Preliminary abundance estimation of North Pacific sei whale based on the 2012 IWC-POWER sighting survey data

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KEYWORD: ABUNDANCE ESTIMATE, NORTH PACIFIC, SEI WHALE, SURVEY-VESSEL, IWC-POWER.

ABSTRACT

Abundance of North Pacific sei whale (*Balaenoptera borealis*) was preliminary estimated using sighting data obtained during the 2012 International Whaling Commission-Pacific Ocean Whale and Ecosystem Research (IWC-POWER) Cruise. Sensitivity analyses were also conducted to investigate robustness of the abundance estimate to alternative assumptions on stratification and detection functions. Abundance in the eastern North Pacific (north of 40°N, south of the Alaskan coast including both the US and Canadian EEZ between 150°W-135°W), from July to August was estimated as 12,180 (CV=0.327) for the base case scenario. The abundance estimate ranged between 12,062 (CV=0.327) and 13,446 (CV=0.388) for the scenarios considered in the sensitivity analyses. In the near future abundance estimate of sei whale in the North Pacific will be refined by considering all IWC-POWER sighting data obtained in the period 2010 to 2012. Abundance information will be useful for the *in-depth assessment* of this species in the North Pacific being planned by the IWC Scientific Committee (IWC/SC).

INTRODUCTION

Commercial whaling of the sei whale (*Balaenoptera borealis*) was conducted in the North Pacific until 1976 when the commercial take of this species was banned by the IWC. The population size of the North Pacific sei whale after the exploitation period was estimated at 9,000 whales (or 21% of the initial size) (IWC, 1977). Information on abundance estimate and abundance estimate trend of the sei whales in the North Pacific in recent years is required.

In recent years sighting data of sei whales have been collected in the western North Pacific through dedicated Japanese whale sighting surveys, and the sighting component of the Japanese Whale Research Program under Special Permit in the western North Pacific (JARPN and JARPN II). Distribution of sei whales based on Japanese Scouting Vessels (JSV), JARPN and JARPN II sighting data was summarized by Miyashita *et al*., (1995), Matsuoka *et al*. (2000; 2009). Sei whale abundance in the western North Pacific (east of Japanese coast, west of 170°E, north of 35°N, south of Russian EEZ) based on JARPN II sighting data was estimated at 5,406 whales (CV=0.300) in July and August (Hakamada *et al*., 2009).

The IWC-POWER surveys started in 2010. These surveys were planned to cover the central and eastern North Pacific (Figure 1). Preliminary abundance estimates of sei whales were made based on the sighting data collected during the 2010 and 2011 IWC-POWER surveys. Abundance estimates of 9,286 whales (CV=0.35) and 6,587 whales (CV=0.42) were obtained in the central North Pacific (north of 40°N, south of Aleutian Islands, and between 170°E and 170°W), and in the eastern North Pacific (north of 40°N, south of Alaskan Peninsula, between 170°W and 150°W), respectively (Hakamada *et al*, 2011; 2012).

The plan for the 2012 IWC-POWER sighting survey was agreed at the 2011 IWC-POWER planning meeting. The plan was made following the guidelines agreed at the IWC-POWER planning meeting in 2010 (IWC, 2012a). The 2012 survey was carried out successfully and results are presented in Matsuoka *et al*. (2013).

An *in-depth assessment* of this species in the North Pacific is being planned by the IWC/SC to start in 2013 (IWC, 2012b). It is expected that new abundance estimates for sei whales derived from the IWC-POWER and other surveys will contribute for this assessment in conjunction with new information on stock structure (IWC, 2012b).

This paper reports preliminary abundance estimates of the sei whale based on the 2012 IWC-POWER sighting data and standard line transect methodology (e.g. Branch and Butterworth, 2001).

