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The number of sperm whales in the western North Pacific in the JARPN II Offshore survey area

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ABSTRACT

The number of sperm (*Physeter macrocephalus*) whales in the western North Pacific in early and late seasons in the JARPNII offshore component were estimated based on 2008-2014 JARPNII surveys. The numbers are to be used for input of ecosystem modeling of the western North Pacific. Given that the area is a migration corridor of the whales, the numbers were estimated for early season (May-June) and late season (July-Sep.). The estimates were 11,459 (in 2009) and 11,652 (in 2011 and 2012) in the early and 10,843 (in 2008) in the late season for the sperm whales. It is important to note that these estimates should not be used for assessment because the estimated figures represent only a part of the population considered.

INDTRODUCTION

It is important to estimate prey consumption and to develop ecosystem models. The number of whales in the study area can be used for prey consumption estimates and ecosystem modelling. From the previous results, prey species are different between early and late seasons (Tamura *et al*., 2009) and therefore the ecosystem in the JARPN II survey area may be different in the early and the late seasons. For this reason, the number of whales distributed are estimated in the early (May - June) and late (July – September) seasons, respectively.

MATERIALS AND METHODS

Sighting data used in this study

Dedicated sighting surveys were conducted during 2008-2014. Among the surveys, survey data that covered the JARPN II survey area (i.e. east of Japanese coast, west of 170ºE, north of 35ºN, south of Russian and US EEZ) were used for this analysis. Survey period and vessels for these surveys are shown in Table 1. The numbers of whales distributed in the JARPN II survey are were estimated in early (May-June) and late season (July-Sep). Considering the survey period and survey area, there are three data sets to estimate the number of the whales in the JARPN II survey area. For the early season, the numbers were estimated for the 2009 survey, and 2011 and 2012 1st surveys combined. For the late season, the numbers were estimated for the 2008 survey. Figures 1 shows plots of primary effort and sightings for the sperm whales in the early and late seasons. Primary sightings of the sperm whales were distributed uniformly in the JARPN II survey area in the early and the late seasons.

Abundance estimation

Analytical procedures are similar to Hakamada and Matsuoka (2015).

For this analysis it is assumed that g(0)=1. Detections are truncated at 3.0 n.miles for sperm whales. Abundance and its CV were estimated based on a Horvitz-Thompson like estimator of abundance expressed by formula (1) and (2), respectively.

$$P = \frac{A}{2WL}\sum_{i=1}^{n}\frac{s_i}{p_i(z_i)}$$
$$= \frac{A}{2L}\sum_{i=1}^{n}s_i\hat{f}(0\mid \mathbf{z}_i) \qquad (1)$$

where P is abundance estimate, A is area size of the surveyed area, W is truncation distance (3.0 n.miles),

L is searching effort, n is the number of schools detected within perpendicular distance of W, s_i is school size of ith detection, $p_i(z_i)$ is the probability that school i is detected given that it is within the perpendicular distance W and given the covariate z_i. $f(0|z_i)$ is conditional probability density function of distance 0 given covariates z_i

$$\mathrm{var}(P) = \left(\frac{A}{2WL}\right)^2 \left\{ \frac{1}{L(K-1)} \sum_{k=1}^{K} l_k \left(\frac{P_{Ck}}{l_k} - \frac{P_C}{L} \right)^2 + \sum_{j=1}^{r} \sum_{m=1}^{r} \frac{\partial P_C}{\partial \theta_j} \frac{\partial P_C}{\partial \theta_m} H_{jm}^{-1}(\theta) \right\} \quad (2)$$

where K is the number of transect, l_k is searching distance in kth transect, P_{Ck} is abundance estimate in covered region (within 3 n.miles from track line surveyed) in kth transect, P_C is abundance estimate in the covered region, $H_{jm}^{-1}(\theta)$ is the jmth element of inverse of Hessian matrix of detection function for covariate θ.

