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Sighting survey procedures for abundance estimates of large whales in JARPA and JARPAII, and results for Antarctic minke whales

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ABSTRACT

This paper provides an overview of the sighting surveys and analytical procedures for abundance estimates of large baleen whales under the non-lethal component of JARPA/JARPAII. The paper also summarizes the abundance estimates and abundance trends for Antarctic minke whales based on sighting data collected by JARPA and JARPAII surveys between 1989/90 and 2008/09.

INTRODUCTION

There are two main sources of sighting data for abundance estimates of large whales in the Antarctic. One is the International Decade for Cetacean Research (IDCR)/Southern Ocean Whale and Ecosystem Research (SOWER) program (Matsuoka *et al.*, 2003), and the other is the sighting surveys conducted as part of the non-lethal component of the Japanese Whale Research Programs in the Antarctic (JARPA, JARPAII and NEWREP-A).

One of the features of the sighting surveys under the Japanese whale research programs is that, unlike the IDCR/SOWER program, surveys are repeated in the same area and in the same months every second austral summer season, over a long period. Therefore, those sighting surveys facilitate both estimations of abundance trends and the extent of inter-year variability in local abundance in a particular area.

The objective of this paper was to outline the sighting procedures adopted during JARPA/JARPAII and the analytical procedures used to estimate whale abundance and abundance trends from sighting data. A summary of the results for Antarctic minke whales based on the JARPA and JARPAII sighting data is also presented. Surveys and analytical procedures used took into consideration the recommendations from the Scientific Committee (SC) of the International Whaling Commission (IWC) (see IWC 2008, pp. 349).

MATERIALS AND METHODS

Survey area and geographical stratification

The main research areas were IWC Management Areas IV (70°E–130°E) and V (130°E–170°W) until 1994/95. Since 1995/96 the sighting surveys also covered Areas IIIE (35°E–70°E) and VIW (170°W–145°W), south of 60°S. Each of these Areas was divided into smaller strata as shown in Figure 1. The surveys were conducted from the end of December to March in each austral summer season, with the surveys in Areas IV and V concentrated in January and February in most years, which coincides with the peak period for migration of Antarctic minke whales to their Antarctic feeding grounds (Kasamatsu *et al.*, 1996). The starting and ending dates in JARPA/JARPAII surveys are shown in Figure 2.

Research vessels

JARPA/JARPAII comprised a combination of sighting and sampling surveys, and several specialized vessels participated in the surveys as Sighting Sampling Vessels (SSVs) and Sighting Vessels (SVs). *Kyo-Maru No. 1*, *Toshi-Maru No. 25* and *Toshi-Maru No. 18* operated from 1989/90. *Kyoshin-Maru No. 2* operated since 1995/96. *Yushin-Maru* operated since the 1998/1999 survey as the replacement of *Toshi-Maru No. 18*. *Yushin-Maru No. 2* operated since the 2001/2002 survey as the replacement of *Toshi-Maru No. 25*. *Yushin-Maru No. 3* operated since the 2007/2008 survey as the replacement of *Kyo-Maru No. 1*. *Kaiko-Maru* operated from 2005/06 to 2008/09 surveys. Details of the vessels were provided in Matsuoka *et al.* (2011) and Hakamada *et al.* (2013).

Line transect method

Tracklines are designed randomly or systematically so that they are independent from distribution of the objects (e.g., whales). Tracklines consist of parallel lines or zigzag lines as shown in Figure 3. In shipboard or aerial

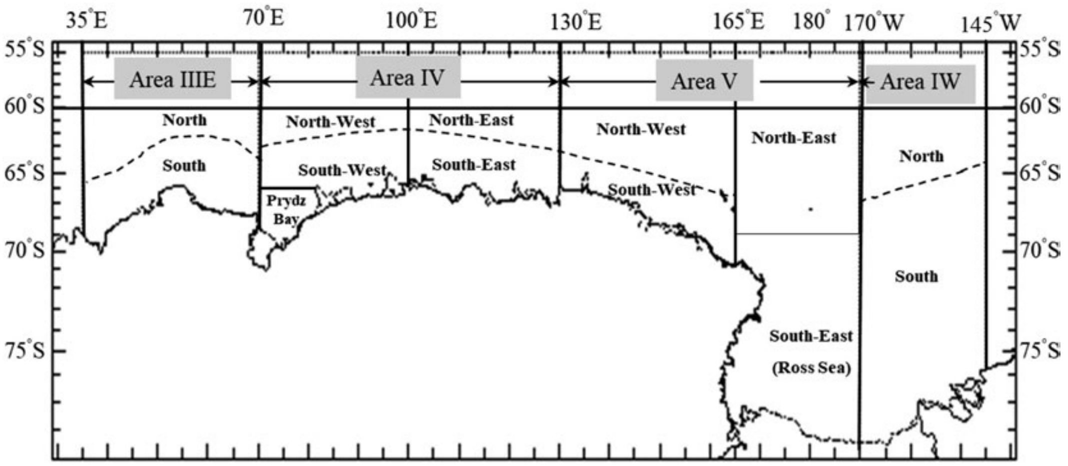

Figure 1. Research area for the sighting surveys under the JARPA/JARPAII. Dotted lines indicate 45n.mile lines from the ice edge lines.

