Preliminary analysis of abundance estimate for sei whale in the North Pacific based on sighting data obtained during IWC-POWER surveys in 2010-2012

TAKASHI HAKAMADA and KOJI MATSUOKA

Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055
Contact e-mail:hakamada@cetacean.jp

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 2010-2012 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 detection functions and mean school size. Abundance in the central and eastern North Pacific (north of 40°N, south of the Alaskan coast including both the US and Canadian EEZ between 170°E-135°W), from July to August was estimated as 34,150 (CV=0.270) for the base case scenario. In the sensitivity analysis, abundance estimates ranged from 26,926 (CV=0.217) to 33,664(CV=0.269) and there were no significant differences among thre sensitivity estimates. Abundance information of sei whale based on IWC-POWER cruise data 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 sei whale (*Balaenoptera borealis*) was conducted in the North Pacific until 1976 when the commercial take of this species was banned by the International Whaling Committee (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).

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 and its second phase (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 170ºE, north of 35ºN, 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 Pacific Ocean Whale Ecosystem Research (IWC-POWER) surveys started in 2010 and have been conducted every year (Matsuoka *et al*., 2011; 2012; 2013 2014). Abundance for the sei whales was preliminary estimated for each IWC-POWER survey in the period 2010-2012 (Hakamada *et al*., 2011; 2012; Hakamada and Matsuoka, 2013).

This paper presents the results of abundance estimates of sei whales for the combined data of the period 2010-2012, and examines if abundance estimates would be improved in comparison with the previous individual survey estimates. This paper responds to some recommendations for additional analyses made by Hakamada and Matsuoka (2013).

MATERIALS AND METHODS

Survey area

Survey areas for the 2010-2012 IWC-POWER surveys are shown in Figure 1. In 2010, the central North Pacific (north of 40ºN, south of Aleutian Islands, between 170ºE and 170ºW) was surveyed, and the survey area was divided into two strata by the latitudinal line of 47ºN. In 2011, the eastern North Pacific north of 40ºN, south of Alaskan Peninsula, and between 170ºW and 150ºW area was surveyed. The survey area was divided into northern and southern strata by the EEZ line of the USA. In 2012, the eastern North Pacific north of 40ºN, south of the Alaskan coast including both the US and Canadian EEZ, between 150ºW and 135ºW area was surveyed. The survey area was divided into northern and southern strata by the EEZ line of the USA and Canada.

Research vessel

The sighting survey was conducted by the research vessel *Kaiko-Maru* (*KK1*) in 2010 and *Yushin-Maru No.3* (*YS3*) in 2011 and 2012. Specifications of *KK1* and *YS3* are provided in Matsuoka *et al*. (2011) and Matsuoka *et al*. (2013), respectively.

Survey design

Cruise tracks were designed using the program DISTANCE (Thomas *et al*., 2010) following the principles outlined in the IWC Scientific Committee's Requirements and Guidelines for Surveys (IWC, 2005). Planned cruise tracks and survey order were shown in Figure 2. Observed distance and angles were corrected using data obtained from the Angle and Distance Experiment.

Survey mode

Closing mode and IO mode were conducted in the 2010 survey. Passing with abeam closing mode was used during the survey in 2011 and 2012 survey. More details of closing and IO modes are provided in Matsuoka *et al*. (2011), and more details of passing with abeam closing mode are provided in Matsuoka *et al* (2012; 2013). Because the use of passing mode in the IWC-POWER would result in very high proportions of unidentified cetaceans, the POWER 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). Sighting and effort data in both survey modes were pooled for abundance estimation because of limited sample size same as in the case of IDCR/SOWER based abundance estimation for large baleen whales (Branch and Butterworth, 2001; Branch, 2011). Duplicate sightings in IO mode are excluded from the analysis.

Data used

Analyses in this paper are based on sighting data obtained during the POWER surveys during 2010-2012. Data validation by the IWC Secretariat was completed for the data obtained in 2010 and 2011 but the validation work has not been completed for the 2012 data. In this analysis, data that were not validated by IWC Secretariat was used.

Analytical procedure

For this analysis it is assumed that g(0)=1. 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 truncated sighting data for schools are grouped into intervals of 0.3 n. miles to estimate the detection function. Multiple Covariate Distance Sampling (MCDS) Engine in DISTANCE program was used. MCDS methods are based on a Horvitz-Thompson like estimator of abundance (Thomas *et al*., 2010). We consider Half Normal and Hazard Rate models as candidate models for the detection function. Full model of the detection function was provided by

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

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

where *x* is perpendicular distance, *a* and *b* are parameter, *Beaufort* is categorical variable for Beaufort sea state and Year is categorical variable for year.