Multiple Covariate Distance Sampling (MCDS) Engine in DISTANCE program was used (Thomas *et al.*, 2010). Given previous discussions at the IA sub-committee on detection function (IWC, 2015), Half Normal and Hazard Rate models were considered as candidate models for the detection function. Full model of the detection function was provided by

$$g(x) = 1 - \exp\left\{ -\left(x \Big/ a\exp(Size + Beaufort + Year) \right)^{-b} \right\} \quad (3)$$

$$g(x) = \exp\left[-x^2 \Big/ 2a^2 \exp\{2(Size + Beaufort + Year)\} \right] \quad (4)$$

where x is perpendicular distance, a and b ($b \geqq 1$) are parameter, *Size* is observed school size, *Beaufort* is categorical variable for Beaufort sea state (good: 0-3, bad: 4-5) and *Year* is categorical variable for year. To estimate detection function, all primary sightings occurred during 2008-2014 were used.

AIC was used to select the best model to estimate detection probability of $1/Wf(0|z_i)$.

Smearing was not conducted on running MCDS because MCDS doesn't deal with smearing. Perpendicular distance was not binned on fitting detection function because selection of cut point could affect results of model selection and coefficient estimates of detection function different from previous analysis.

Sensitivity analysis

Effect of including/excluding covariates in the detection function such as Beaufort sea state, school size and year were examined. If difference in AIC of detection function is not substantially different among the models, weighted average by Akaile weight (Buckland *et al*, 1997; Burnham and Anderson, 2002) would be estimated.

Averaged abundance

Average of abundance estimates base case and in sensitivity analysis were also estimated. By using Akaike weight, weight is larger as the model is better. Akaike weights are defined as follows;

$$w_i = \frac{\exp(-\Delta \mathrm{AIC}_i/2)}{\sum_{j=1}^{16} \exp(-\Delta \mathrm{AIC}_j/2)} \quad (5)$$

The weighted average of the abundance estimates P_w and their standard errors were estimated by equations as follows.

$$P_w = \sum_{i=1}^{16} w_i P_i \quad (6)$$

$$\mathrm{CV}(P_w) = \frac{\sqrt{\sum_{i=1} w_i^2 \ \mathrm{var}(P_i) + 2\sum_{i \neq j} w_i w_j \ \mathrm{cov}\left(P_i, P_j\right)}}{P_w} \quad (7)$$

where

$$\Delta\mathrm{AIC}_i = \mathrm{AIC}_i - \mathrm{AIC}_{\min} \quad (8)$$

RESULTS

The number of the whales distributed in JARPN II survey area

Table 2 shows AIC for each model of detection functions for sperm whales. Hazard rate model with Beaufort and Year as covariate was selected. Figure 2 shows plot of the selected detection function for sperm whales. Figure 3 shows QQ-plot of the detection function for the sperm whales. These figures suggests the fit of the detection function good. Table 3 shows the estimated number by strata for sperm whales. Table 4 shows abundance estimate in the early season for sperm whale. The numbers of the whales in the early season were estimated for 2008 and 2011+ the 1st survey in 2012 combined in each stratum. Table 5 shows the estimated number of the whales distributed in the late season for sperm whales. The numbers in the late season were estimated for 2009. The numbers in the JARPN II survey area are similar to each other in the early and the late seasons.

Sensitivity analysis

Table 6 shows that the number of the whales distributed shown in Tables 4 and 5 would change when applying detection functions other than the best model. For comparison, the estimated number applying the best detection function is also included in the table. Table 7 shows weighted averages using Akaike weight. CVs are under-estimates because variances of AIC are not taken into account. The difference in point estimate is small. The estimated number in 2011+ the 1st survey in 2012 combined is less robust than other two estimates. This is because the difference in the estimate between hazard rate model and half normal model is larger for 2011+ the 1st survey in 2012 combined than the other two estimates.

