Preliminary estimation of North Pacific sei whale abundance based on the 2011 IWC-POWER sighting survey data

TAKASHI HAKAMADA[1], KOJI MATSUOKA[1] and TOSHIHIDE KITAKADO[2]

[1]*The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055*
[2]*Tokyo University of Marine Science and Technology, 5-7, Konan 4, Minato-ku, Tokyo 108-8477, Japan*
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 2011 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 estimate in the eastern North Pacific (north of 40^{o}N, south of Alaskan Peninsula, between 170^{o}W and 150^{o}W), from July to August was 6,587 (CV=0.420) for the base case scenario. Abundance estimate ranged between 6,162 (CV=0.417) and 7,403 (CV=0.550) 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^{o}E, north of 35^{o}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. Preliminary abundance estimates of sei whales were made based on the sighting data collected during the 2010 IWC-POWER survey. An abundance estimate of 9,286 whales (CV=0.35) was obtained for an area in the central North Pacific comprised north of 40°N, south of Aleutian Islands, and between 170°E and 170°W) (Hakamada *et al*, 2011).

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

An *in-depth assessment* of this species in the North Pacific is being planned by the IWC/SC to start in 2013 (IWC, 2011b). 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, 2011b).

This paper reports preliminary abundance estimates of the sei whale based on the 2011 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 Alaskan Peninsula, and between 170°W and 150°W. The survey area was divided into northern and southern strata by the EEZ line of the USA (Figure 1). The area sizes of the northern and southern strata were 193,560n.miles^2 and 569,167n.miles^2, respectively. They were calculated using Arc GIS (ver. 9.31).

Brief narrative

The 2011 IWC-POWER survey was conducted in the period 11 July – 8 September 2011. The ship departed Shimonoseki on 11 July and started the sighting surveys on 21 July at 170º00’W. It completed the sighting surveys in the northern stratum on 31 July at 150º00’W and started the sighting survey in the southern stratum on 1 August. It completed the sighting surveys on 31 August at 170º00’W and arrived at Hakodate on 8 September (Matsuoka *et al*., 2012).

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*. (2012).

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 2. Observed distance and angles were corrected using data obtained from the Angle and Distance Experiment. All sighting data obtained were validated by the authors.

Survey mode

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*., 2012).

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 and detection functions, sensitivity is conducted as following.

1. Abundance is estimated without stratification.
2. Alternative detection function is applied.
3. Width of perpendicular distance intervals is changed from 0.3 to 0.6.

RESULTS

Sighting effort

Survey order in the research area is shown in Figure 2. The searching effort was 723.8 n. miles and 1,674.0 n.miles in the northern and southern strata, respectively (Table 1). Survey coverage was higher in the southern stratum (78%) than in the northern stratum (58%) because poor weather conditions were found in the northern stratum (Matsuoka *et al*., 2012).

Sightings

Plots for searching effort and primary sightings of the sei whales are shown in Figure 3. There were 37 primary sightings (72 individuals) in the research area. Sei whales were distributed in the southern stratum mainly between 160°W and 170°W.

Abundance estimate

Table 1a shows the abundance estimates for the base case scenario and for the scenarios of the sensitivity test. 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 4 shows the the plot of the detection function for the base case scenario. Abundance estimate of sei whale is 6,587 (CV=0.420) for the base case scenario (Table 1).

Sensitivity Analysis

Without stratification

Table 1b shows the abundance estimates for the sensitivity 1. For this sensitivity, encounter rate and its CV is calculated. Encounter rate is slightly smaller than the base case scenario. ESW and estimated mean school size are common with the base case scenario. Abundance estimate is 6,162 (CV=0.417) 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 was higher than the base case, therefore the use of half-normal model was preferable to estimate ESW. Figure 5 shows the plot of the detection function for sensitivity 2. Abundance estimate is 7,403 (CV=0.550) for the sensitivity 2.

Width of perpendicular changes from 0.3 to 0.6

Table 1d shows the abundance estimates for the sensitivity 3. ESW estimate and its CV would not change substantially from the base case. Figure 6 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 6,572 (CV=0.421) for the sensitivity 3.

