-Proportionality).

3. Results

The trace plots of each parameters indicated the convergence and the $\hat{R}$ statistics of all the parameters was less than 1.1. When $\hat{R}$ is near 1, we can generally think that the analysis is acceptable in terms of convergence of MCMC simulations (Gelman et al., 2004). We repeated the analyses with different initial values several times so that we got almost identical results from every run. We therefore judged that we had the converged posterior samples.

The estimated population trend $\bar{\lambda}$ was 0.01 at the median value (90% posterior confidence interval [-0.016, 0.031]). The depletion D_{2000} was estimated to be 1.56 at the median value (90% CI [0.56, 3.31]). The observation errors $\nu_{i,a}$s were within 0.13 and 0.24 and the process error was 0.05 at the median. The summary of estimated main parameters was given in Table 1.

The plots of depletion D_{2000} were shown in Fig. 2 with trajectories of 5%-ile, 25%-ile, and 50%-ile. For comparison, we attached the confidence intervals of initial depletion statistics in the J1 O trials with $\mathrm{MSYR_{mat}} = 1\%$ of Hypotheses A, C, and D (IWC, 2004). The 90% confidence intervals of J1 O trials with $\mathrm{MSYR_{mat}} = 1\%$ were [0.70, 0.83], [0.25, 0.42], and [0.29, 0.47] for Hypotheses A, C and D, respectively (IWC, 2004). Because the result of Hypothesis B was omitted in IST in 2003, we do not mention the result of Hypothesis B. However, as Hypothesis B involves only one stock to the east of Japan, its results will be more optimistic than even those for Hypothesis A. The confidence interval of initial depletion of Hypothesis A was included in the 90% confidence interval of depletion D_{2000}, while those of Hypotheses C and D were not included in it. It is worth while mentioning that if the full range of C and D robustness trials is considered, only in a very few cases is there slight overlap with 90% confidence interval for depletion D_{2000}.

The summary statistics of sensitivity tests was given in Table 2. We can see that the lower limits of depletion of each sensitivity test declined to some extent. The plots from the sensitivity tests were shown in Figs. 3 ('DR' trial) and 4 ('NP' trial). The lower limits of trajectories in two plots were similar. The confidence interval of initial depletion of Hypothesis A was within the confidence intervals of depletion D_{2000}. On the other hand, the lower limits of confidence intervals of depletion D_{2000} slightly overlapped with the upper limits of initial depletion statistics of Hypotheses C and D, while most values of initial depletion statistics of Hypotheses C and D, which included the median values, were still outside the confidence intervals of depletion D_{2000}.

4. Discussion

Historically, there was a lot of discussion on the proportional relationship between CPUE and population size in fisheries circles including the International Whaling Commission (Cooke, 1985; IWC, 1989a). We also have to acknowledge our analysis to be of an initial nature. However, we believe that the CPUE series could give us valuable information on the status of stocks if we are sufficiently cautious about uncertainty of relationship between CPUE and stock size.

Cooke (1985) pointed out that proportionality between CPUE and population abundance did not hold giving a number of reasons, mainly on the theoretical basis. Some hold true for North Pacific minke whales but some do not. North Pacific minke whales are very difficult to detect and most of sightings are composed of a single animal. The former may cause variations in catchability and handling time so that CPUE is not proportional to stock size, while the latter removes some important impacts such as schooling effects. We incorporated observation and process errors into our model to deal with uncertainty as reasonably as we can. In addition, we carried out the sensitivity test in which CPUE is proportional to the square root of abundance. Although there is a degree of arbitrariness in choosing the square root dependence for the sensitivity test, it is worth noting that when CPUE data were included in the early RMP trials (IWC, 1989b), this was the alternative to linear proportionality chosen to be considered by the Scientific Committee, and further that Rose and Kulka (1999) showed that CPUE of northern cod, which might have been considerably hyperstable because of shoaling effects, was approximately proportional to the square root of local density.

We made efforts as many as we can at present to take account of uncertainty. For example, the use of corrected CPUE time series, incorporating observation and process errors, and carrying out a few sensitivity tests. Nevertheless, our analyses gave the impression that the stock decline of Hypotheses C and D is too extreme to be realistic. In addition, we used the exponential trend in our analysis to continue until 2000, whereas in reality catches were reduced substantially after 1987 because of the moratorium of commercial whaling, so that any negative trend the model caused from 1988 to 2000 may well have been overestimated by our approach which used the data up until 1987 only. So, our approach is likely to overestimate the extent of population decline. As a result, we conclude that the plausibility of Hypotheses C and D is much lower than that of Hypothesis A and hence it is unnecessary to consider stock scenarios C and D when accounting for the effect of catches on the O stock.

