Integration of 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 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 in the rest of the areas can be integrated for obtaining better knowledge on abundance for J-stock animals. This paper attempted to integrate all the abundance estimates derived from Japanese and Korean surveys since 2000 under the assumption of g(0)=1 (Miyashita et al. 2009 and An et al. 2009). Survey timing slightly differs among the survey blocks, and therefore we need to eliminate chances of double-counting due to possible south-to-north migration as far as possible. For this purpose, as an option, we conducted analysis by using only abundance estimates in the period of May to June as well as that based on all the abundance estimates by ignoring migration. A log-linear model with fixed year and survey block effects and random effects for the process error was employed. 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 2004 were given by the model with and without a year trend in abundance. A yearly trend was not significant in each analysis. Under the assumption of no year trend the estimate of total abundance in surveyed areas in May to June season was 5,851 (CV=0.194) and that in all the seasons was 6,214 (CV=0.192). The spatially extrapolated estimates in a whole of SA5, SA6 and SA10 in the seasonal treatments were also give as 13,790 (CV=0.169) and 14,332 (CV=0.174), respectively. These abundance estimates, however, still have downward biases because of the assumption of g(0)=1 and hence they should be adjusted by using information on the actual g(0). Furthermore, 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), has started its work for integrating knowledge on abundance in sub-areas (SAs) 5, 6 and 10, where Japan and Korea have conducted sighting surveys. During the last SC in Santiago, a report on the summary of abundance estimates in each country under the assumption of g(0)=1 was submitted. However, it was recommended that the esw be estimated by pooling the each country's data of perpendicular distance across the areas, years and vessels with investigation of better covariate sets. The papers, An et al. (2009) and Miyashita et al. (2009), responded to this recommendation. The abundance estimates in those papers were used in this paper to integrate information on abundance available so far. The work was endorsed in NPM Working Group at SC60. For this integration, we employ a log-linear model with fixed year and survey block effects and random effect for the process error. In the next section, we begin with explanation of data used in this paper and then illustrate a statistical model.

2. MATERIALS AND METHODS

2.1 Underlying abundance estimates in surveyed blocks

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 (Table 1, An et al. 2009, Miyashita et al. 2009). 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.

The surveys were not originally intended to summarize the abundance in these areas, and hence the survey seasons were unfortunately uncommon (Table1). Survey timing slightly differs among the survey blocks, and therefore we need to eliminate chances of double-counting due to possible south-to-north migration as far as possible. For this purpose, as an option, we conducted analysis by using only abundance estimates in the period of May to June as well as that based on all the abundance estimates by ignoring migration. For example, any survey results in block 6ES were excluded from analysis for May to June season (Table 2). In this way, we estimate two sets of abundance by the two different seasonal treatments.

Abundance estimates and their CVs were provided using the best model in each country (An et al. 2009, Miyashita et al. 2009). In this paper, combined estimates and their associated variance-covariance matrix were employed based on the models below (only estimates and their CVs were shown in Table 2). Information on the size of block and coverage of survey in block as well as the size of sub-area are given in Table 3.

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 $\tilde{N}_{by}$. We assume that a vector of abundance estimates $\hat{N} = (..., \hat{N}_{by},...)$ has a multivariate log-normal distribution as follows:

$$\log \hat{N}_{by} = \log \tilde{N}_{by} + \varepsilon_{by},$$
$$\varepsilon = (....,\varepsilon_{by},...)' \sim N(0,\hat{\Sigma}), \qquad (1)$$

where $\hat{\Sigma}$ is a 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 2000-2008 in each block;

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

Model 2: True abundance level is exponentially increasing (deceasing) since 2000. We use 2004 as a reference year, so μ_b is the logarithm of abundance in 2004;

$$\log N_{by} = \mu_b + \phi(y - 2004). \qquad (4)$$

Unknown parameters are fixed effects for blocks and year 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:

$$Y = X\beta + \rho + \varepsilon,$$
$$\rho \sim N(0,D), \quad D = \sigma^2\mathbf{I}, \qquad (5)$$
$$\varepsilon \sim N(0,\hat{\Sigma}),$$

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 $\hat{\Sigma}$ are the variance-covariance matrix for $\rho = (\cdots,\rho_{ay},\cdots)'$ and ε, respectively.