AIC was used to select the best model to estimate *ESW*.

When MCDS Engine is executed, smearing cannot be conducted in DISTANCE. If the models with no covariate was selected, the observed data of radial distance and angle would be smeared using the method II of Buckland and Anganuzzi (1988) so as to improve fitting of the detection function.

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 .In order to examine if mean school size should be estimated for each stratum or for all data combined, analysis of variance (ANOVA) was conducted.

Sensitivity Analysis

Some sensitivity analysis were conducted to examine the effect of alternative assumptions for detection function and mean school size.

1. Estimating *ESW* using alternative models (Half Normal model)
2. Estimating *ESW* for each survey
3. Estimating mean school size for each stratum.

RESULTS

Searching effort and primary sightings

Searching effort and primary sightings for each stratum are summarized in Table 1. Searching effort are 1816.2, 2397.8 and 2126.1 in 2010, 2011 and 2012, respectively. Survey coverage for each stratum during the 2010-2012 IWC-POWER surveys is shown in Table 2. Coverage is lower in the northern strata in 2010 and 2011 due to poor weather conditions in those years (Matsuoka *et al*., 2011; 2012). In the southern strata, coverage is good due to good weather condition (Matsuoka *et al*., 2011; 2012; 2013). The truncated and smeared numbers of sightings are 48.9, 36.9 and 76.0 in 2010, 2011 and 2012, respectively. Figure 3 shows the plot of track line actually surveyed and the position of sei whale primary sightings during the 2010-2012 IWC-POWER surveys. Most of the primary sightings occurred in the southern strata.

Model selection of detection function

Table 3 gives AIC for each candidate model. Among the models, Hazard Rate model with no covariates was selected. Therefore, Hazard Rate model with no covariates were used to estimate *ESW* for the base case in this study. Figure 4 shows the detection function and observed frequency of detection. Chi-square statistics is 4.245 with 7 degrees of freedom (p=0.751), which suggests that fitting model is good.

Mean school size

Figure 5 shows distribution of observed school size for all primary sighting of the sei whales whose school size was confirmed. Results of ANOVA suggests that data should be pooled to estimate mean school size rather estimate by strata (Table 4). As shown in Table 5, effect of school size on detection was not significant at 15% level (i.e. p-value was 0.158) therefore observed mean school size was used to estimate abundance.

Abundance estimate
Table 1 shows abundance estimates in each stratum for the base case. *ESW* estimate was 1.518 (CV=0.185), the estimated mean school size was 1.852 (CV=0.057) and the total abundance estimate was 34,150 (CV=0.270) for the base case.

Sensitivity analysis
1. Estimating ESW using alternative detection function
Abundance estimates for this sensitivity are shown in Table 6a. Abundance estimate and its CV were 26,948 and 0.230, respectively. Abundance estimate is not significantly different from that in the base case. Right panel in Figure 4 shows the plot. Chi-square statistics is 7.280 with 8 degrees of freedom (p=0.507), which suggests that fitting is worse than the base case.

2. Estimating ESW for each survey
Half Normal model was selected for all surveys, which is different from the base case. This agrees with the results showing that AIC is smaller for Half Normal model than Hazard Rate model when year is used as a covariate. Abundance estimates and its CV were 26,926 and 0.217, respectively (Table 6b). Abundance estimate is not significantly different from that for base case. Detection function for each survey is shown in Figure 6. The fitting of the detection functions are not substantially different from the base case.

3. Estimating mean school size for each stratum
Abundance estimates would not differ from that in the base case (Table 6c). Abundance estimates of 33,664 (CV=0.269) is not substantially different from that for the base case. Difference in stratification to estimate mean school size would not affect the abundance estimates.

DISCUSSIONS

Precision of abundance estimates in northern strata
In northern strata, there were few sightings of the sei whales, which lead lower precision of abundance estimates in northern strata. In the northern stratum, there were some poor weather conditions (heavy winds or poor visibility) in the US EEZ in 2010 and 2011 due to a strong low pressure system moving eastwards (Matsuoka *et al*, 2011; 2012). Possible causes of small number of sightings in northern stratum may be (1) poor weather condition and/or (2) lower density than in the southern strata.

Detection function
Figure 7 shows distance and angles for each sei whale primary sightings during the 2010-2012 POWER surveys. Maximum of forward distance is larger than that of perpendicular distance. This could affect the shape of frequency data of sightings by intervals of perpendicular distance. There is not significant differences between *ESW* estimates for the base case and sensitivities 1 and 2. Small *ESW* estimates differences would be arise from the selection of the detection function. A possible solution for this is to apply model averaging (Buckland *et al*., 1997). Further consideration should be given to the adjustment terms of the detection function.