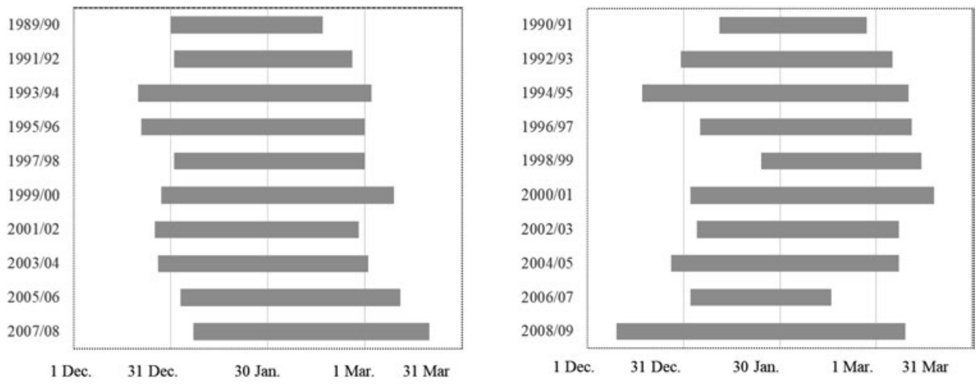

Figure 2. Starting and ending dates of JARPA/JARPAII sighting surveys for abundance estimation of large whales in Areas IV and V.

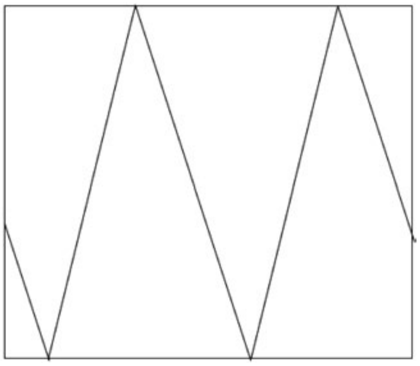

Figure 3. Example of zigzag lines used during a line transect survey.

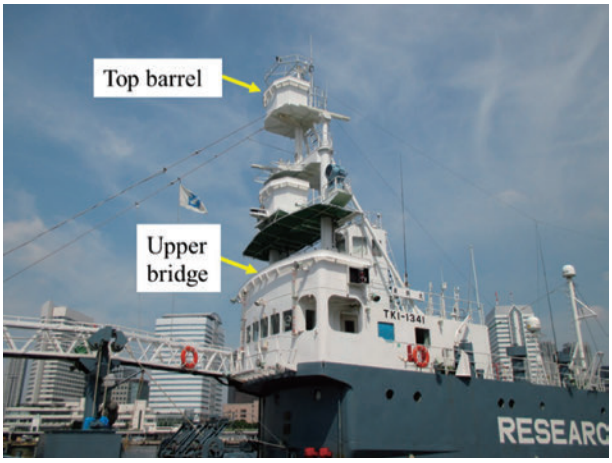

Figure 4. Platforms of observation of whale schools in specialized vessels used during JARPA and JARPAII.

surveys, there is significant cost for travelling from one transect to another. In such circumstance, zigzag lines (or saw-tooth line) are used to save costs (Buckland *et al.*, 2015).

During the line transect survey, observers on the research vessels search for whale schools from the platforms on the research vessels (Figure 4). When a whale school is detected, the distance between the school and the observer (r), and the angle from the track line (ϑ) are recorded (Figure 5). Position of the research vessel and time of the detection are also recorded.

After the detection of a whale school, in principle, the vessels approach the school to confirm the species and school size. Activities of the research vessel are recorded to calculate distance and time on-effort. Weather (e.g., air temperature, sea surface temperature, Beaufort scale, visibility etc.) are recorded every hour during sighting surveys to record the weather condition that could potentially affect the detectability.