MATERIALS AND METHODS

Survey area

The surveyed area comprised the eastern North Pacific north of 40°N, south of the Alaskan coast including both the US and Canadian EEZ, and between 150°W and 135°W. The survey area was divided into northern and southern strata by the EEZ line of the USA and Canada (Figure 2). The area sizes of the northern and southern strata were 142,427n.miles^2 and 529,362n.miles^2, respectively. They were calculated using Arc GIS (ver. 9.31).

Brief narrative

The 2012 IWC-POWER survey was conducted in the period 24 July – 30 August 2012. The ship departed Shiogama on 13 July and started the sighting surveys on 24 July at 150°00'W. It completed the sighting surveys in the northern stratum on 3 August at 135°00'W and started the sighting survey in the southern stratum on 3 August. It completed the sighting surveys on 30 August at 150°00'W and arrived at Shiogama on 5 September (Matsuoka *et al*., 2013).

Research vessel

The sighting survey was conducted by the research vessel *Yushin-Maru No.3* (*YS3*). Specifications of the vessel are provided in Matsuoka *et al*. (2013).

Survey design

Cruise tracks were designed using the program DISTANCE (Thomas *et al*., 2010) following the principles outlined in the IWC/SC's Requirements and Guidelines for Surveys (IWC, 2005). Planned cruise tracks and survey order were shown in Figure 3. Observed distance and angles were corrected using data obtained from the Angle and Distance Experiment. All sighting data obtained were validated.

Survey mode

Because use of passing mode in the POWER would result in very high proportions of unidentified cetaceans, the technical advisory group (TAG) recommended that Passing with abeam closing mode (NSP) is the most appropriate survey mode, both with respect to confirming species identity and school size (IWC, 2013). Passing with abeam closing mode was used during the survey. Two topmen were observing from the barrel at all times. There was open communication between the upper bridge and the barrel. The observers on the upper bridge should communicate with the topmen only to clarify information and should not direct the topmen to disrupt their normal search procedure unless directed to do so by the Cruise Leader (Matsuoka *et al*., 2013).

Analytical procedure

For the analysis it is assumed that $g(0)=1$. The observed data of radial distance and angle are smeared using the method II of Buckland and Anganuzzi (1988). Detections are truncated at 3.0 n.miles. Abundance and its CV were estimated by formula (1) and (2), respectively. DISTANCE ver 6.0 (Thomas *et al*., 2010) is used for abundance estimation.

$$N = \frac{AnE(s)}{2wl} \quad (1)$$

$$CV(N) = \sqrt{\left\{CV\left(\frac{n}{l}\right)\right\}^2 + \{CV(w)\}^2 + \{CV(E(s))\}^2} \quad (2)$$

where N is abundance estimate, A is area size of the surveyed area, n is the smeared number of schools detected within perpendicular distance of 3.0 n.miles, $E(s)$ is estimated mean school size, w is effective strip half width (ESW) and l is searching distance.

The smeared and truncated sighting data for schools are grouped into intervals of 0.3 n. miles to estimate the detection function. We consider half-normal and hazard-rate models as candidate models for the detection function. Model is selected by AIC. Mean school size is estimated from the primary sightings whose school size was confirmed. Regression method in Buckland *et al.* (1993) is applied to estimate mean school size.

Sensitivity Analysis

In order to examine the robustness of the abundance estimate to alternative assumption on stratification for estimation of mean school size and detection functions, sensitivity is conducted as following.

1. Mean school size was estimated by stratum.
2. Alternative detection function is applied.
3. Width of perpendicular distance intervals is changed from 0.3 to 0.6 n.miles.

RESULTS

Sighting effort

Survey order in the research area is shown in Figure 3. The searching effort was 767.5 n. miles and 1,358.6 n.miles in the northern and southern strata, respectively (Table 1). Survey coverage was relatively high in the southern (85%) and the northern (80%) strata (Matsuoka *et al*., 2013).