References

Anderson, G. R. V. and Weaver, K. E. (1991) Preliminary assessment of vessel and area CPUE patterns in Japanese coastal minke whaling: Okhotsk Sea - West Pacific 1977-1987. Paper SC/43/Mi37 presented to the IWC/SC (unpublished). 14pp.

Butterworth, D. S. (1996) The effect on stocks of proposed scientific permit catches of minke whales from Antarctic areas V and VI and form the North Pacific. Paper SC/48/O1 presented to the IWC/SC (unpublished). 13pp.

Cooke, J. G. (1985) On the relationship between catch per unit effort and whale abundance. Report of the International Whaling Commission 35: 511-519.

Gelfand, A. E., and Smith, A. F. M. (1990) Sampling-based approaches to calculating marginal densities. Journal of the American Statistical Association 85: 398-409.

Gelman, A, Carlin, J. B., Stern, H. S., and Rubin, D. B. (2004) *Bayesian Data Analysis*. Chapman and Hall, New York.

Hakamada, T. (2004) Examination of the effects on the whale stocks of future catches under JARPNII. Appendix of Paper SC/56/O1 presented to the IWC/SC (unpublished). 14pp.

International Whaling Commission (1989a) Report of the comprehensive assessment workshop on catch per unit effort (CPUE), Reykjavik, 16-20 March 1987. pages 15-20 in G. P. Donovan (ed.) "The Comprehensive Assessment of Whale Stocks: the eraly years," International Whaling Commission, Cambridge, UK.

International Whaling Commission (1989b) Report of the comprehensive assessment workshop on management, Reykjavik, 23-25 March 1987. pages 21-28 in G. P. Donovan (ed.) "The Comprehensive Assessment of Whale Stocks: the eraly years," International Whaling Commission, Cambridge, UK.

International Whaling Commission (2004) Report of the sub-committee on the Revised Management Procedure. Journal of Cetacean Research and Management 6 (Supplement): 75-184.

Kawahara, S. (2003) A review of Japan's small-type whaling and CPUE analyses to address the relative plausibility of trials on western North Pacific minke whales. Paper SC/55/IST16 presented to the IWC/SC (unpublished). 9pp.

McAllister, M. K. and Kirkwood, G. P. (1998) Bayesian stock assessment: a review and example application using the logistic model. ICES Journal of Marine Science 55: 1031-1060.

Meyer, R. and Millar, R. B. (1999) BUGS in Bayesian stock assessments. Canadian Journal of Fisheries and Aquatic Sciences 56: 1078-1086.

Punt, A. E., and Hilborn, R. (1997) Fisheries stock assessment and decision analysis: the Bayesian approach. Reviews in Fish Biology and Fisheries 7: 35-63.

Rose, G. A., and Kulka, D. W. (1999) Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua*) declined. Canadian Journal of Fisheries and Aquatic Sciences 56 (Suppl. 1): 118-127.

Spiegelhalter, D. J, Thomas, A., and Best, N. G. (2003) WinBUGS Version 1.4 User Manual. Medical Reasearch Council Biostatistics Unit, Institute of Public Health, Cambridge, UK, http://www.mrc-bsu.cam.ac.uk/bugs.

Table 1. The 5%-ile, 25%-ile, and 50%-ile of posterior distribution of $\bar{\lambda}$ and D_{2000} under the basecase trial

	5%-ile	25%-ile	50%-ile
$\bar{\lambda}$	-0.016	0.001	0.010
D_{2000}	0.556	1.086	1.563

Table 2. The 5%-ile, 25%-ile, and 50%-ile of posterior distribution of $\bar{\lambda}$ and D_{2000} under the 'DR' trial

	5%-ile	25%-ile	50%-ile
$\bar{\lambda}$	-0.027	-0.004	0.010
D_{2000}	0.405	0.891	1.538

Table 3. The 5%-ile, 25%-ile, and 50%-ile of posterior distribution of $\bar{\lambda}$ and D_{2000} under the 'NP' trial