Trackline design and sighting procedures in JARPA/JARPAII

Survey design and procedures used under JARPA and JARPAII fundamentally followed the 'Requirements and Guidelines for Conducting Surveys and Analyzing Data within the Revised Management Scheme (RMS)' (IWC, 2012). More details on trackline design and sighting procedures in JARPA and JARPAII are found in Hakamada *et al.* (2013) and Hakamada and Matsuoka (2014a). The Sighting Vessels (SVs) conducted the surveys in closing mode (SVC) up to and including 1996/97. Surveys in passing mode (SVP) started in 1997/98 because previous studies (Butterworth and McQuaid, 1986; Haw, 1991) had shown potential effect on abundance estimate of the survey mode.

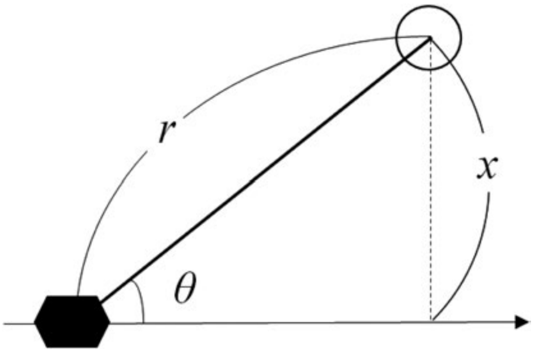

Figure 5. Illustration of the detection of whales from observers on research vessels. Black hexagon indicates a research vessel, white circle indicates a whale school, horizontal line indicates a trackline, *r* is distance to the whale school from the research vessel, ϑ is an angle from the track line and *x* is perpendicular distance from the trackline.

The trackline was designed to cover the whole research area and the design was consistent throughout the JARPA and JARPAII surveys. The starting points were selected at random from 1n.mile intervals on lines of longitude. Trackline way points (where the trackline changes direction) were systematically allocated on the ice edge and on the locus of points 45n.miles from that edge in southern strata, and on this locus and the 60°S latitude line in the northern strata.

There were two modifications in trackline design in JARPAII surveys in relation to the previous JARPA, which responded to recommendations from the IWC SC to improve abundance estimation. One is that a saw-tooth type trackline for the southern strata was not used. The other is that the northern and southern strata were surveyed in the same period (Nishiwaki *et al.*, 2014). As noted above, JARPA/JARPAII comprised a combination of sighting and sampling surveys using SSVs and SVs. SSVs and SVs surveyed the area independently. An example plot of sightings on tracklines actually surveyed is shown in Figure 6.

Smearing parameters and truncation distance

The data recorded for radial distance and angle are smeared using the Method II of Buckland and Anganuzzi (1988). The smearing parameter values were estimated for Antarctic minke (Hakamada *et al.*, 2013; Hakamada and Matsuoka, 2014a) whales. After the smearing, the perpendicular distances are truncated at 1.5n.miles for Antarctic minke whales. This treatment is the same as

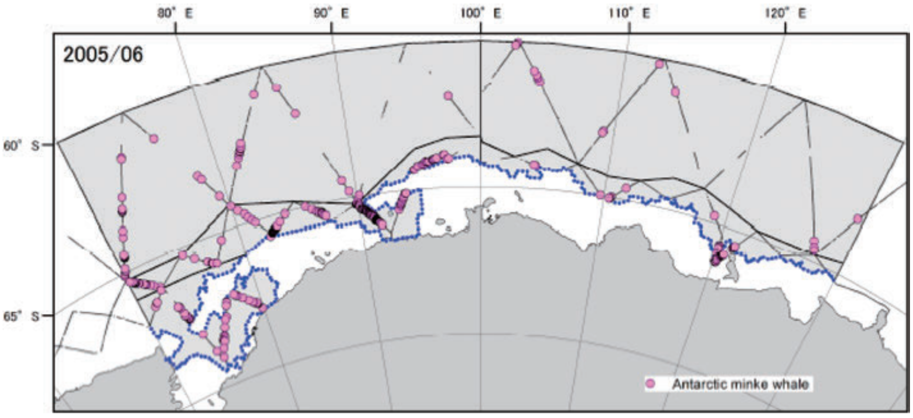

Figure 6. Primary searching effort (thin lines) and associated primary sightings of Antarctic minke whales (pink circles) in Area IV together with the ice edge (dotted blue line) in the 2005/06 JARPAII survey.

the one employed in abundance estimation from the IWC IDCR/SOWER surveys (Branch and Butterworth, 2001a; Branch, 2006). The number of sightings remaining after smearing and truncation includes sightings with both confirmed and unconfirmed school sizes.

Correction of observed angle and distance

To be able to correct for bias in distance and angle estimation, a distance and angle estimation experiment was conducted on each vessel each year (Nishiwaki *et al.*, 2014). The correction factors estimated in Matsuoka *et al.* (2011) and Hakamada and Matsuoka (2014b) were used for these analyses. More details of the methodology for the estimation of the correction factors are found in Burt and Stahl (2000).