Abundance estimate for North Pacific sei whales incluing outside of POWER research area.
Estimate in the IWC-POWER research area was 34,150 (CV=0.270). Sei whale abundance estimate in the western North Pacific (east of Japanese coast, west of 170ºE, north of 35ºN, south of Russian EEZ) based on JARPN II data was 5,406 (CV=0.300) in July and August (Hakamada *et al*., 2009).

Estimation of stock abundance requires information on stock structure and distribution. 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 generalized additive model (GAM) is continuous in southern part of survey area during 2010-2012 IWC-POWER.

Under these assumptions and the assumption that there is no correlations among the estimates, the combined abundance estimates for the JARPN II and IWC-POWER research areas in July-August was 39,556 (CV=0.237).

ACKNOWLEDGEMENT

We thank the captain, crews and international researchers onboard the *Yushin-Maru No.3* for their hard work during the survey. We thank Shigetoshi Nishiwaki, Luis A. Pastene and Yu Kanaji for their comments to improve earlier version of this manuscript. Marion Huge is thanked for her work for data validation and kindly responding our queries on IWC-POWER data. We also thank Greg Donovan of the Head of Science of the IWC, the steering group (Hidehiro Kato (Convener), An Yong-Rock, John Bannister, Robert Brownell, Phillip Clapham, Paul Ensor, Tomio Miyashita, Hiroto Murase, Luis Pastene and Paul Wade) and the POWER Technical Advisory Group (Mark Bravington, Sharon Hedley, Natalie Kelly, Toshihide Kitakado and Debra Palka) for their scientific contributions to organize the POWER cruises.

REFERENCES

Branch, T. A. and Butterworth, D. S. 2001. Estmates of abundance south of 60oS for cetacean species sighted frequently on the 1978/79 to 1997/98 IDCR-SOWER surveys. *J. Cetacean Res. Manage*. 3:251-270.

Branch, T.A. 2011. Humpback abundance south of 60°S from three complete circumpolar sets of surveys. *J.Cetacean Res. Manage.* (*SPECIAL ISSUE*) 3: 53-69.

Buckland S. T. and Anganuzzi A. A. 1988. Comparison of smearing methods in the analysis of minke sightings data from IWC/IDCR Antarctic cruises. *Rep. Int. Whal. Commn* 38: 257-63.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. Distance Sampling: Estimating Abundance of Biological Populations. Chapman and Hall, reprinted 1999 by RUWPA, University of St Andrews. 446pp.

Buckland, S. T., Burnham, K. P. and Augustin, N.H. 1997. Model selection: an integral part of inference. *Biometrics* 53: 603-618.

Hakamada, T. Matsuoka, K and Miyashita, T. 2009. Distribution and the number of western North Pacific common minke, Bryde’s, sei and sperm whales distributed in JARPN II Offshore component survey area. Paper SC/J09/JR15 submitted to the Expert Workshop to review results of JARPN II. (unpublished) 18pp.

Hakamada, T., Kiwada, K., Matsuoka, K and Kitakado, T. 2011 Preliminary estimation of North Pacific sei whale abundance derived from 2010 IWC/Japan Joint Cetacean Sighting Survey data. Paper SC/63/IA13 submitted to IWC Scientific Committee, June 2011. (unpublished) 7pp.

Hakamada, T., Matsuoka, K. and Kitakado, T. 2012. Preliminary estimation of North Pacific sei whale abundance based on the 2011 IWC-POWER sighting survey data. Paper SC/64/IA11 submitted to IWC Scientific Committee, June 2012, (unpublished) 11pp.

Hakamada, T. and Matsuoka, K. 2013. Preliminary abundance estimation of North Pacific sei whale based on the 2012 IWC-POWER sighting survey data. Paper SC/65a/IA9 submitted to IWC Scientific Committee, June 2013. (unpublished). 11pp.

International Whaling Commission. 1977. *Rep. Int. Whal. Commn*., 27:6-17.International Whaling Commission. 2005. Report of the Scientific Committee. Annex D. Report of the sub-committee on the Revised Management Procedure. Appendix 3. Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme. *J. Cetacean Res. Manage*. (*Suppl*.) 7:92-101.