	5%-ile	25%-ile	50%-ile
$\bar{\lambda}$	-0.028	0.001	0.018
D_{2000}	0.411	1.165	2.320

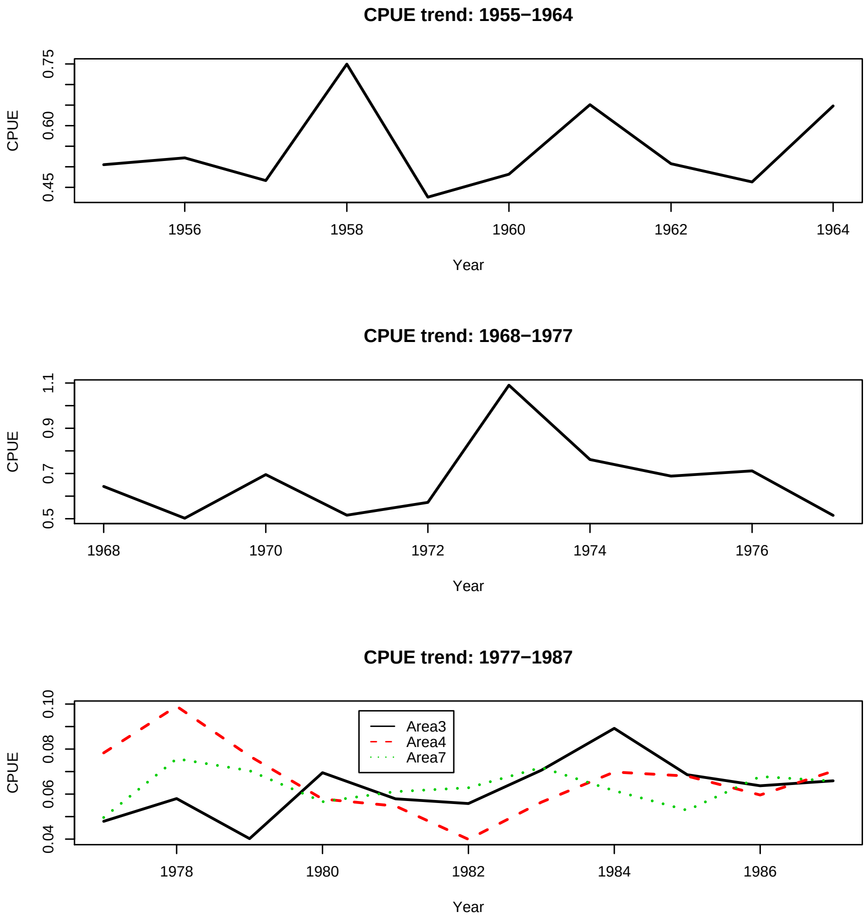

Figure 1. The CPUE time series data corrected for vessel tonnage effects used in the analysis.

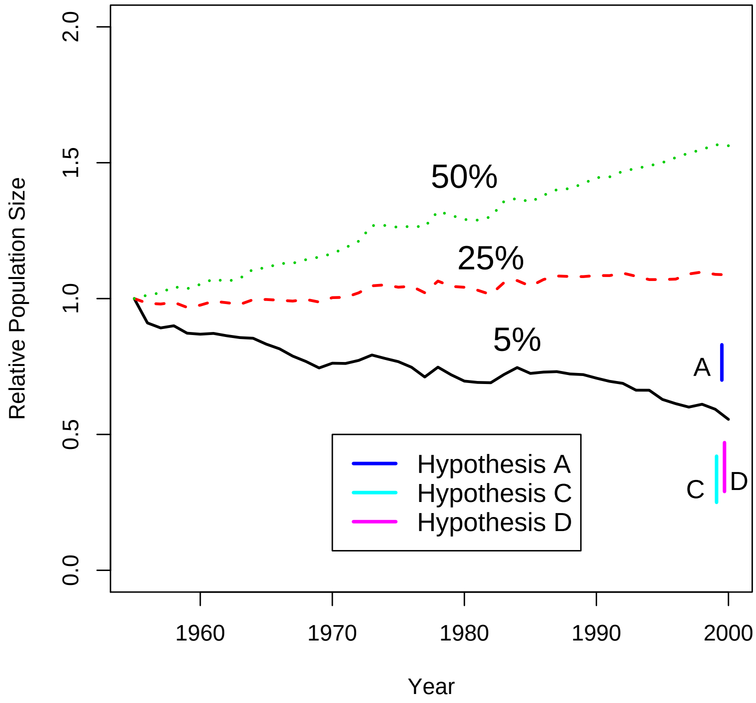

Figure 2. Comparison between 90% CIs of the depletion from the analysis in this article and initial depletion statistics under the Basecase trial for $\text{MSYR}_{\text{mat}} = 1\%$.