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

$$\beta(\sigma^2) = (X'V(\sigma^2)^{-1}X)^{-1}X'V(\sigma^2)^{-1}Y \qquad (6)$$

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

The additional variance σ^2 is estimated by the REML method (Punt et al., 1997, McCulloch and Searle, 2001; Pawitan, 2001), which maximizes

$$l_{REML}(\sigma^2) = -\frac{1}{2}\log\left|V(\sigma^2)\right| - \frac{1}{2}\log\left|X'V(\sigma^2)^{-1}X\right| - \frac{1}{2}(Y - X\beta(\sigma^2))'V(\sigma^2)^{-1}(Y - X\beta(\sigma^2)) \qquad (7)$$

and its uncertainty is assessed by the reciprocal of the second derivative with respect to σ^2. The variance-covariance matrix is estimated as

$$C\hat{o}v(\hat{\beta}) = (X'V^{-1}(\hat{\sigma}^2)X)^{-1}. \qquad (8)$$

3. RESULTS AND DISCUSSION

Abundance estimates based on the two models in the two seasonal treatments were given in Table 4. 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 for the restricted season were 0.171 (SE=0.121) and 0.182 (SE=0.127), respectively, and those for the full season were 0.206 (SE=0.140) and 0.208 (SE=0.139), respectively.

For the model with a yearly trend, the estimate of annual rate of increase using data in May to June seasons was estimated as -0.0460 (SE=0.0579) and that in case of full period was -0.0715 (SE=0.0539). Such negative trends were not significant in both the cases. Under the assumption of no year trend the estimate of total abundance in surveyed areas in May to June season was 5,851 (CV=0.194) and that in all the seasons was 6,214 (CV=0.192). The spatially extrapolated estimates in a whole of SA5, SA6 and SA10 in the seasonal treatments were also give as 13,790 (CV=0.169) and 14,332 (CV=0.174), respectively.

As mentioned earlier, the abundance estimates given in this paper have downward biases because of the assumption of g(0)=1 and hence they should be adjusted by using information on the actual g(0). Furthermore, 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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Table 1. Seasonal coverage of sighting surveys conducted by Japan and Korea for abundance estimation of J-stock common minke whales

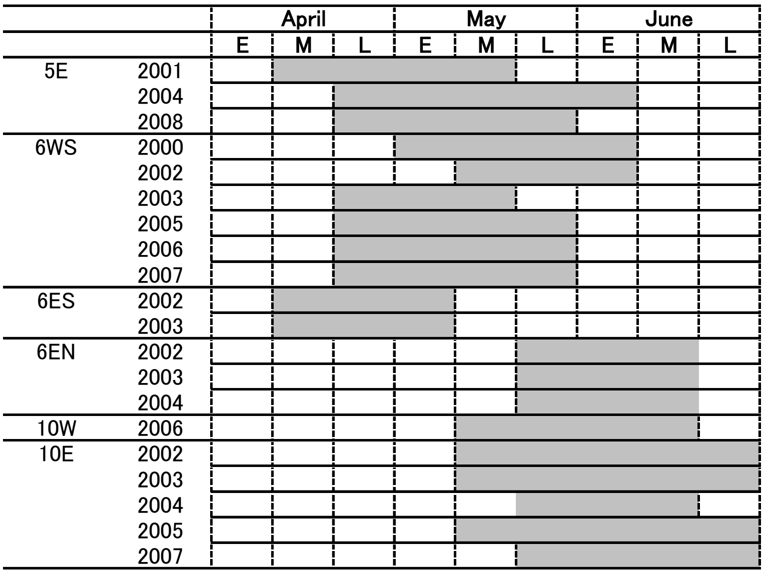

Table2. Abundance estimates employed in this analysis. G(0) was assumed to be 1.

Block	Year	Survey area (nm2)	Abundance	CV	Survey country	May to June
5E	2001	15,678	1,552	0.536	Korea	0
	2004		837	0.339		1
	2008		713	0.393		1
6WS	2000	10,046	1,216	0.411	Korea	1
	2002		936	0.652		1
	2003		575	0.336		1
	2005		1,015	0.293		1
	2006		505	0.472		1
	2007		695	0.440		1
6ES	2002	19,018	905	0.684	Japan	0
	2003		124	0.582		0
6EN	2002	71,914	891	0.608	Japan	1
	2003		935	0.357		1
	2004		727	0.372		1
10W	2006	63,912	2,855	0.327	Japan	1
10E	2002	27,823	816	0.658	Japan	1
	2003		405	0.566		1
	2004		474	0.537		1
	2005		666	0.444		1
	2007		575	0.327		1

Table3. 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 4. Abundance in a reference year 2004 estimated by the integration work.

