The number of the western North Pacific common minke whales (*Balaenoptera acutorostrata*) distributed in JARPNII coastal survey areas

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ABSTRACT
In order to examine the impact of common minke whales on Japanese fisheries in Kushiro and Sanriku regions through estimating the amount of prey consumed by minke whales or using an ecosystem model, it was required to estimate the number of the common minke whales distributed in each of the survey areas during the JARPNII survey periods. Because it was considered that the impact of the minke was important in the operation area of the coastal fishery, the number of the common minke was estimated. The estimated numbers off Kushiro were 461 and 433 in early (May-June) and late seasons (July-September) in 2012, respectively. The estimated number off Sanriku in the early season was 124 in 2012. Note that these numbers are not abundance estimates of the minke whale stock in the areas because the sighting data we used for the estimation covered only a part of the stock distribution.

INTRODUCTION

Elucidation of feeding ecology and ecosystem studies is one of the main objectives of the JARPNII. Common minke whales (*Balaenoptera acutorostrata*) consume some of the main Japanese fishery resources off Kushiro and off Sanriku. The impact of whales on Japanese fisheries in the JARPNII survey area can be assessed from estimating the amount of prey consumed by the whales in survey areas (Tamura *et al*., 2009; 2016: SC/F16/JR17). Hakamada *et al*. (2009) estimated abundance of common minke whales in Sanriku and Kushiro coastal survey areas for prey consumption estimates by common minke whales in these regions.

MATERIALS AND METHOD

In 2012, two dedicated sighting surveys are conducted which covered sub-areas 7CS, 7CN, 7WR and 7E by the dedicated sighting survey vessel Y*ushin-Maru No.3* (*YS3*) (Matsuoka *et al*., 2013). Because sufficient searching effort were allocated in sub-areas 7CS and 7CN, which includes Sanriku and Kushiro coastal areas, sighting data obtained during these sighting surveys can be used to estimate the number of common minke whales distributed in these coastal areas. The first survey was conducted in sub-areas 7CS, 7CN and a northern part of 7WR (North of 41ºN, hereafter 7WRN) in May and June (Figure 1). Hereafter, we refer this period as the "early" season. The second survey was conducted in sub-areas 7CN and the part of sub-area 7WR in September (Figure 1). We refer period from July to September as "late" season. In this analysis, the number of the common minke whales distributed in Sankiku in the early season and those in Kushiro area in early and late seasons are based on sighting data collected during the dedicated sighting survey conducted in 2012.

Dedicated sighting surveys were conducted in Kushiro area in 2002, 2003, 2004, 2005, 2006 and 2007 and in Sanriku area in 2003, 2004, 2005 and 2006 (Kiwada *et al*., 2009; Miyashita, 2009). The generic survey area in those surveys in Sanriku and Kushiro area are shown in Figure 2a. Sanriku area is in sub-area 7CS. The coastal part of Kushiro area is in sub-area 7CN and the offshore part of Kushiro area is in sub-area 7WRN (Figure 2b).

Abundance estimation

First, common minke whale density/abundances were estimated for each sub-area. Secondly, density estimates for each sub-area were multiplied by area size of Sanriku/Kushiro area, where the dedicated sighting surveys were conducted. In the first step, analytical procedures used are similar to Hakamada and Matsuoka (2015) as follows.

For this analysis it is assumed that g(0)=0.798 with CV=0.134 (Okamura *et al.*, 2010). Detections are truncated at 1.5 n.miles. Abundance and its CV were estimated based on a Horvitz-Thompson like estimator of abundance expressed by formula (1) and (2), respectively.

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

where P is abundance estimate, A is area size of the surveyed area, W is truncation distance (1.5 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 dedicated sighting surveys 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.

In the second step, multiply density estimate in each sub-area by area size of Sanriku/Kushiro survey area shown in Figure 2a.

RESULTS

Table 1 shows abundance estimate for each sub-area. The estimated number in 7CN and 7WRN combined are similar to each other in early and late seasons. Figure 3 shows plot of selected detection function by AIC and its QQ-plot. The fit seems good. Using density estimation in Table 1, the estimated numbers off Kushiro were 461 and 433 in early (May-June) and late season (July-September) in 2012, respectively. The estimated number off Sanriku in the early season was 124 in 2012 (Table 2).

