g(0) estimates for western North Pacific common minke whales.

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ABSTRACT
The abundance of common minke whales in the sub-area 10, 11, and 12 was re-estimated using the IO passing mode sighting survey data in 2003, 2005, 2006 and 2007. The hazard probability model provides the estimate of g(0) and abundances. The latest estimate of g(0) for Top barrel & Upper bridge was 0.798, while the g(0) for Top barrel & IO platform & Upper bridge was 0.859. The resultant abundance estimates were 42,080 (2003 sub-area 12 - Okhotsk), 2,078 (2005 sub-areas 8, 9 and 12 -Russian EEZ), 1,211 (2006 sub-area 10 - Japanese EEZ), 3,391 (2006 sub-area 10 - Russian EEZ), 502 (2007 sub-area 11 - Japanese EEZ), and 575 (2007 sub-area 10 - Japanese EEZ).

INTRODUCTION

Japan conducted the IO passing mode sighting surveys in the sub-areas 10, 11, and 12 in 2003, 2005, 2006 and 2007. Using the data from the Sea of Japan, we provided a preliminary abundance estimates assuming g(0) < 1 (Miyashita and Okamura 2007, Okamura et al. 2008, 2009). In this paper, we revised the estimates of g(0) and abundances by adding the 2003 and 2005 data obtained from the Okhotsk Sea and into the analysis.

MATERIALS AND METHODS

The survey areas were categorized into 2003OKH (2003 sub-area 12 - Okhotsk), 2005KURIKAM (2005 sub-areas 8, 9 and 12 -Russian EEZ), 2006JPN (2006 sub-area 10 - Japanese EEZ), 2006RUS (2006 sub-area 10 - Russian EEZ), 2007OKH (2007 sub-area 11 - Japanese EEZ), and 2007SJ (2007 sub-area 10 - Japanese EEZ). The research effort distance was 1,054.46 for 2003OKH, 1732.86 for 2005KURIKAM, 174.2 n.miles for 2006JPN, 1,157.2 n.miles for 2006RUS (excluding the ROS block which did not have any sighting for minke whales), 564.0 n.mile for 2007OKH, and 1051.4 n.miles for 2007SJ. The number of primary sightings was 41 schools for 2003OKH, 9 schools for 2005KURIKAM, 3 schools for 2006JPN, 45 schools for 2006RUS, 23 schools for 2007OKH, and 16 schools for 2007SJ, respectively, when the sightings were truncated at the perpendicular distance of 1.5 n.miles. All the sighting data with the truncation distance of 1.5 n.miles were employed for the estimation of detection function, including g(0), and abundance without any stratification.

For the estimation of esw including g(0), a hazard probability model by Okamura and Kitakado (2009: OK method) was used. In the Russian and Japanese waters, minke whales

consist of single animals in general. So, we do not need the complicated handling of school size distribution as in Okamura and Kitakado (2009). In addition, because the sample size is small for g(0) estimation, we can investigate only the effect of limited covariates. Unlike Antarctic minke whale surveys, this study has on-board identification of simultaneous and delayed duplicates. So, we adopted a considerably short time (15 seconds) as an error of recorded time. The detailed description of the model is given in Appendix.

Weather condition considered was Beaufort scale (0-3: good, 4: bad).

RESULTS AND DISCUSSION

The observed school size was almost 1 with a few sightings with the school size of 2 or 3. We therefore did not include the school size into detection function as a covariate. The school size was regressed using a traditional regression, log(s) ~ g(x), so that the coefficient of g(x) was significant at 15% significance level. Thus, the corrected mean school size was used for abundance estimation.

The model without weather condition covariate has the lower AIC value than that with weather condition covariate. Thus, we did not include the weather condition in the afterward analysis. Whether the weather condition is included or not in the analysis was insensitive to the resultant abundance estimates. The difference between (x,y)- and (R,A)-Q functions was small in terms of abundance estimation, while the difference of AICs for (R,A)-Q function model has the marginally lower AIC value.

Table 1 shows the results on estimation of g(0) for models. The estimates were given for Top, IO, and upper bridge as well as their combination. Diagnostic plots for detection functions including g(0) against the perpendicular distance were also provided in Figure 1, which indicated that the models were well-fitted. The estimates of g(0) were 0.716 (se 0.16) for TOP barrel, 0.617 (se 0.19) for IO platform, 0.505 (se 0.21) for upper bridge, and 0.798 (se 0.13) for Top barrel & upper bridge (Table 1).