May to June Model 1

Sub-area	Block	Abundance in surveyed area in		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					6,007	0.317
	5E	783	0.317	1,626	0.317		
6	6WS	795	0.207	1,654	0.207	4,244	0.165
	6WN						
	6ES						
	6EN	845	0.271	845	0.271		
10	10W	2,858	0.369	2,858	0.369	3,539	0.302
	10E	570	0.229	681	0.229		
Total		5,851	0.194	7,663	0.166	13,790	0.169

May to June Model 2

Sub-area	Block	Abundance in surveyed area in		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					6,488	0.335
	5E	846	0.335	1,756	0.335		
6	6WS	793	0.209	1,650	0.209	4,175	0.168
	6WN						
	6ES						
	6EN	814	0.278	814	0.278		
10	10W	3,134	0.392	3,134	0.392	3,848	0.326
	10E	598	0.239	715	0.239		
Total		6,185	0.215	8,068	0.185	14,511	0.186

Full season Model 1

Sub-area	Block	Abundance in surveyed area in		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					6,821	0.309
	5E	889	0.309	1,846	0.309		
6	6WS	794	0.213	1,650	0.213	3,986	0.163
	6WN						
	6ES	287	0.482	575	0.482		
	6EN	830	0.280	830	0.280		
10	10W	2,842	0.386	2,842	0.386	3,525	0.315
	10E	572	0.237	683	0.237		
Total		6,214	0.192	8,426	0.161	14,332	0.174

Full season Model 2

Sub-area	Block	Abundance in surveyed area in		Abundance in block		Abundance in sub-area	
		Estimate	CV	Estimate	CV	Estimate	CV
5	5WS+5WN					7,238	0.313
	5E	943	0.313	1,959	0.313		
6	6WS	791	0.214	1,644	0.214	3,842	0.165
	6WN						
	6ES	260	0.488	520	0.488		
	6EN	784	0.284	784	0.284		
10	10W	3,281	0.402	3,281	0.402	4,015	0.335
	10E	614	0.243	734	0.243		
Total		6,674	0.211	8,922	0.176	15,095	0.182

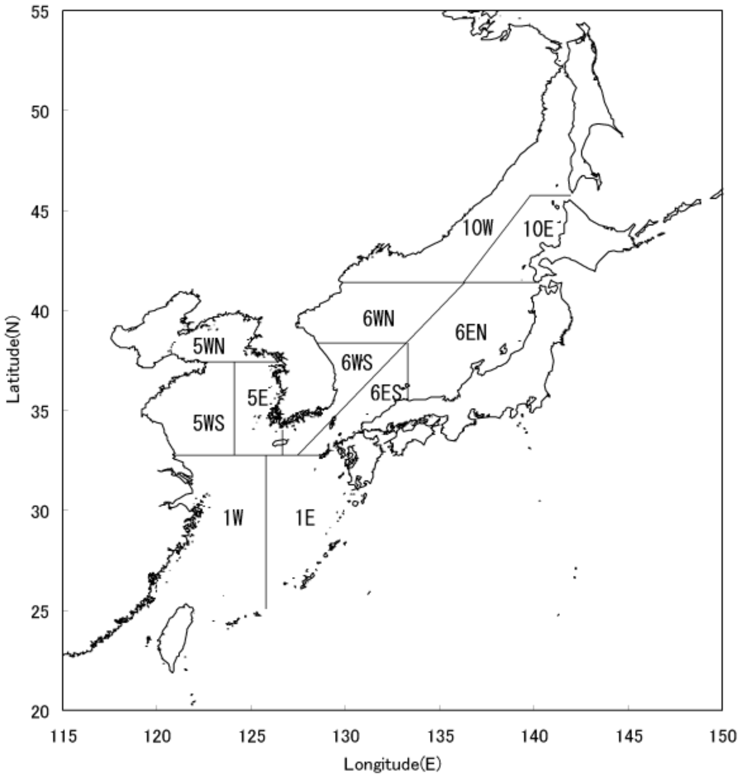

Figure 1. Definition of sub-areas and survey blocks