International Whaling Commission. 2005. Report of the Scientific Committee. Annex D. Report of the sub-committee on the Revised Management Procedure. Appendix 3. Requirements and Guidelines for Conducting Surveys and Analysing Data within the Revised Management Scheme. *J. Cetacean Res. Manage.* (*Suppl.*) 7:92-101.

International Whaling Commission. 2013. Report of the Technical Advisory Group (TAG) meeting on the short and medium term objectives and plans for the IWC-POWER cruises. Tokyo 26-28 September 2011. *J. Cetacean Res. Manage.* (Suppl.) 14: (in press)

Kanda, N., Goto, M., Yoshida, H. and Pastene, L. A. 2009. Stock structure of sei whales in the North Pacific as revealed by microsatellite and mitochondrial DNA analyses. Paper SC/J09/JR32 submitted to the Expert Workshop to review results of JARPN II. (unpublished) 14pp.

Kanda, N., Goto, M., Matsuoka, K., Yoshida, H. and Pastene, L. A. 2011. Preliminary microsatellite

analysis of sei whales obtained from the North Pacific in 2010. Paper SC/63/IA12 submitted to IWC Scientific Committee. May, 2011. (unpublished) 4pp.
Kanda, N., Matsuoka, K., Yoshida, H. and Pastene, L. A. 2013. Microsatellite DNA analysis of sei whales obtained from the 2010-2012 IWC/POWER. Paper SC/65a/IA5 submitted to IWC Scientific Committee. June 2013. (unpublished). 6pp.
Matsuoka, K., Hakamada, T., Y., and Miyashita, T., 2000. Distribution pattern of minke whales based on sighting data during the JARPN 1994-1999. Paper SC/F2K/J16 presented to the IWC Scientific Committee Workshop to Review the Japanese Whale Research Programme under Special Permit for North Pacific Minke Whales (JARPN), Tokyo, 7-10 February 2000 (unpublished). 17pp.
Matsuoka, K., Kiwada, H., Fujise,Y. and Miyashita, T. 2009. Distribution of blue (*Balaenoptera musculus*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*) and north pacific right (*Eubalaena japonica*) whales in the western North Pacific based on JARPN and JARPN II sighting surveys (1994 to 2007). Paper SC/J09/JR35 submitted to the Expert Workshop to review results of JARPN II. (unpublished). 12pp.
Matsuoka, K., Hakala, S., Kim, H. W., Aki, M. and Shinyashiki, Y. 2011. Cruise Report for 2010 IWC/Japan Joint Cetacean Sighting Survey Cruise in the North Pacific. Paper SC/63/O5 presented to IWC Scientific Committee. June 2011. (unpublished) 43pp.
Matsuoka, K., Mizroch, S. and Komiya, H. 2012. Cruise report of the 2011 IWC-Pacific Ocean Whale and Ecosystem Research (IWC-POWER). Paper SC/64/IA5 submitted to IWC Scientific Committee. June 2012. (unpublished). 27pp.
Matsuoka, K., Mizroch, S., An, Y., Kumagai, S. and Hirose, K. 2013. Cruise report of the 2012 IWC-Pacific Ocean Whale and Ecosystem Research (IWC-POWER). Paper SC/65a/IA8 submitted to IWC Scientific Committee. June 2013. (unpublished). 43pp.
Matsuoka, K. 2014. Cruise report of the 2013IWC-Pacific Ocean Whale Ecosystem Research (IWC-POWER). Paper SC/65b/IAxx submitted to IWC Scientific Committee
Miyashita,T., Kato,H. and Kasuya,T. 1995. Worldwide map of cetacean distribution based on Japanese sighting data (Volume 1). National Research Institute of Far Seas Fisheries, Shimizu, 140pp.
Murase, H., Hakamada, T., Kiwada, H., Inagake, D., Okazaki, M., Tojo, N. and Matsuoka, K. 2009. Preliminary results of estimation of sei whale (*Balaenoptera borealis*) distributuion and abudnace in the whole North Pacific basin. Appendix 2 of paper SC/J09/JR36 submitted to the Expert Workshop to review results of JARPN II. (unpublished) 11pp.
Murase, H., Kitakado, T., Matsuoka, K. and Kato, H. 2013. Preliminary analysis of spatial distribution of fin, sei and humpback whales in the offshore eastern subarctic Pacific using 2010-2012 IWC-POWER data. Paper SC/65a/IA10 submitted to IWC Scientific Committee, June 2013. (unpublished). 9pp.
Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14.

Table 1. Abundance estimates for the sei whales and their CV's for each stratum based on 2010-2012 IWC-POWER cruises from July to August for base case. *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.