DISCUSSION

Assumption that g(0)=1 causes underestimation of the number for the sperm whales. Barlow and Sexton (1996) estimated g(0) for sperm whales is 0.87 with CV = 0.09 based on synchronously diving whales with a 30-min dive cycle (25-min dives followed by 5 min at the surface). Whitehead (2002) derived that g(0) for the sperm whales depends on the time period for which a sperm whale at the surface on the track line of the survey vessel is visible considering diving behavior. The time period can be estimated using the distance that the observer can detect the sperm whales and vessel speed. The estimate of g(0) could change if the Beaufort sea state and school size affects the detectability of schools. Investigation of g(0) is necessary in the future to provide for unbiased estimates of the number of sperm whales.

The estimated number of sperm whales is similar for the early and the late seasons while the estimated number is different between the early and the late seasons for large baleen whales (Hakamada and Matsuoka, 2016a: SC/F16/JR12; 2016b: SC/F16/JR13). In previous analysis the abundance was estimated as 15,929 in the early and 20,292 in the late seasons assuming g(0)=0.64 (Hakamada *et al*., 2009), which corresponds to 9,592 and 12,279 under the assumption that g(0)=1. The difference between these two estimates is larger than that of present study. Whether these results imply that the number of sperm whales doesn't change from the early season to the late season cannot be confirmed at this stage and should be further investigated.

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Table 1. Summary information on dedicated sighting survey under JARPN II during 2008-2014.

Year	Vessels	Period	Survey area
2008	KK1, KS2	2Jul.-29Aug.	SA7, 8, 9
2009	KK1, YS1	23May-23Jun.	SA7, 8, 9
2011	YS1, YS2,YS3	5May-5Jun.	SA8,9
2012 1st	YS3	18May-29Jun.	SA7CS,7CN,7WR,7E

Table 2. AIC for each model of detection functions for base case. For selected model, AIC is indicated by bold letters. HR: Hazard Rate and HN: Half Normal.

Sperm whale

Model	HR	HN
School size+Beaufort+Year	1155.5	1156.4
School size+Beaufort	1160.4	1159.1
School size+Year	1160.9	1163.4
Beaufort+Year	**1153.5**	1155.2
School size	1166.2	1165.9
Beaufort	1158.4	1158.5
Year	1158.9	1161.5
No covariate	1164.2	1164.5

Table 3. Abundance estimates for the sperm whales and their CV's for each stratum based on 2008, 2009, 2011 and 2012 JARPN II cruises for the best model of detection function. *A* is area size of the surveyed area, n_s and n_w are the number of schools detected and the number of individuals detected within perpendicular distance of 3.0 n.miles, *L* is searching distance, *P* is abundance estimate and CI is abbreviation for confidence interval.

Year	Stratum	*A*	*L*	n_s	n_w	n_w/L	CV(n_w/L)	***P***	CV(P)	95%LL	95%UL
2008	7	166,306	886.5	22	129	0.146	0.569	**6,351**	0.564	1,709	23,594
2008	8	162,789	1193.6	21	34	0.028	0.503	**1,170**	0.545	396	3,457
2008	9	499,235	3067.0	64	89	0.029	0.319	**3,322**	0.312	1,784	6,186
2009	7	166,306	1036.5	31	156	0.151	0.337	**5,325**	0.361	2,314	12,253
2009	8	162,789	1084.5	22	41	0.038	0.347	**1,532**	0.390	631	3,718
2009	9	362,113	2274.1	35	109	0.048	0.594	**4,601**	0.676	1,208	17,530
2011	8	162,789	1101.5	26	51	0.046	0.411	**2,906**	0.370	1,106	7,637
2011	9N	208,660	1496.4	12	30	0.020	0.677	**1,814**	0.761	337	9,756
2011	9S	290,575	1492.8	17	30	0.020	0.426	**2,204**	0.503	721	6,739
2012	7CS	26,826	850.9	17	29	0.034	0.481	**330**	0.555	108	1,006
2012	7CN	16,171	649.2	1	2	0.003	1.014	**14**	1.020	2	100
2012	7WRN	6,874	175.7	7	14	0.080	0.366	**195**	0.306	76	503
2012	7WRS	66,117	750.1	45	121	0.161	0.471	**3,837**	0.448	1,443	10,197
2012	7E	48,208	302.3	4	5	0.017	0.365	**351**	0.412	124	992

Table 4. Abundance estimate for sperm and killer whales in JARPN II survey area (i.e. sub-areas 7, 8 and 9 excluding foreign EEZ) in early season for 2009 and 2011+1st survey in 2012 combined assuming that g(0)=1.