DISCUSSION

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 assumption on stratification and detection functions examined in this study. As far as using data used in this analysis, further sensitivity test would not be expected to change abundance estimate substantially. As mentioned later, investigating detection function using covariates such as Beaufort and pooling data with sighting data collected in other year, can refine abundances estimate of the sei whales.

Sightings in northern stratum

No primary sightings were made in the northern stratum. It is possible that sei whales did not migrate into the northern stratum during the survey period because of the low Sea Surface Temperature (SST) observed there. The range of the SST in the sighting positions of sei whales was from 11.4 °C to 22.4 °C (Matsuoka *et al*.,2012). The range of SST in the northern stratum was different (6.9°C-13.9°C) (Matsuoka *pers. commn.*). A survey in a later period in the northern stratum probably had found sei whales might. It is suggested the use of spatial modeling (e.g. Konishi *et al*, 2009; Murase *et al*., 2009) to investigate relationship between environmental, geographical and seasonal covariates and the density of this species. In addition smaller survey coverage in the northern stratum could have reduced the possibility of primary sighting of the sei whales in that stratum.

Abundance estimate 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°E, north of 35°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 central North Pacific (north of 40°N, south of Aleutian Islands, between 170°E and 170°W) was 9,286 (CV=0.35) derived from 2010 IWC-POWER survey data (Hakamada *et al*., 2011). Kanda *et al*. (2009; 2011) suggested that the open water of the North Pacific was mainly occupied by the individuals from a single stock of the sei whales. Under this assumption and the assumption that there is no correlations among the estimates, the combined abundance estimates was 21,278 (CV=0.243) 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 with covariate such as Beaufort state, year, strata (north/south) will be examined. Also an examination of stratification of data to estimate mean school size will be carried out.

ACKNOWLEDGEMENT

We thank Hiroshi Hatanaka and Luis A. Pastene for their valuable comment to improve this manuscript. We also thank Steering Group of the IWC-POWER (Hidehiro Kato (Convener), Yong-Rock An, Robert Brownell, Phillip Clapham, Paul Ensor, Tomio Miyashita, Hiroto Murase, Luis Pastene and Lars Walløe) for their assistance on planning and execution of the cruise. We also thank the captain, crews and international researchers onboard the *Yushin-Maru No.3* for their hard work during the survey.

REFERENCES

Branch, T. A. and Butterworth, D. S. 2001. Southern Hemisphere minke whales: standardised abundance estimates from the 1978/79 to 1997/98 IDCR-SOWER surveys. *J. Cetacean Res. Manage.* 3:143-174.

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.

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, May 2011. Tromsø, Norway. (unpublished) 7pp.

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. 2011a. Report of the Workshop on Planning for an IWC co-ordinated North Pacific research cruise programme. Paper SC/63/Rep5 submitted to IWC Scientific Committee. May, 2011. Tromsø, Norway. (unpublished) 33p.

International Whaling Commission. 2011b. Report of the Scientific Committee. Annex G Report of Sub-Committee on In-depth Assessment.

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. Tromsø, Norway. (unpublished) 4pp

Konishi, K., Kiwada, H., Matsuoka, K., Hakamada, T. and Tamura, T. 2009. Density prediction modeling and mapping of common minke, sei and Bryde's whales distribution in the western North Pacific using JARPN II (2000-2007) data set. Paper Sc/J09/JR19 submitted to the Expert Workshop to review results of JARPN II. (unpublished) 20pp.

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., 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. (unpublished).

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.

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 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	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
Southern	569,167	36.7	1,674.0	2.191	0.378	1.842	0.144	1.946	0.114	0.012	6,587	0.420	2,987	14,522

b. Abundance was estimated without stratification.

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
Survey area	762,727	36.7	2,397.8	1.529	0.375	1.842	0.144	1.946	0.114	0.008	6,162	0.417	2,810	13,513

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	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
Southern	569,167	36.7	1,674.0	2.191	0.378	1.401	0.387	1.663	0.099	0.013	7,403	0.550	2,702	20,278

d. Width of perpendicular distance intervals was changed from 0.3 to 0.6.