Year	Stratum	*A* (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
2010	Northern	238,627	4.0	490.5	0.816	0.502	1.518	0.185	1.852	0.057	0.005	1,187	0.535	444	3,176
	Southern	365,244	44.9	1325.7	3.390	0.326	1.518	0.185	1.852	0.057	0.021	7,555	0.379	3,687	15,480
2011	Northern	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
	Southern	569,167	36.9	1,674.0	2.207	0.386	1.518	0.185	1.852	0.057	0.013	7,665	0.421	3,471	16,926
2012	Northern	142,427	1.8	767.5	0.238	0.661	1.518	0.185	1.852	0.057	0.001	207	0.657	64	668
	Southern	529,362	74.2	1,358.6	5.429	0.293	1.518	0.185	1.852	0.057	0.033	17,536	0.354	8,939	34,403
	Total	2,038,387	161.8	6,340.1	2.552	-	-	-	-	-	0.017	**34,150**	**0.270**	20,286	57,489

Table 2. Survey coverage for each stratum during the 2010-2012 IWC-POWER surveys.

Survey year	Northern	Southern
2010	34%	70%
2011	58%	78%
2012	80%	85%

Table 3. AIC estimate for each model of detection functions for base case. For selected model, AIC is indicated by bold letters. HN: Half Normal and HR: Hazard Rate

Model	HN	HR
Beaufort+Year	718.40	722.71
Beaufort	719.59	719.14
Year	716.67	719.00
No covariate	716.16	**714.63**

Table 4. Results for ANOVA to examine if null hypothesis that mean school size are equal among the strata can be rejected.

	Sum of Squares	Degree of freedom	Mean square	F-statistics	*p* -value
Between strata	3.865	4	0.966	0.479	0.751
Within strata	324.593	161	2.016	-	-
Total	328.458	165	-	-	-

Table 5. 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
-0.173	0.172	-1.006	0.158

Table 6. The abundance estimates for the sei whales and their CV's for each stratum for sensitivity tests. The Notations is as for Table 1.

a. Sensitivity 1

Year	Stratum	*A* (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
2010	Northern	238,627	4.0	490.5	0.816	0.502	1.590	0.117	1.852	0.057	0.005	1,133	0.516	438	2,935
	Southern	365,244	44.9	1325.7	3.390	0.326	1.590	0.117	1.852	0.057	0.020	7,210	0.350	3,701	14,047
2011	Northern	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
	Southern	569,167	36.9	1,674.0	2.207	0.386	1.842	0.144	1.852	0.057	0.013	6,316	0.421	3,471	16,926
2012	Northern	142,427	1.8	767.5	0.238	0.661	2.195	0.109	1.852	0.057	0.001	143	0.657	64	668
	Southern	529,362	74.2	1,358.6	5.429	0.293	2.195	0.109	1.852	0.057	0.033	12,124	0.354	8,939	34,403
	Total	2,038,387	161.8	6,340.1	2.552	-	-	-	-	-	0.013	**26,926**	**0.217**	17,690	40,983

b. Sensitivity 2

Year	Stratum	*A* (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
2010	Northern	238,627	4.0	490.5	0.816	0.502	1.923	0.070	1.852	0.057	0.004	937	0.507	367	2,393
	Southern	365,244	44.9	1325.7	3.390	0.326	1.923	0.070	1.852	0.057	0.016	5,962	0.338	3,130	11,354
2011	Northern	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
	Southern	569,167	36.9	1,674.0	2.207	0.386	1.923	0.070	1.852	0.057	0.013	6,048	0.421	3,471	16,926
2012	Northern	142,427	1.8	767.5	0.238	0.661	1.923	0.070	1.852	0.057	0.001	163	0.657	64	668
	Southern	529,362	74.2	1,358.6	5.429	0.293	1.923	0.070	1.852	0.057	0.033	13,838	0.354	8,939	34,403
	Total	2,038,387	161.8	6,340.1	2.552	-	-	-	-	-	0.013	**26,948**	**0.230**	17,253	42,090

c. Sensitivity 3

Year	Stratum	*A* (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
2010	Northern	238,627	4.0	490.5	0.816	0.502	1.518	0.185	1.000	0.000	0.003	641	0.535	240	1,715
	Southern	365,244	44.9	1325.7	3.390	0.326	1.518	0.185	1.867	0.086	0.021	7,615	0.384	3,681	15,756
2011	Northern	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
	Southern	569,167	36.9	1,674.0	2.207	0.386	1.518	0.185	1.682	0.099	0.013	7,665	0.421	3,471	16,926
2012	Northern	142,427	1.8	767.5	0.238	0.661	1.518	0.185	2.000	0.500	0.001	207	0.657	64	668
	Southern	529,362	74.2	1,358.6	5.429	0.293	1.518	0.185	1.838	0.095	0.033	17,536	0.354	8,939	34,403
	Total	2,038,387	161.8	6,340.1	2.552	-	-	-	-	-	0.017	**33,664**	**0.269**	20,059	56,496