Sightings

Plots for searching effort and primary sightings of the sei whales are shown in Figure 4. There were 79 primary sightings (148 individuals) in the research area. Figure 5 shows composition of observed school size for primary sightings during the surveys. 51 schools are solitary schools out of 79 sightings (64.5%).

Sei whales were distributed mainly in the southern stratum between 135°W and 145°W.

Abundance estimate

Table 1 shows the abundance estimates for the base case scenario (1a) and for the scenarios of the sensitivity test (1b-1d). The effect of school size on detection was not significant at the 15% level. Therefore the observed mean school size is used to estimate abundance (Table 2). The AIC for half normal model is smaller than that for hazard-rate model (Table 3), and half-normal model is selected by AIC. Figure 6 shows the plot of the detection function for the base case scenario (using AIC-selected detection function). Abundance estimate of sei whale is 12,180 (CV=0.327) for the base case scenario (Table 1a).

Sensitivity Analysis

Estimating mean school size by stratum

Table 1b shows the abundance estimates for the sensitivity 1. For this sensitivity, mean school size and its CV were calculated by strata. Mean school size estimates were not different substantially but CV in northern stratum is higher than the base case. Encounter rate and ESW and their CVs are common with the base case scenario. Abundance estimate is 12,163 (CV=0.327) for the sensitivity 1.

Alternative detection function

Table 1c shows the abundance estimates for the sensitivity 2. The CV of ESW derived from the hazard-rate model (0.237) was higher than the base case (0.110), therefore the use of half-normal model was preferable to estimate ESW. Figure 7 shows the plot of the detection function for sensitivity 2. The fitting of the model is worse than the base case. Abundance estimate is 13,446 (CV=0.388) for the sensitivity 2.

Width of perpendicular changes from 0.3 to 0.6 n.miles

Table 1d shows the abundance estimates for the sensitivity 3. ESW estimate and its CV would not change substantially from the base case. Figure 8 shows the plot of the detection function for sensitivity 3. Shape of the detection function is not substantially changed from that for the base case. Abundance estimate is 12,062 (CV=0.327) for the sensitivity 3.

DISCUSSION

Distribution of the sei whales

Figure 4 shows that the sei whales mainly distributed in the eastern part of the survey area (145°W-135°W). This may suggest that sei whales distributes to the east of 135°W longitudinal line. Sighting survey in this area could provide useful sighting data to estimate sei whale abundance there.

Robustness of abundance estimates

Abundance estimates in the sensitivity analyses did not differ substantially from the base case. Sensitivity analysis suggested that abundance estimate is robust to alternative assumptions on stratification to estimate mean school size and detection functions examined in this study. Investigating detection function using covariates such as Beaufort state and year and pooling data with sighting data collected in other year, could refine abundances estimate of the sei whales.

Abundance estimate for North Pacific sei whales in previous studies

There were some sei whale abundance estimates in previous studies as mentioned earlier. Sei whale abundance estimate in the western North Pacific (east of Japanese coast, west of 170^{o}E, north of 35^{o}N, south of Russian EEZ) based on JARPN II data was 5,406 (CV=0.300) in July and August (Hakamada *et al*., 2009). Abundance estimate in the 2010POWER was 9,286 (CV=0.35) (Hakamada *et al*., 2011) and that in the 2011POWER was 6,587 (CV=0.420). Kanda *et al*. (2009; 2011; 2013) suggested that the open water of the North Pacific was mainly occupied by the individuals from a single stock of the sei whales. Murase *et al*., (2009; 2013) suggested that distribution of the sei whales predicted by a generalised additive model is continuous in southern part of survey area during 2010-2012 IWC-POWER. Under this assumption and the assumption that there is no correlations among the estimates, the combined abundance estimates was 33,458 (CV=0.195) in the parts of North Pacific surveyed by those surveys in July - August.

Future work

Abundance estimate for the sei whale will be refined using all IWC-POWER sighting data for the period 2010-2012. Detection function (Half normal and Hazard rate) with covariate such as Beaufort state and year, will be examined using MCDS engine in the program DISTANCE. Also an examination of stratification of data to estimate mean school size will be carried out.