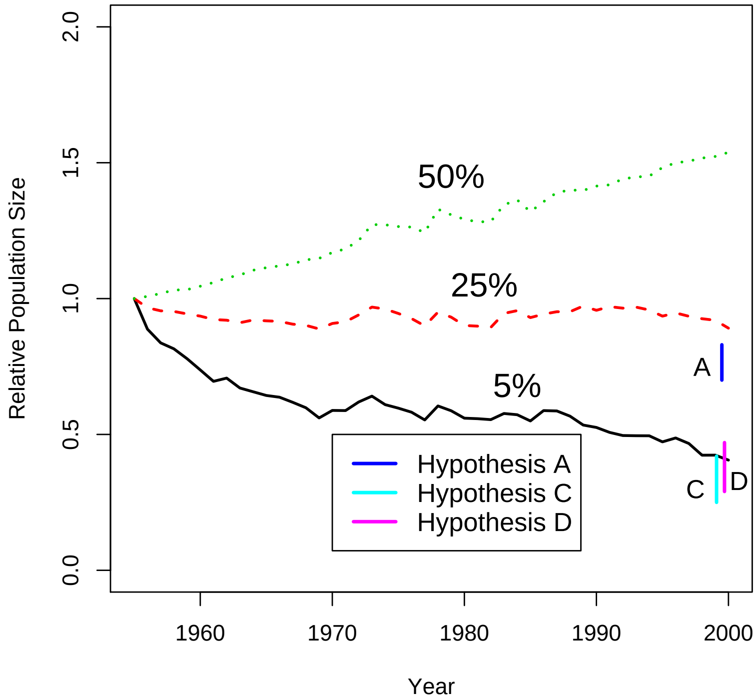

Figure 3. Comparison between 90% CIs of the depletion from the analysis in this article and initial depletion statistics under the 'DR' trial for $\mathrm{MSYR}_{\mathrm{mat}} = 1\%$.

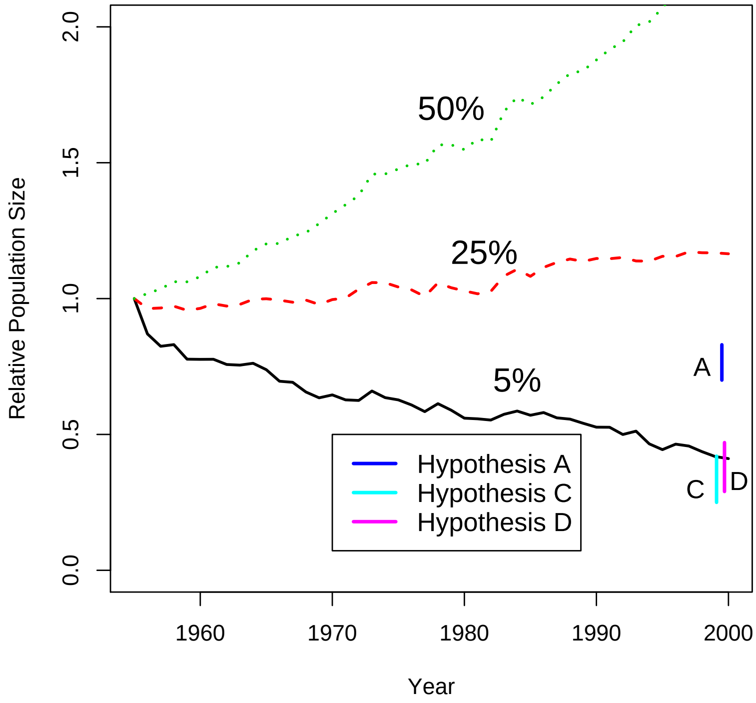

Figure 4. Comparison between 90% CIs of the depletion from the analysis in this article and initial depletion statistics under the 'NP' trial for $MSYR_{mat} = 1\%$.