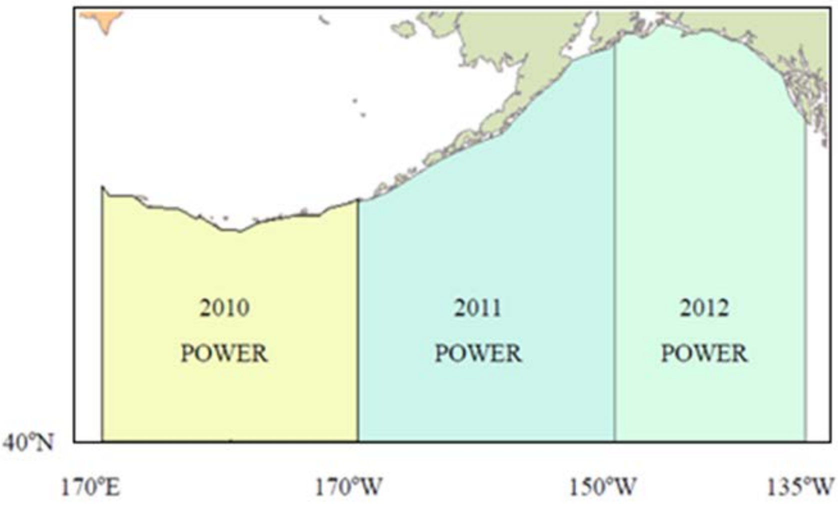

Figure 1. Survey area for 2010-2012 IWC-POWER surveys.

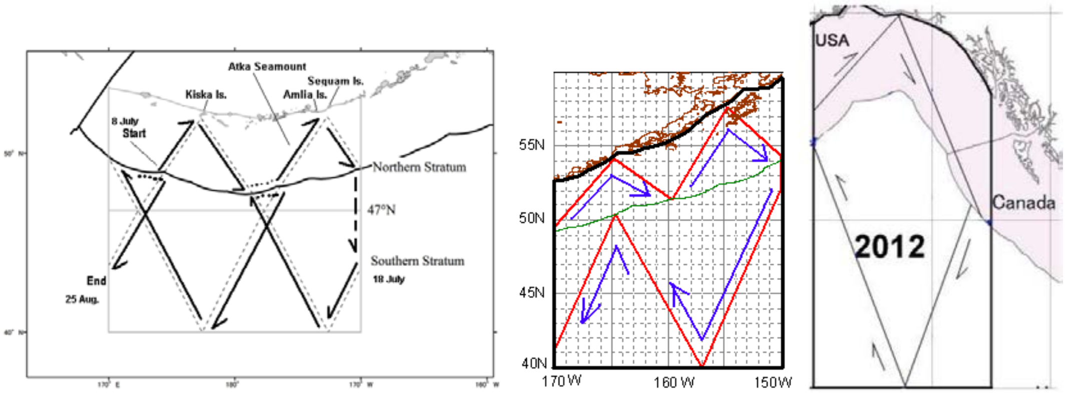

Figure2. Planned track line for 2010-2012 IWC-POWER surveys. Arrows show survey order. Left panel is for 2010, middle panel is for 2011 and right panel is for 2012.

