Update of the integrated abundance estimates for common minke whales in sub-areas 5, 6 and 10 using sighting data from Japanese and Korean surveys

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ABSTRACT

Japan and Korea have conducted a series of sighting surveys in sub-areas (SAs) 5, 6 and 10 where are one of main habitats of the J-stock of common minke whales. Although parts of SA5 and SA6 were not covered by the surveys due to territorial reasons, information on abundance from sighting data from Japanese and Korean surveys in the rest of the areas can be integrated for obtaining better knowledge on abundance for J-stock animals. Work for the integration has been conducted under the NPM Working Group (e.g. Kitakado et al. 2009). This paper attempts to update on the work by using new information on abundance (An *et al*. 2010, Miyashita *et al*. 2009, 2010, and Okamura *et al*. 2010). A log-linear model with fixed year and survey block effects and random effects for the process error was employed. Estimates of g(0) and their uncertainties given in were also taken into account. The extent of the process error was estimated through an integrated likelihood function, and other fixed effects were estimated using linear predictors. The predicted abundance estimates in blocks, sub-areas, and a whole of the three sub-areas in a reference year 2009 were produced by the model with and without a year trend in abundance. The results showed that the yearly trend was not significant. Under the assumption of no year trend, the estimate of total abundance in surveyed areas was 7,103 (CV=0.230) and the spatially extrapolated estimates in a whole of SA5, SA6 and SA10 was given as 16,162 (CV=0.277). It should be noted that J-stock animals are also distributed in the East China Sea, Pacific coast of Japan and the Sea of Okhotsk (IWC 2004, Kanda et al.2009), and therefore this fact should be taken account when the abundance in J-stock is used in its management.

1. INTRODUCTION

The Working Group on the in-depth assessment of western North Pacific common minke whales, with a focus on J-stock (NPM), worked for integrating knowledge on abundance in sub-areas (SAs) 5, 6 and 10, where Japan and Korea have conducted sighting surveys. Kitakado *et al*. (2009) reported their results of the integration with consideration of the additional variance based on the abundance estimates up to 2008 surveys by Japan and Korea (see also Appendix 7, IWC 2010). Now that Korean abundance estimates were revised and available up to 2009 (An *et al*. 2010). Furthermore, estimates of g(0) by the Japanese survey were revised (Okamura *et al*. 2010). For these reasons, this paper aims at providing updated abundance estimates with consideration of the additional variance and g(0) based on underlying abundance estimates under g(0)=1 from Japanese and Korean surveys from 2000 to 2009 and revised g(0) estimates from Japanese surveys.

2. MATERIALS AND METHODS

2.1 Underlying abundance estimates in surveyed blocks and g(0) estimates

Figue 1 shows the definition of sub-areas and survey blocks. Japan and Korea have conducted a series of sighting surveys since 2000 in SA5, SA6 and SA10, where are main habitats of the J-stock of common

minke whales (An *et al*. 2010 and Miyashita *et al*. 2009, 2010). Table 1 showed abundance estimates and their CVs based on the best model in each country under the assumption of $g(0)$=1 (An *et al*. 2010 and Miyashita *et al*. 2009, 2010). Japanese surveys focused on the eastern blocks of SA6 and a whole of SA10 while Korea concentrated on its survey in the eastern side of SA5 and one of blocks in SA6. Although parts of SA5 and SA6 were not covered by the surveys due to territorial reasons, information on abundance from sighting data in other areas can be integrated for obtaining better knowledge on abundance for J-stock animals. We employed these estimates as underlying data for abundance.

To correct those abundance esitmates with $g(0)$=1, we used estimates of $g(0)$ obtained from Japansese surveys (see Okamura *et a*l. 2010). For Japanese surveys in 2006 and 2007, which had IO platforms, we made use of the value of $\hat{g}_{A\cup B\cup C}(0)$ = 0.856 (CV=0.120) for the correction. For the rest of Japanese surveys without any IO platforms and Korean surveys, the value of $\hat{g}_{A\cup C}(0)$ = 0.798 (CV=0.168) was assumed. Note that the height of upper bridge of the Korean vessel is lower than that of the Japanese vessel, and therefore the use of the Japanese g(0) estimate for the correction of Korean abundance estimates is considered conservative.