DISCUSSION

It is important to note that the numbers of the minke whales estimated in this paper do not represent the number of the whale in a whole stock because the sighting data we used covered only a limited area of the stock distribution. For this reason, the estimated number of the common minke whales in Sanriku and Kushiro area themselves should not be used for assessment of this whale stocks.

In this study, it was assumed that density of the common minke in Sanriku area is the same as that in 7CS and that the density in coastal part of Kushiro area is same as that in 7CN and that in offshore part of Kushiro is same as that in 7WRN. If there is a tendency that the common minke density increases as the coast is approached, these assumptions on density in Sanriku and Kushiro area would cause an underestimate of the number of whales.

Table 3 shows abundance estimate in Hakamada *et al.* (2009) with assuming g(0) estimate of 0.798 with CV=0.134 in Okamura *et al.* (2010). Comparing previous estimates,, there were no significant differences from the estimates in 2012 and the abundance estimates fluctuate among years. One of possible reason for this fluctuation could be fluctuation in environmental variables such as sea surface temperature. Murase *et al*. (2007) showed that high surface temperature caused low influx of common minke whales to the Kushiro water in September 2006. Mean water temperature at 10m depth is low in 2002-2004 and high in 2006-2007 (Okazaki *et al., 2*016; SC/F16/J06)). Comparing abundance estimates in Kushiro (Table 3), it was suggested water temperature is negatively correlated to the number of the minke whale off Kushiro. Further sighting surveys is necessary to investigate relation between sea water temperature and the numbers of the common minke whales in the coastal areas.

In previous analysis, the number in sub-area 7CS was estimated 890 animals (CV=0.393) while abundance estimates in sub-area 7CN in early (May to June) and late season (September) were 302 animals (CV=0.454) and 398 animals (CV=0.507), respectively, assuming g(0)=1 based on the dedicated sighting surveys in 2012 (Hakamada *et al*., 2013). This difference in abundance estimate is probably due to difference in estimation of detection function. The difference in estimation of detection function is a result of the data set and covariates used. In the previous analysis, primary sightings of minke whales in 2012 was used whereas primary sightings for 2008-2014 were used in this analysis. As for covariates, sub-area and Beaufort sea state were used in the previous analysis whereas Beaufort sea state, school size and year were used in present analysis. Reconsideration of stratification of data and covariates to estimate detection function may improve precision of detectability of the sightings.

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Table 1. Abundance estimate in sub-areas 7CS, 7CN and 7WRN based on JARPNII dedicated sighting surveys in 2012 assuming g(0)=1. 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 1.5 n.miles, L is searching distance, P is abundance estimate and CI is abbreviation for confidence interval.

Year	Stratum	Period	Season	A	L	n_s	n_w	n_w/L	CV(n_w/L)	***P***	CV(P)	95%LL	95%UL
2012	7CS	18 - 24 May, 24 - 29 Jun	early	26,826	850.9	17	19	0.022	0.287	**537**	0.346	269	1,070
2012	7CN	24May - 2 Jun	early	16,171	649.2	17	23	0.035	0.501	**542**	0.601	164	1,790
2012	7WRN	2 - 3 Jun	early	6,874	175.7	2	2	0.011	0.913	**64**	0.935	3	1,471
2012	7CN	15 - 25 Sep	late	16,171	550.2	19	23	0.042	0.472	**599**	0.525	205	1,757
2012	7WRN	26 - 27 Sep	late	6,874	177.4	-	-	-	-	**-**	-	-	-

Table 2. Abundance estimate in Sanriku and Kushiro using density estimates in Table 1 and assuming g(0)=0.789 in Okamura *et al*. (2010). Early refers to May-June and late refers to July – September.