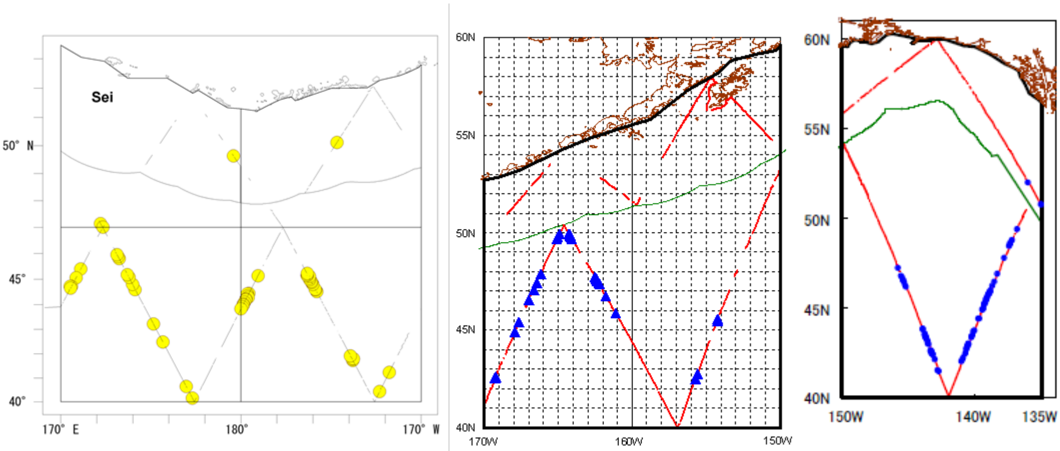

Figure 3. Plot of actually surveyed track line and position of primary sightings of the sei whales during 2010-2012 IWC-POWER surveys.

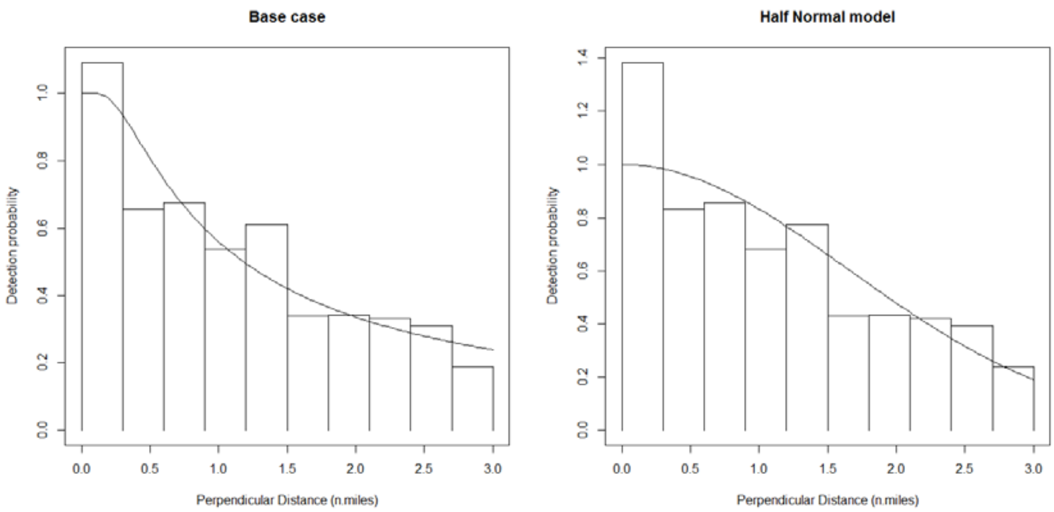

Figure 4. Plot of the estimated detection function and fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line for base case (left panel) and sensitivity 2 (right panel).

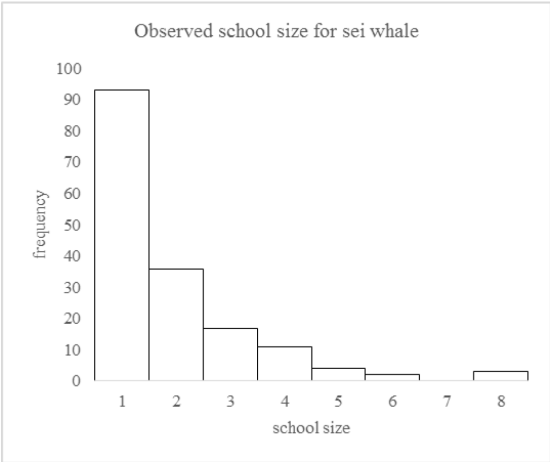

Figure 5. Frequency of observed school size of sei whales during the 2010-2012 IWC-POWER surveys. Only sightings whose school size was confirmed are used.