As shown in An *et al*. (2010) and Miyashita *et al*. (2009, 2010), survey timing slightly differs among the survey blocks. It was concerned, based on the assumption of south-to-north migration, that chances of double-counting might have happened, when all the estimates were used once (Annex G1, IWC 2010). Goto *et al*. (2010) however draw a hypothesis that such a typical migration pattern of ordinal winter breeding baleen whales is not applicable to J-stock animals. Given the hypothesis, we conduct our analysis using all the abundance estimates without any treatment of eliminating abundance estimates formerly carried out in Kitakado *et al*. (2009) as an option.

2.2 Statistical models

Let $\tilde{N}_{by}$ be the actual abundance in the *b*-th block in year *y* and let $\hat{N}_{by}$ an estimate of $\tilde{N}_{by}$. Also, let $\tilde{g}(0)_{by}$ be an estimate of $g(0)$ for the survey in block *b* and year *y*. We assume that a vector of abundance estimates $\hat{N} = (..., \hat{N}_{by}, ...)$ has a multivariate log-normal distribution as follows:

$$\begin{aligned} &\log \hat{N}_{by} = \log[\tilde{g}(0)_{by}\, \tilde{N}_{by}] + \varepsilon_{by}, \\ &\varepsilon = (...., \varepsilon_{by}, ...) \sim N(0, \hat{\Sigma}), \end{aligned} \qquad (1)$$

where $\hat{\Sigma}$ is a known variance-covariance matrix for the logarithm of the abundance vector $\hat{N} = (..., \hat{N}_{by}, ...)$. We also assume that the true abundance level varies randomly over years as

$$\log \tilde{N}_{by} = \log N_{by} + \rho_{by}, \qquad (2)$$

where N_{by} is an expected abundance in the *b*-th block in year *y*, and ρ_{by} is a random effect accounting for inter-annual change in the distribution of the whale population in the surveyed area. The random effects are assumed to be independent and identically distributed as the normal distribution $N(0, \sigma^2)$, where σ^2 is called the additional variance.

Next, we consider models for the expected abundance level. Let μ_b is a mean area-specific log-abundance at a specific year in the *b*-th block. Then, we investigate the following two models for N_{by}:

Model 1: True abundance level is constant in 2000-2009 in each block;

$$\log N_{by} = \mu_b \qquad \text{for all } y. \tag{3}$$

Model 2: True abundance level is exponentially increasing (deceasing) since 2000. We used 2009 as a reference year, so μ_b is the logarithm of abundance in 2009;

$$\log N_{by} = \mu_b + \phi(y - 2009). \tag{4}$$

Here, the estimates of $g(0)$, $\tilde{g}(0)_{by}$, were also regarded as random quantities with an estimated variance-covariance matrix for a full account of estimation uncertainty as follows:

$$\tilde{g}(0)_{by} = \begin{cases} \tilde{g}_{A\cup C}(0) & \text{if the survey does not have IO platform,} \\ \tilde{g}_{A\cup B\cup C}(0) & o.w. \end{cases} \tag{5}$$

and

$$(\log \tilde{g}_{A\cup C}(0),\ \log \tilde{g}_{A\cup B\cup C}(0)) \sim N((\log \hat{g}_{A\cup C}(0), \log \hat{g}_{A\cup B\cup C}(0)),\ \hat{\Lambda}), \tag{6}$$

where $\hat{\Lambda}$ is a known variance-covariance matrix for ($\log \hat{g}_{A\cup C}(0)$, $\log \hat{g}_{A\cup B\cup C}(0)$).

2.3 Estimation

In this paper, the integrated likelihood with an REML treatment was employed for the estimation of parameters (Punt *et al*., 1997, McCulloch and Searle, 2001; Pawitan, 2001; Kitakado *et al.* 2009), where the random effects $(...., \rho_{by}, ...)$ and random quantities $\log \tilde{g}_{A\cup C}(0)$ and $\log \tilde{g}_{A\cup B\cup C}(0)$ were integrated out from the likelihood as random variables.