The resultant abundance estimates for both models were given in Table 2. The point estimates were 42,080 for 2003OKH, 2,078 for 2005KURIKAM, 1,211 for 2006JPN, 3,391 for 2006RUS, 502 for 2007OKH, and 575 for 2007SJ. Although the abundance estimates for the Sea of Japan were lower than Okamura et al. (2009), this would be due to the lower mean school size (E(s) = 1 and observed mean school size = 1.14) corrected by school size regression.

REFERENCES

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Table 1. g(0)s for each platform and the combined platforms. A, B, and C denote Top, IO platform, and Upper bridge, respectively.

	g0	SE
A	0.716	0.161
B	0.617	0.192
C	0.505	0.213
AUB	0.824	0.121
AUC	0.798	0.134
BUC	0.748	0.160
AUBUC	0.859	0.103

Table 2. Abundance estimates using the OK method with estimation of g(0). nL and nS denote the numbers of replicate lines and sighting, respectively.

year	block	areasize (n.m^2)	effort (n.m)	nL	nS	density	abund	CV
2003	11W	15243	62.7	2	16	0.346	5,281	0.55
2003	CE	110770	248.5	4	4	0.022	2,423	0.69
2003	CNW	149213	235.8	4	1	0.006	860	0.60
2003	CSW	155305	231.9	4	3	0.018	2,730	0.41
2003	OSW	194272	161.4	3	4	0.034	6,543	0.46
2003	SHA	156762	114.2	3	13	0.155	24,244	0.46
2003	OKH_Total	781565	1054.5	20	41	0.054	42,080	0.13
2005	BEN	74303	578.1	6	2	0.005	349	1.52
2005	BES	65401	259.5	4	2	0.010	685	0.51
2005	KUL	137519	895.3	9	5	0.008	1,044	0.47
2005	KURICAM_Total	277223	1732.9	19	9	0.007	2,078	0.12
2006	JPN	51763.7	174.2	3	3	0.023	1,211	0.64
2006	RCM	36496.3	776.1	14	19	0.033	1,214	0.45
2006	RCN	14205.7	252.5	7	23	0.124	1,758	0.45
2006	RCS	13210.0	128.6	3	3	0.032	419	0.83
2006	RUS_Total	63911.9	1157.2	24	45	0.053	3,391	0.13
2007	OKH	9064.0	564.0	11	23	0.055	502	0.36
2007	SJ	27822.5	1051.4	11	16	0.021	575	0.25