Early	Sperm	
	P	CV(P)
2009	**11,459**	0.332
2011+2012_1st	**11,652**	0.266

Table 5. Abundance estimate for sperm and killer whales in the JARPN II survey area in late season for 2008 assuming *g*(0)=1.

Late	Sperm	
	P	CV(P)
2008	**10,843**	0.358

Table 6. Abundance estimate for sperm whale in JARPN II survey area in the early and the late seasons for sensitivity test (i.e. applying alternative detection function other than the best model). Bold letter indicates the estimate is based on the best model. It is assumed that *g*(0)=1.

Early (2009)

Model	Covariates	**P**	CV(P)	Model	Covariates	P	CV(P)
Hazard Rate	S+B+Y	11,187	0.298	Half Normal	S+B+Y	13,134	0.255
	S+B	14,490	0.333		S+B	13,700	0.287
	S+Y	11,156	0.246		S+Y	11,109	0.229
	B+Y	**11,459**	**0.332**		B+Y	10,939	0.248
	S	13,969	0.258		S	12,916	0.233
	B	14,305	0.297		B	12,004	0.251
	Y	11,220	0.229		Y	10,808	0.221
	None	13,809	0.226		None	11,870	0.218

Early (2011+2012)

Model	Covariates	**P**	CV(P)	Model	Covariates	P	CV(P)
Hazard Rate	S+B+Y	11,578	0.267	Half Normal	S+B+Y	8,547	0.223
	S+B	9,773	0.241		S+B	8,068	0.214
	S+Y	10,496	0.277		S+Y	8,130	0.220
	B+Y	**11,652**	**0.266**		B+Y	8,576	0.211
	S	8,705	0.248		S	7,592	0.217
	B	9,747	0.234		B	7,859	0.209
	Y	10,512	0.263		Y	8,085	0.216
	None	8,686	0.236		None	7,467	0.212

Late (2008)

Model	Covariates	**P**	CV(P)	Model	Covariates	P	CV(P)
Hazard Rate	S+B+Y	10,642	0.164	Half Normal	S+B+Y	11,150	0.136
	S+B	13,895	0.176		S+B	12,236	0.135
	S+Y	9,976	0.182		S+Y	9,832	0.145
	B+Y	**10,843**	**0.358**		B+Y	10,068	0.127
	S	12,416	0.199		S	11,179	0.140
	B	13,764	0.134		B	11,123	0.116
	Y	10,014	0.155		Y	9,646	0.134
	None	12,325	0.148		None	10,595	0.125

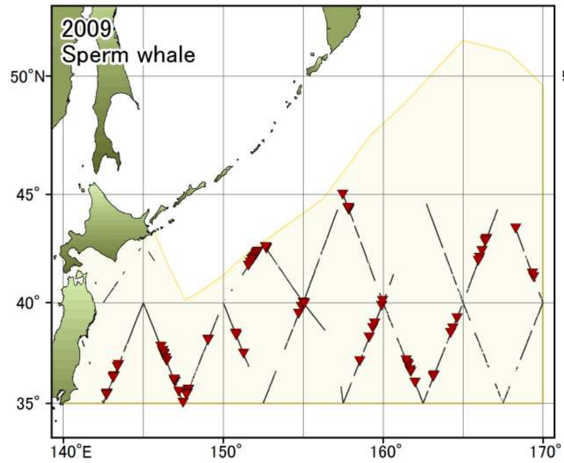
Table 7. Weighted average of abundance estimates in Table 6 by Akaike weight for sensitivity.