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
Northern	193,560	0.0	723.8	0.000	0.000	-	-	-	-	0.000	0	-	-	-
Southern	569,167	36.7	1,674.0	2.191	0.378	1.846	0.147	1.946	0.114	0.012	6,572	0.421	2,975	14,514

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
-0.285	0.344	-0.828	0.207

Table 3. AIC estimate for each model of detection functions for base case.

Model	AIC
Half Normal	**162.6**
Hazard Rate	**163.4**

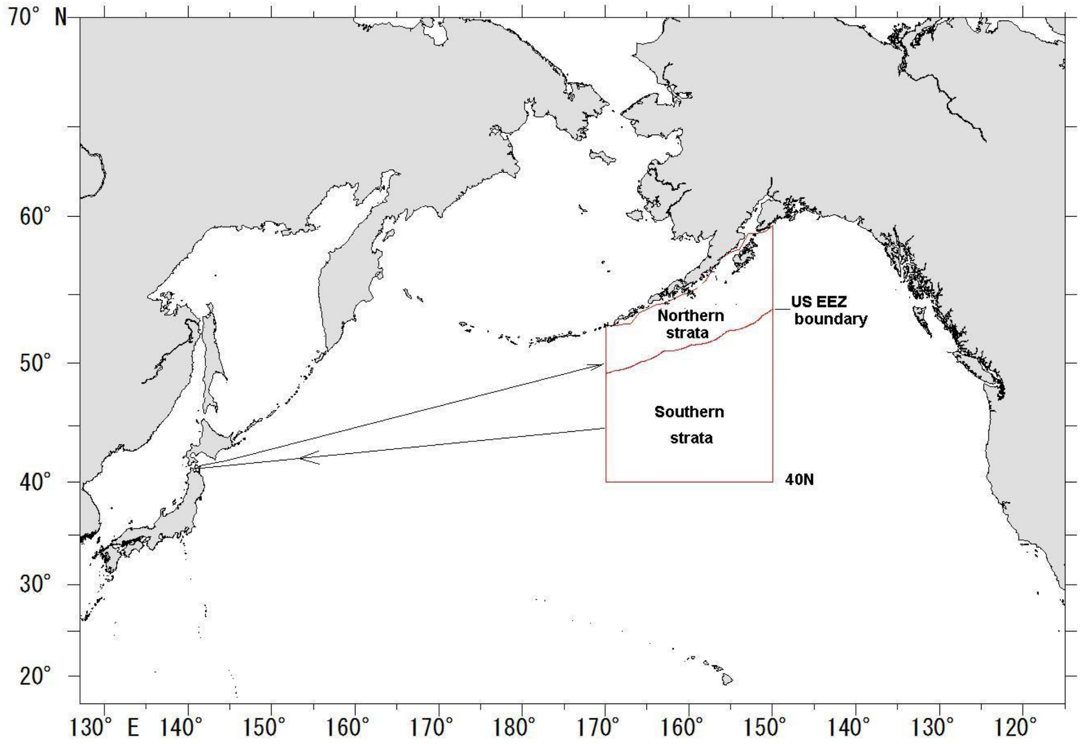

Figure 1. Research area of the 2011 IWC-POWER cruise. The area was divided into northern and southern strata by the US EEZ boundary line.

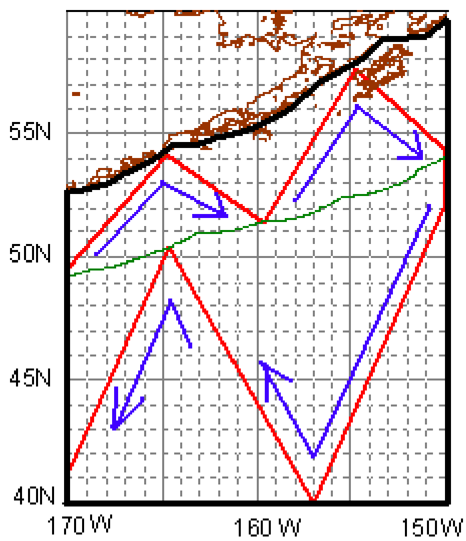

Figure 2. Planned cruise track (red line) and survey order (blue arrows). Survey strared at 170°W and completed at 170°W. The survey area was divided into northern and southern strata by the US EEZ boundary (green line).