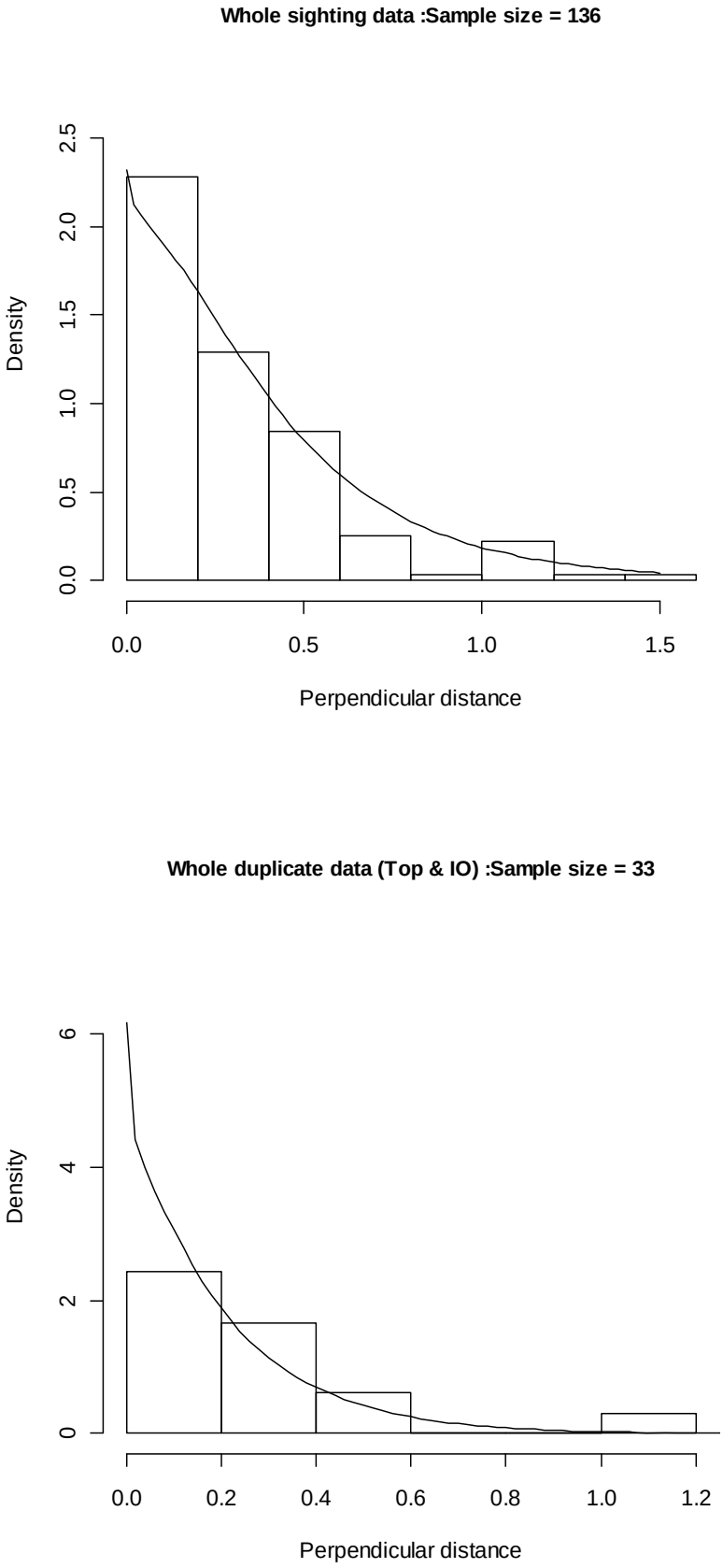

Fig. 1. Graphical diagnosis of the OK model.

APPENDIX

A.1. The hazard probability model and the likelihood function

The detection probability density function of the animal positioned at the perpendicular distance x and the forward distance y assuming a Poisson surfacing pattern with the mean surfacing rate λ is

$$p(x,y) = \frac{\lambda}{v} Q(x,y) \exp\left\{ -\frac{\lambda}{v} \int_y^\infty Q(x,y')dy' \right\}, \tag{A.1}$$

We construct a likelihood function as follows:

$$P(x_i, y_i, u_i) = \frac{p(x_i, y_i, u_i)}{\text{esw}}, \tag{A.2}$$

where u_i is a type of detection pattern, p is a detection probability density function, and esw is

$$\text{esw} = \int_0^{x_{max}} \int_0^\infty \sum_u^{\text{all patterns}} p(x,y,u)dxdy. \tag{A.3}$$

The total likelihood function is then given by

$$L = \prod_{i=1}^n P(x_i, y_i, u_i). \tag{A.4}$$

We estimate parameters by maximizing the logarithm of the total likelihood function.

A.2. Abundance estimation

The population size is estimated with a Horvitz-Thompson-like estimator,

$$\hat{P} = \frac{A}{2L} \sum_{i=1}^n \frac{\text{E}(s)}{\hat{\text{esw}}_{A \cup B \cup C}(\eta_i)}, \tag{A.5}$$

where L is total survey distance, A is the size of survey area, η_i is a vector of covariates, and the numerator $\text{E}(s)$ is the mean observed school size.

An estimator for the unconditional asymptotic coefficient of variation of $\hat{P}$ is estimated using the method similar to standard line transect sampling, and then,

$$\hat{\text{CV}}(\hat{P}) = \sqrt{\hat{\text{CV}}(e\hat{s}w)^2 + \hat{\text{CV}}(\text{E}(s))^2 + \hat{\text{CV}}(n/L)^2}, \tag{A.6}$$

where θ is a vector of estimated parameters.

A.3. detection probability function of sighting cues

The hazard probability model is given by a logistic form,

$$Q(x,y) = \frac{1}{1 + \exp[(\tau_r R^{\gamma_r} + \tau_a A^{\gamma_a}) + \omega]} \tag{A.7}$$

where τ_r, τ_a, γ_r, and γ_a are scalar parameters with positive values. The parameter ω is related to several covariates with a log-link function as follows:

$\omega \sim$ Platform + Weather.