Year	Area	Season	P	CV(**P**)	95%LL	95%UL
2012	Sanriku	early	124	0.371	61	251
2012	Kushiro	early	461	0.593	157	1,352
2012	Kushiro	late	433	0.542	160	1,172

Table 3. The number of the minke whales distributed off Sanriku in early season and those off Kushiro in late season during the survey period assuming g(0)=0.789 in Okamura *et al*. (2010) for comparison. Estimate is slightly changed from previous analysis (Hakamada *et al*., 2009) due to update of g(0) estimate assumed. Early refers to May-June and late refers to July – September.

Sanriku

Year	Area	Season	P	CV(**P**)	95%LL	95%UL
2004	Sanriku	early	260	0.557	94	719
2005	Sanriku	early	401	0.321	217	741
2006	Sanriku	early	216	0.407	101	466

Kushiro

Year	Area	Season	P	CV(**P**)	95%LL	95%UL
2002	Kushiro	late	551	0.350	283	1,073
2003	Kushiro	late	888	0.406	413	1,908
2004	Kushiro	late	338	0.352	173	660
2005	Kushiro	late	290	0.350	149	564
2006	Kushiro	late	221	0.351	113	431
2007	Kushiro	late	130	0.553	47	358

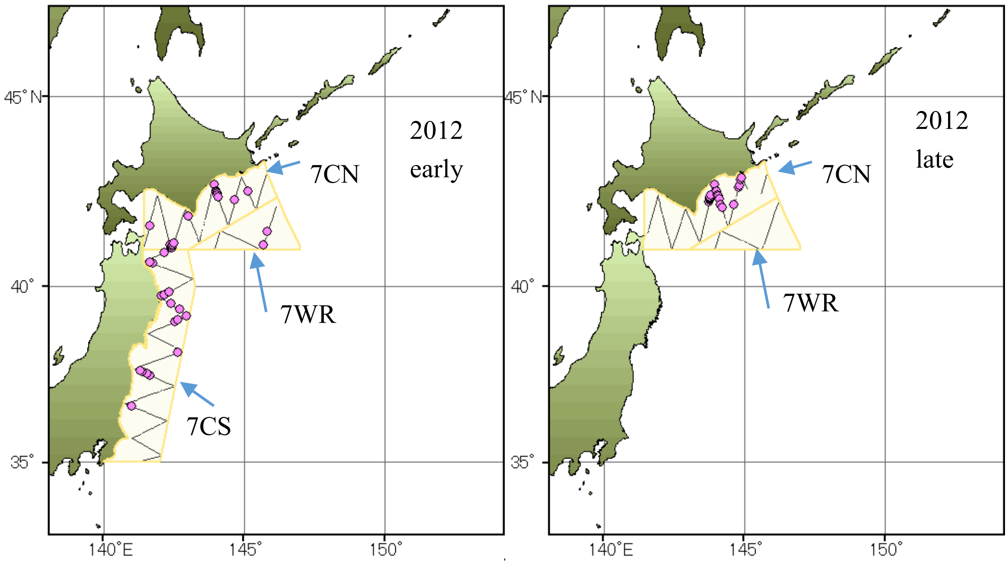

Figure 1. Plot of primary sightings of the minke whales and track lines actually surveyed in sub-areas 7CS, 7CN and a northern part of sub-area 7WR. Left panel is the plot for the first survey (May-June) in 2012 and right panel is plot for the second survey (September) in 2012.