ACKNOWLEDGEMENT

We thank the captain, crews and international researchers onboard the *Yushin-Maru No.3* for their hard work during the survey. We thank Luis Pastene for their valuable comment to improve this manuscript. We also thank Greg Donovan of the Head of Science of the IWC, the steering group (Robert Brownell, Phillip Clapham, Paul Ensor, Tomio Miyashita, Luis Pastene and Lars Walløe) and the technical advisory group (Sharon Hedley, Mark Bravington, and Natalie Kelly) for their scientific contributions to organize the POWER cruise.

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Table 1. Abundance estimates for the sei whales and their CV's by stratum from July to August. *A* is area size of the surveyed area, *n* is the smeared number of schools detected within perpendicular distance of 3.0 n.miles, *l* is searching distance, *ESW* is effective strip half width, *E*(*s*) is estimated mean school size, *D* is density (individual/n.miles^2), *P* is abundance estimate and CI is abbreviation for confidence interval.

a. Encounter rate was estimated separately by stratum (base case).

Stratum	Area (n.miles^2)	*n*	*l* (n.miles)	*n*/*l**100	CV	*ESW* (n.miles)	CV	E(*s*)	CV	*D* (ind./n. miles^2)	*P* (ind.)	CV	95% CI LL	95% CI UL
Northern	142,427	1.7	767.5	0.228	0.629	2.196	0.110	1.842	0.093	0.001	136	0.645	43	433
Southern	529,362	73.7	1,358.6	5.424	0.297	2.196	0.110	1.842	0.093	0.023	12,044	0.330	6,416	22,608
Total	**671,789**	**75.4**	**2,126.1**	**3.548**						**0.018**	**12,180**	**0.327**	**6,527**	**22,729**

b. Encounter rate and mean school size were estimated separately by stratum.

Stratum	Area (n.miles^2)	*n*	*l* (n.miles)	*n*/*l**100	CV	*ESW* (n.miles)	CV	E(*s*)	CV	*D* (ind./n. miles^2)	*P* (ind.)	CV	95% CI LL	95% CI UL
Northern	142,427	1.7	767.5	0.228	0.629	2.196	0.110	2.000	0.500	0.001	148	0.811	37	595
Southern	529,362	73.7	1,358.6	5.424	0.297	2.196	0.110	1.838	0.095	0.023	12,015	0.330	6,394	22,581
Total	**671,789**	**75.4**	**2,126.1**	**3.548**						**0.018**	**12,163**	**0.327**	**6,515**	**22,708**

c. Alternative detection function (Hazard rate model) was applied.

Stratum	Area (n.miles^2)	*n*	*l* (n.miles)	*n*/*l**100	CV	*ESW* (n.miles)	CV	E(*s*)	CV	*D* (ind./n. miles^2)	*P* (ind.)	CV	95% CI LL	95% CI UL
Northern	142,427	1.7	767.5	0.228	0.629	1.989	0.237	1.842	0.093	0.001	150	0.679	45	502
Southern	529,362	73.7	1,358.6	5.424	0.297	1.989	0.237	1.842	0.093	0.025	13,296	0.391	6,348	27,849
Total	**671,789**	**75.4**	**2,126.1**	**3.548**						**0.020**	**13,446**	**0.388**	**6,458**	**27,997**

d. Width of perpendicular distance intervals was changed from 0.3 to 0.6 (n.miles).