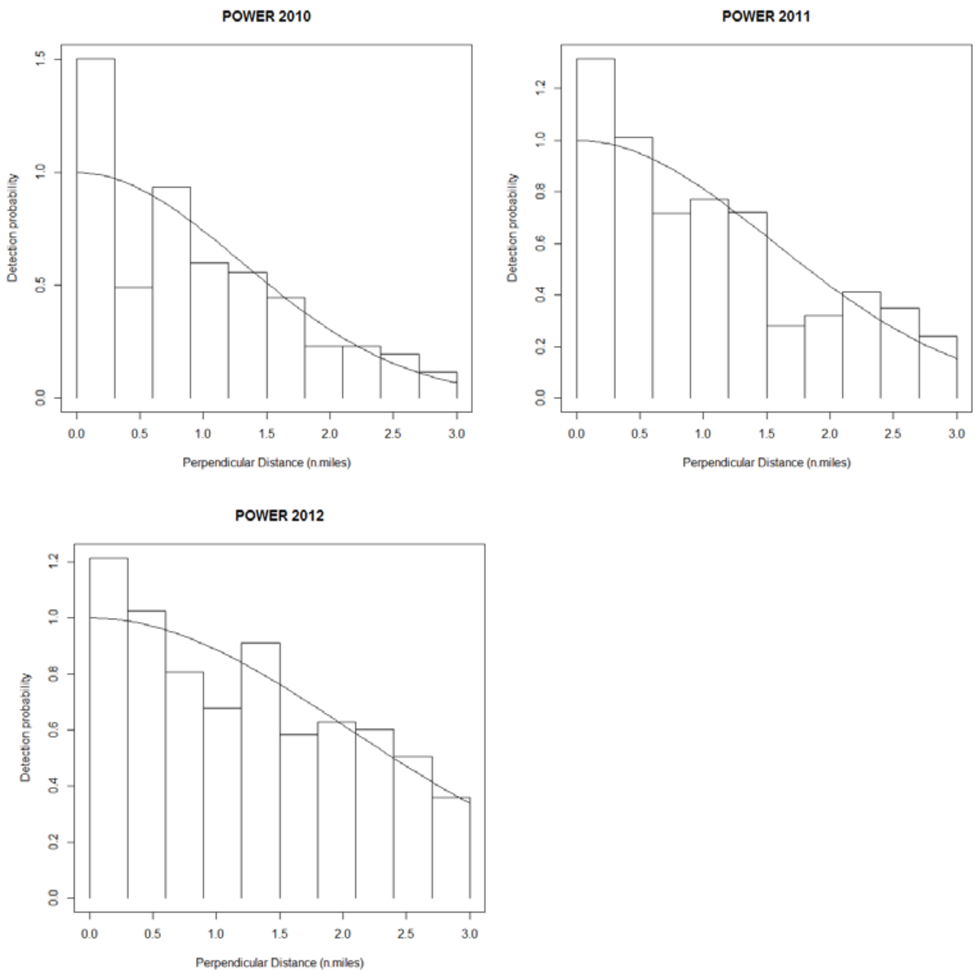

Figure 6. Plot of the estimated detection function and fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line for each survey in sensitivity 2. Left upper panel is for 2010, right panel is for 2011 and left lower panel is for 2012.

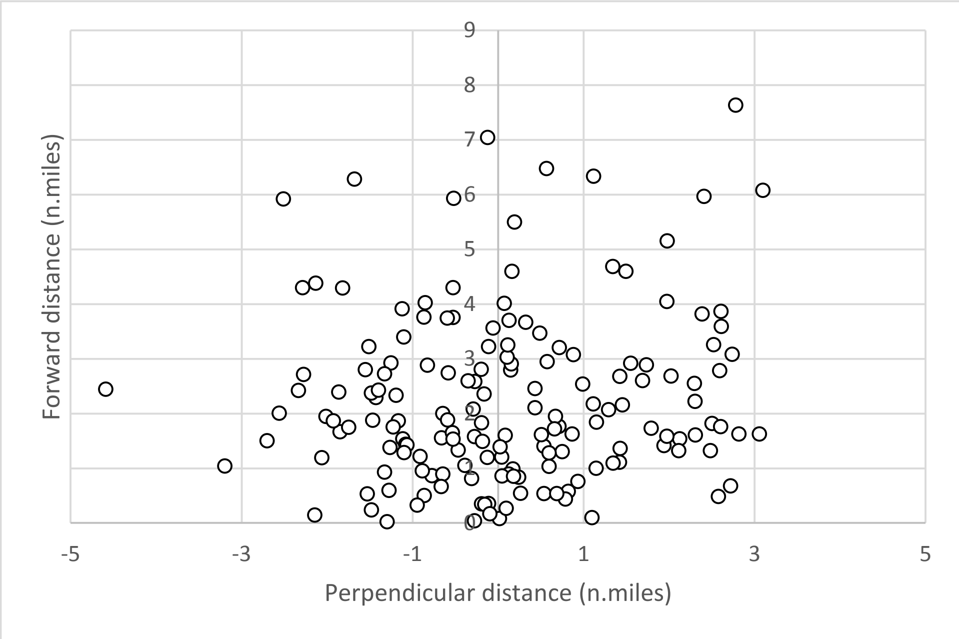

Figure 7. Distribution of perpendicular and forward distances for sei whale primary sightings during the 2010-2012 IWC-POWER surveys.