Unknown parameters are fixed block- and year- effects and the additional variance σ^2. It is well-known that the conventional ML method causes underestimation of the variance factor, and therefore we use an REML method for this purpose. As in a conventional notation of mixed effect models, we represent the model as a linear form as follows:

$$\begin{aligned} &Y = X\beta + \rho + u, \\ &\rho \sim N(0, D), \qquad D = \sigma^2 \mathbf{I}, \\ &u \sim N(0, \hat{\Psi}), \end{aligned} \tag{7}$$

where $Y = \log \hat{N}$ is the vector of log-abundance estimates, X is a design matrix for the fixed-effects in linear predictor for $\log N_{by}$, and D and $\hat{\Psi}$ are the variance-covariance matrix for $\rho = (\cdots, \rho_{ay}, \cdots)'$ and u, respectively.

For fixed σ^2, the best linear unbiased estimator of β is derived by

$$\beta(\sigma^2) = (X'V(\sigma^2)^{-1}X)^{-1}X'V(\sigma^2)^{-1}Y \tag{8}$$

where $V(\sigma^2) = D + \hat{\Psi}$.

The additional variance σ^2 is estimated by maximizing

$$l_{REML}(\sigma^2) = -\frac{1}{2}\log\left|V(\sigma^2)\right| - \frac{1}{2}\log\left|X'V(\sigma^2)^{-1}X\right| - \frac{1}{2}(Y - X\beta(\sigma^2))'V(\sigma^2)^{-1}(Y - X\beta(\sigma^2)) \quad (9)$$

and its uncertainty is assessed by the reciprocal of the second derivative with respect to σ^2. The variance-covariance matrix for $\hat{\beta} = \beta(\hat{\sigma}^2)$ is estimated as

$$C\hat{o}v(\hat{\beta}) = (X'V^{-1}(\hat{\sigma}^2)X)^{-1}. \quad (10)$$

3. RESULTS AND DISCUSSION

Abundance estimates based on the two models were given in Table 3. Abundance levels in surveyed areas in blocks predicted by the linear models were further extrapolated to the abundance in the full block using the estimated densities. Also, abundance in a sub-area was calculated by the extrapolation with a mean of density estimates among blocks in the sub-area.

The estimated additional standard errors in Models 1 and 2 were 0.263 (SE=0.140) and 0.288 (SE=0.152), respectively. The annual rate of increase in Model 1 was estimated at 0.0061 (SE=0.051); the trend was not significant. Under the assumption of no year trend the estimate of total abundance in surveyed areas was 7,103 (CV=0.230) and the spatially extrapolated estimates in a whole of SA5, SA6 and SA10 was given as 16,162 (CV=0.277). As expected because of the small value of annual increase rate, the difference in estimates between Models 1 and 2 was negligible.

It should be noted that J-stock animals are also distributed in the East China Sea, Pacific coast of Japan and the Sea of Okhotsk (IWC 2004, Kanda et al.2009), and therefore this fact should be taken account when the abundance in J-stock is used in its management.

There are still unsurveyed areas in the sub-areas focused in this paper. In the terms of getting better knowledge on the trend as well as reducing the uncertainty by the process error, a large-scale sighting survey with multiple countries cooperation could be most effective.

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Table1. Abundance estimates employed in this analysis (g(0) was assumed to be 1).

Block	Year	Survey area (nm2)	Abundance	CV	Survey country
5E	2001	15,678	1,534	0.523	Korea
	2004		799	0.321	
	2008		680	0.372	
6WS	2000	10,046	549	0.419	Korea
	2002		391	0.614	
	2003		485	0.343	
	2005		336	0.317	
	2006		459	0.516	
	2007		574	0.437	
	2009		884	0.286	
6ES	2002	19,018	905	0.684	Japan
	2003		124	0.582	
6EN	2002	71,914	891	0.608	Japan
	2003		935	0.357	
	2004		727	0.372	
10W	2006	63,912	2,855	0.327	Japan
10E	2002	27,823	816	0.658	Japan
	2003		405	0.566	
	2004		474	0.537	
	2005		666	0.444	
	2007		575	0.327	

Table2. Sizes of blocks and their coverage by surveys.