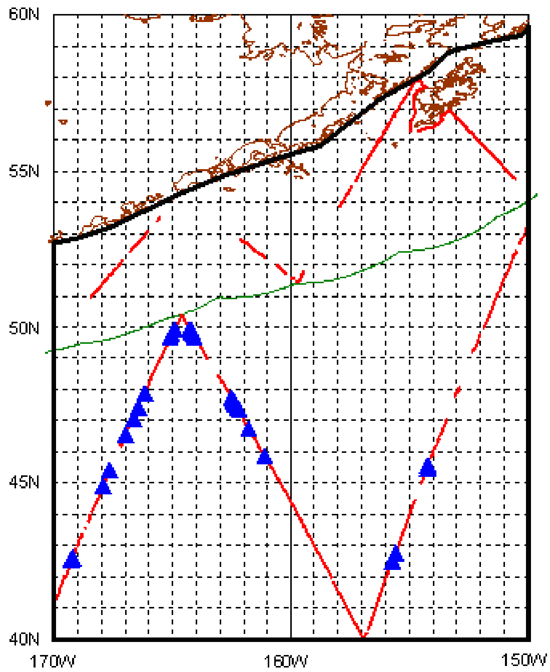

Figure 3. Plot of actual survey track (red line) and positions of primary sightings of the sei whales (triangle) during the 2011 IWC-POWER survey.

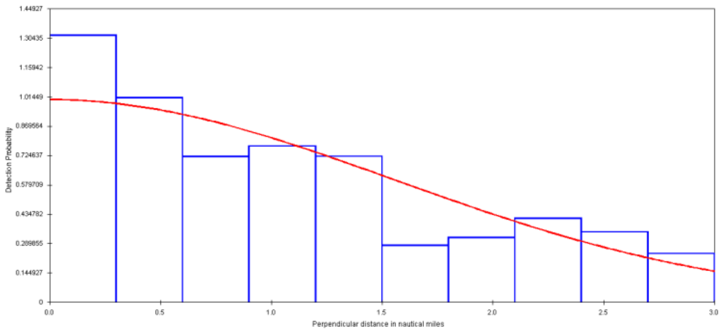

Figure 4. Plot of the estimated detection function fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line for base case scenario.

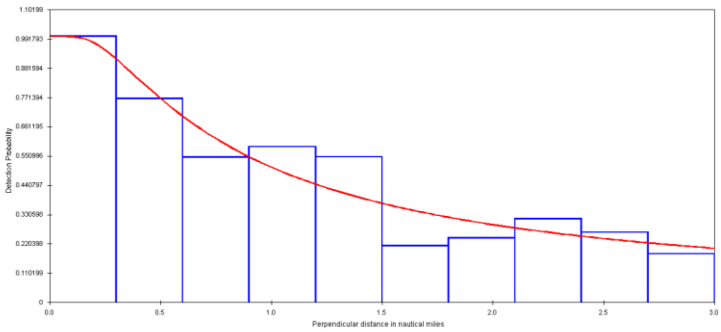

Figure 5. Plot of the estimated detection function fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line, for sensitivity 2 (hazard rate model was used).

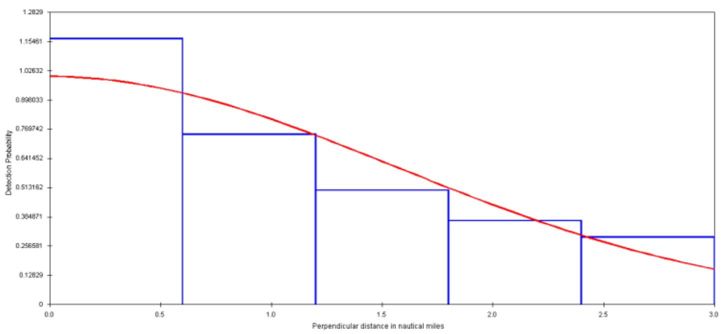

Figure 6. Plot of the estimated detection function fitted to the number of schools as a function of perpendicular distance (n. miles) from the track line, for sensitivity 3 (width of interval was doubled).