A.4. Specification of detection function for each sighting pattern

There are three platforms with two independent observers and one semi-independent observer. The detection pattern is therefore complicated by taking account of duplicate sightings. The probability density function for each sighting pattern is given below. The contribution to the likelihood function of detection with each sighting pattern is calculated by each probability density divided by $\mathrm{esw}_{A\cup B\cup C}$ which is given by

$$\begin{aligned}\mathrm{esw}_{A\cup B\cup C} &= \int_0^{x_{max}} \int_0^{\infty} \frac{\lambda}{v} Q_{A\cup B\cup C}(x,y) \\ &\times \exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_{A\cup B\cup C}(x,y')dy'\right\} dxdy. \end{aligned} \tag{A.8}$$

1. A

$$\begin{aligned} p(x,y,A) &= \frac{\lambda}{v}\left\{Q_{A\cup B}(x,y) - Q_B(x,y)\right\} \exp\left\{-\frac{\lambda}{v}\int_0^y Q_B(x,y')dy'\right\} \\ &\times \exp\left[-\frac{\lambda}{v}\left\{\int_y^{\infty} Q_{A\cup B}(x,y')dy' + \int_{y+vT}^{\infty} Q_{A\cup B\cup C\setminus A\cup B}(x,y')dy'\right\}\right], \end{aligned} \tag{A.9}$$

where $T = 15/3600$.

2. B

Same as A except for exchanging the symbols A and B.

3. C

$$\begin{aligned} p(x,y,C) &= \frac{\lambda}{v}\left\{Q_{A\cup B\cup C}(x,y) - Q_{A\cup B}(x,y)\right\} \\ &\times \exp\left[-\frac{\lambda}{v}\left\{\int_0^y Q_{A\cup B}(x,y')dy' + \int_y^{\infty} Q_{A\cup B\cup C}(x,y')dy'\right\}\right]. \end{aligned} \tag{A.10}$$

4. $A \times B$

$$\begin{aligned} p(x,y,AB) &= \frac{\lambda}{v}\Bigg(Q_A(x,y)Q_B(x,y)\exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_{A\cup B}(x,y')dy'\right\} \\ &+Q_A(x,y)\exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_A(x,y')dy'\right\} \\ &\times\left[\exp\left\{-\frac{\lambda}{v}\int_{y+vT}^{\infty} Q_{A\cup B\setminus A}(x,y')dy'\right\} - \exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_{A\cup B\setminus A}(x,y')dy'\right\}\right] \\ &+Q_B(x,y)\exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_B(x,y')dy'\right\} \\ &\times\left[\exp\left\{-\frac{\lambda}{v}\int_{y+vT}^{\infty} Q_{A\cup B\setminus B}(x,y')dy'\right\} - \exp\left\{-\frac{\lambda}{v}\int_y^{\infty} Q_{A\cup B\setminus B}(x,y')dy'\right\}\right]\Bigg) \end{aligned} \tag{A.11}$$

where $T = 15/3600$.

5. $A \to B$

$$p(x,y,A\to B)=\left(\frac{\lambda}{v}\right)^2 Q_B(x,y)\{Q_{A\cup B}(x,y+v\tau_{AB})-Q_B(x,y+v\tau_{AB})\}$$
$$\times\exp\left[-\frac{\lambda}{v}\left\{\int_{y+v\tau_{AB}}^{\infty}Q_{A\cup B\setminus B}(x,y')dy'+\int_{y}^{\infty}Q_B(x,y')dy'\right\}\right] \tag{A.12}$$

where $\tau_{AB}>15/3600$h.

6. $B\to A$

Same as $A\to B$ for exchanging the symbols A and B.

7. $C\to A$

$$p(x,y,C\to A)=\left(\frac{\lambda}{v}\right)^2\{Q_{A\cup B}(x,y)-Q_B(x,y)\}$$
$$\times\{Q_{A\cup B\cup C}(x,y+v\tau_{CA})-Q_{A\cup B}(x,y+v\tau_{CA})\}$$
$$\times\exp\left\{-\frac{\lambda}{v}\int_{y+v\tau_{CA}}^{\infty}Q_{A\cup B\cup C\setminus A\cup B}(x,y')dy'\right\}$$
$$\times\exp\left[-\frac{\lambda}{v}\left\{\int_{y}^{\infty}Q_{A\cup B}(x,y')dy'+\int_{0}^{y}Q_B(x,y')dy'\right\}\right] \tag{A.13}$$

where $\tau_{CA}>15/3600$h.

8. $C\to B$

Same as $C\to A$ for exchanging the symbols A and B.