Stratum	Area (n.miles^2)	*n*	*l* (n.miles)	*n*/*l**100	CV	*ESW* (n.miles)	CV	E(*s*)	CV	*D* (ind./n. miles^2)	*P* (ind.)	CV	95% CI LL	95% CI UL
Northern	142,427	1.7	767.5	0.228	0.629	2.217	0.113	1.842	0.093	0.001	135	0.646	42	429
Southern	529,362	73.7	1,358.6	5.424	0.297	2.217	0.113	1.842	0.093	0.023	11,927	0.331	6,344	22,425
Total	**671,789**	**75.4**	**2,126.1**	**3.548**						**0.018**	**12,062**	**0.327**	**6,453**	**22,545**

Table 2. Results for regression of log of observed school size and detection probability for base case. SE is standard error of the estimate slope.

slope	SE	Student's-*t*	*p*-value
-0.319	0.366	-0.871	0.193

Table 3. AIC estimate for each model of detection functions for base case. Selected model is indicated by an asterisk.

Model	AIC
Half Normal*	347.4
Hazard Rate	349.2

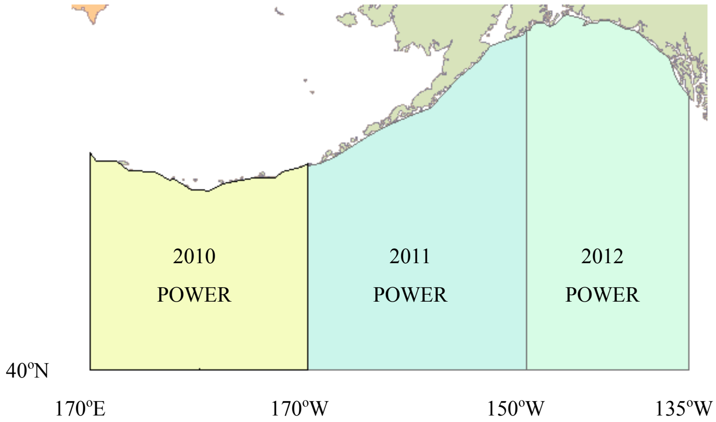

Figure 1. Research area of the 2010-2012 POWER cruises.

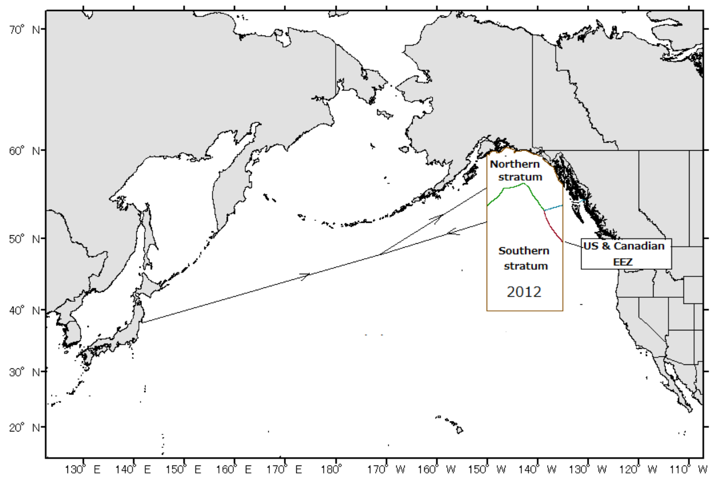

Figure 2. Research area of the 2012 IWC-POWER cruise. The area was divided into northern and southern strata by the US and Canadian EEZ boundary line (Matsuoka *et al*., 2013).

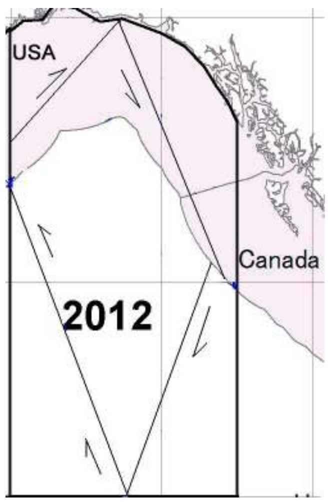

Figure 3. Planned cruise track (line) and survey order (arrows). Bold black line represents boundary for survey area. Grey colored area represents for the US and Canadian EEZ. Survey started at 150ºW and completed at 150ºW.