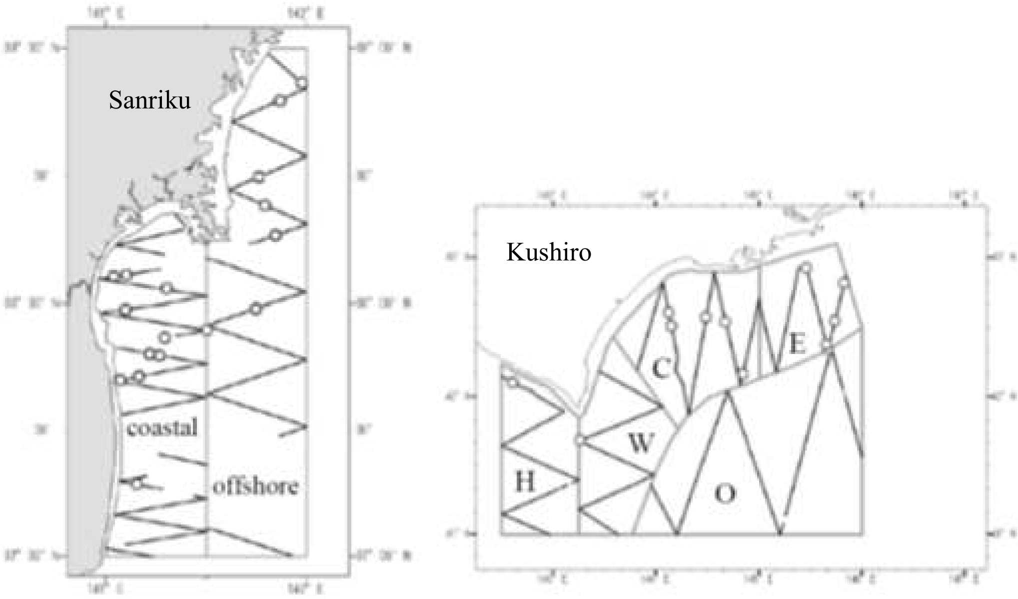

Figure 2a. Survey area off Sanriku (left panel) and off Kushiro (right panel) used to estimate abundance in Table 2. O: Offshore, E: coastal-East, C: coastal-Central, W: coastal-West, and H: off Hidaka sub-prefecture. Offshore area in Kushiro is indicated by O. Rest of the Kushiro areas (Ares H, W, C and E) are coastal area. Figures are referred from Hakamada *et al*. (2009)

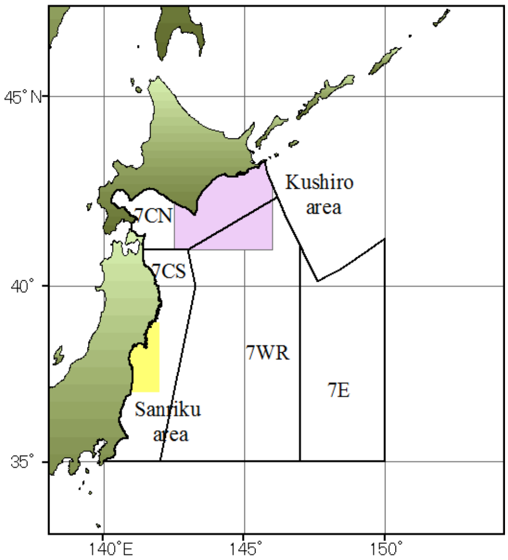

Figure 2b. Dedicated sighting survey area off Sanriku and off Kushiro conducted during 2002-2007 in Sub-areas 7CS, 7CN and northern part of 7WR. Yellow zone is survey area off Sanriku and Purple zone is survey area off Kushiro.

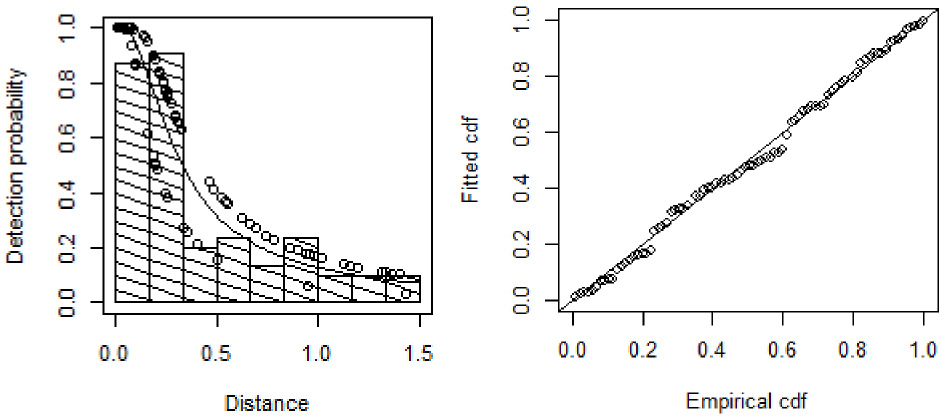

Figure 3. Plot of the estimated detection function fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line for selected model (Left panel) and QQ-plot of the detection function (right panel).