Early

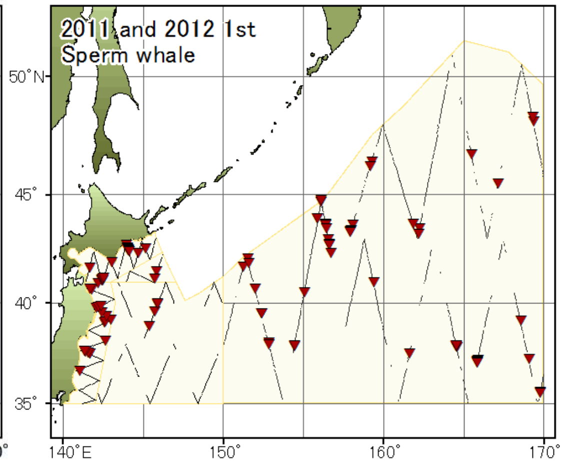
Early	Sperm		
	P	CV(P)	Change from base case
2009	11,701	0.296	2.1%
2011+2012_1st	10,389	0.236	-10.8%

Late

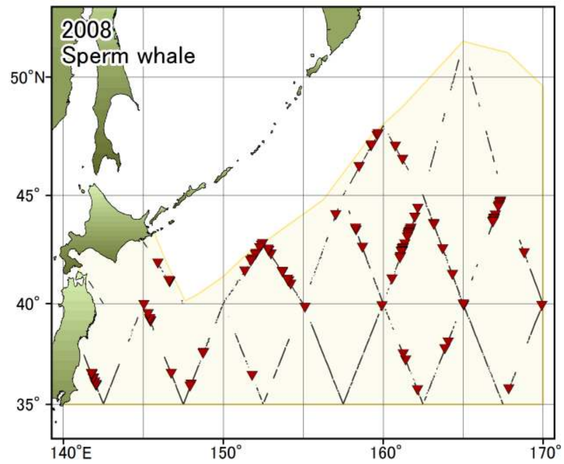
Late	Sperm		
	P	CV(P)	Change from base case
2008	10,857	0.342	0.1%



Early (2009)



Early (2011 and 2012)



Late (2008)

Figure 1. Plot of actually surveyed track line (black lines) and position of the sperm whales (brown triangles) for JARPN II surveys in early and late seasons in 2008, 2009, 2011 and 2012 (1st survey).

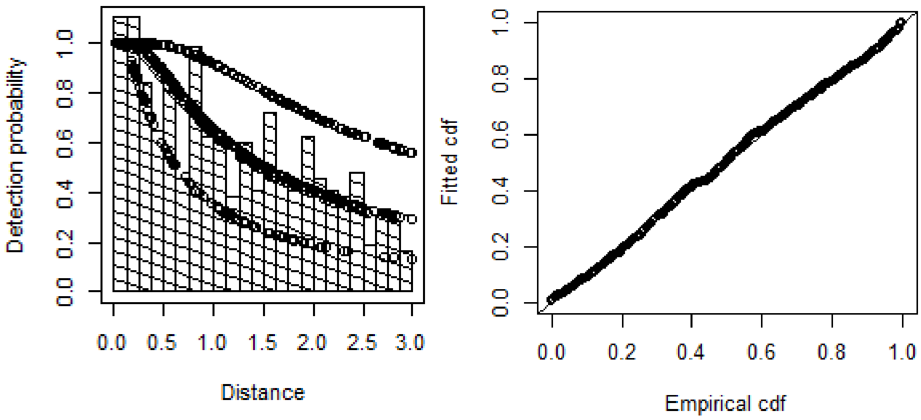


Figure 2. Plot of the estimated detection function fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line (Left panel) and QQ-plot of the detection function for the best model for sperm whale (Right panel).