Sub-area	Block	Survey area (nm2)	Block size (nm2)	Coverage	Size of sub-area (nm2)
5	5WS+5WN	0	87,728	0%	120,280
	5E	15,678	32,552	48.2%	
6	6WS	10,046	20,888	48.1%	180,021
	6WN	0	49,183	0%	
	6ES	19,018	38,035	50.0%	
	6EN	71,914	71,914	100.0%	
10	10W	63,912	63,912	100.0%	134,476
	10E	27,823	33,238	83.7%	

Table 3. Abundance in a reference year 2009 estimated by the integration work. The estimate of year trend in Model 2 is ϕ=0.0061 (SE=0.051).

Model 1 (no year trend):

Sub-area	Block	Abundance in surveyed area in block		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					7,897	0.454
	5E	1,029	0.454	2,137	0.454		
6	6WS	629	0.385	1,308	0.385	4,029	0.372
	6WN						
	6ES	348	0.591	696	0.591		
	6EN	994	0.440	994	0.440		
10	10W	3,417	0.482	3,417	0.482	4,236	0.383
	10E	686	0.288	819	0.288		
Total		7,103	0.230	8,675	0.221	16,162	0.277

Model 2 (with year trend):

Sub-area	Block	Abundance in surveyed area in block		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					8,037	0.479
	5E	1,048	0.479	2,175	0.479		
6	6WS	635	0.410	1,320	0.410	4,094	0.412
	6WN						
	6ES	359	0.642	718	0.642		
	6EN	1,016	0.493	1,016	0.493		
10	10W	3,511	0.550	3,511	0.550	4,346	0.453
	10E	699	0.342	835	0.342		
Total		7,268	0.304	8,858	0.284	16,477	0.320

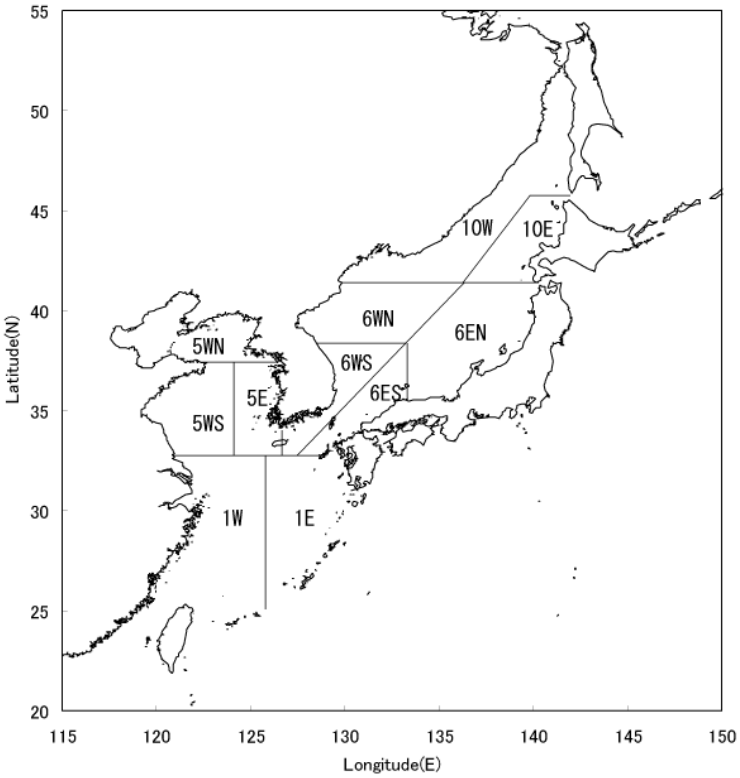

Figure 1. Definition of sub-areas and survey blocks