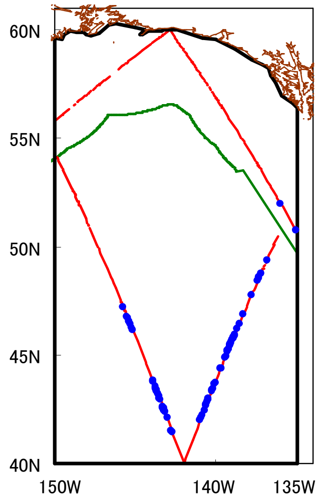

Figure 4. Plot of actual survey track (red line) and positions of primary sightings of the sei whales (blue circle) during the 2012 IWC-POWER survey. Bold black line represents boundary for survey area. Green line represents boundary for the US and Canadian EEZ.

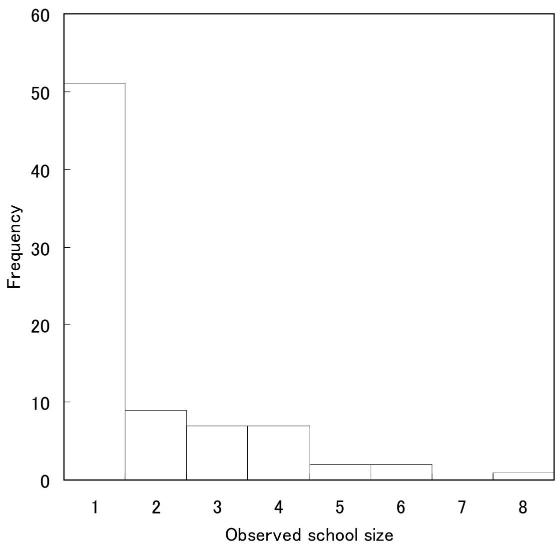

Figure 5. Composition of observed school size for primary sightings of the sei whales during the survey.

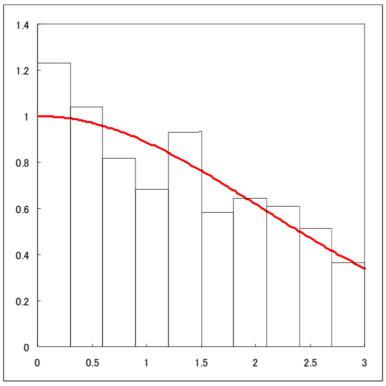

Figure 6. Plot of the estimated detection function (red line) fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line for base case scenario (Half normal model was used).

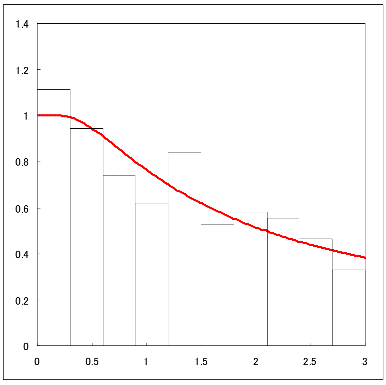

Figure 7. Plot of the estimated detection function (red line) fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line, for sensitivity 2 (Hazard rate model was used).

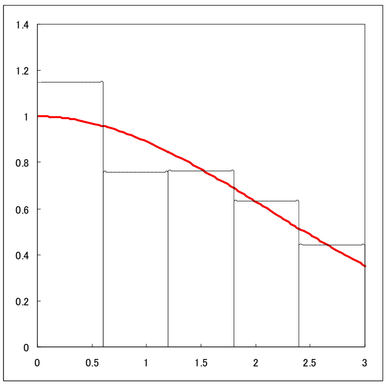

Figure 8. Plot of the estimated detection function (red line) fitted to the number of schools as a function of perpendicular distance (n.miles) from the track line, for sensitivity 3 (Width of interval was doubled).