Abundance estimation

The methodology for abundance estimation used in this study is described by Branch and Butterworth (2001a; 2001b) and Branch (2006), and has been termed the 'standard methodology' in the IWC SC terminology. The program DISTANCE ver. 6.0 (Thomas *et al.*, 2010) was used to provide abundance estimates corresponding to each trackline. The following equation was used for abundance estimation in each stratum:

$$P_i = \frac{AE(s)n_i}{2wL_i} \tag{1}$$

where P_i is the abundance in numbers as estimated from the i th trackline, A is the open ocean area of the stratum, $E(s)$ is the estimated mean school size, n_i is the numbers of primary sightings of schools on the i th trackline, w is the effective search half-width for schools and L_i is the primary search effort on the i th trackline.

For SSVs, the total abundance in each stratum is calculated as:

$$P = \frac{\sum_i L_i P_i}{L} \tag{2}$$

where L is sum of the L_i for each of the SSVs in the stratum.

The CV of the total abundance estimate P, is then calculated for each stratum using the equation:

$$CV(P) = \sqrt{\left\{CV\left(\frac{n}{L}\right)\right\}^2 + \{CV(E(s))\}^2 + \{CV(w)\}^2} \tag{3}$$

where n is the sum of n_i for all the SSVs. Estimation of the CV of n/L is as specified in equation (5) below.

Detection function

A hazard rate model with no adjustment terms was used for the detection function:

$$g(y) = 1 - \exp\left\{-\left(\frac{y}{a}\right)^{-b}\right\} \tag{4}$$

where y is perpendicular distance, and $a>0$ and $b\geq 1$ are parameters of the model to be estimated. It is assumed here that $g(0)=1$ (i.e. the detection probability of a school on the track line is 1). Detections with perpendicular distances of more than 1.5 n.miles were truncated when estimating effective search half-width (ESW) w. More details of this detection function are given in Buckland *et al.* (1993; 2001).

Stratification of data to estimate ESW

In line with an IWC (2008) recommendation, ESWs were estimated by stratum. In cases where the sample size was smaller than 15, the sighting data were pooled among strata to estimate the detection function in line with other IWC (2008) recommendations. In such cases, data were pooled across West-East strata because sighting conditions and school size distributions are expected to be more similar than for North-South strata. In instances where there were less than 15 detections in southern/northern strata, data were aggregated over the whole of each Area.

Estimated mean school size

In line with an IWC (2008) recommendation, mean school sizes were estimated by stratum. Only the primary sightings for which the school size was confirmed were used for the estimation. The method for estimation of the mean school size described in Buckland *et al.* (1993; 2001) was used. More specifically, regressions of the log of observed school size against $f(y)$ was conducted for this purpose. If the regression coefficient was not significant at the 15% level, the observed mean school size for sightings within the truncated distance was substituted instead in the equation (1). If the consequent mean school size estimated was less than 1, then the observed mean school size was substituted instead in the equation (1) even if the regression coefficient was statistically significant at this 15% level. Similarly to the analyses for the IDCR/SOWER data (Branch and Butterworth, 2001a; Branch 2006), for SVP the mean school size estimated from SVC data was used instead of estimating this from SVP data, for which school size estimates are known to be negatively biased as a result of not approaching all schools closely (Butterworth and McQuaid, 1986).

Combined encounter rate taking account of correlation among two or three SSV track lines

The survey by the SSVs comprised two or three parallel tracklines. There may be a positive correlation in the encounter rates along these lines, which would cause a negative bias in the estimate of the CV of the overall encounter rate if the results from each vessel were assumed to be independent. To take this possible covariance into account, the CV of the encounter rate when combined over the two or three SSVs with their parallel tracklines was estimated as:

$$CV\left(\frac{n}{L}\right)=\frac{\sqrt{Var\left(\frac{n}{L}\right)}}{\frac{n}{L}} \tag{5}$$

where

$$n_i=\sum_j n_{i,j},\ L_i=\sum_j L_{i,j}$$

with $n_{i,j}$ and $L_{i,j}$ being the number of primary sightings of minke whale schools and the primary effort on the *i* th transect as surveyed on the *j* th tracklines. The variance of (n/L) is calculated as:

$$Var\left(\frac{n}{L}\right)=\sum_{i=1}^{k}\frac{1}{(k-1)}\left(\frac{L_i}{L}\right)^2\left(\frac{n_i}{L_i}-\frac{n}{L}\right)^2 \tag{6}$$

where *k* is the number of transects on each trackline.

Estimating abundance trend

In order to examine the potential effect of survey timing and that of survey mode, the four models shown below were considered.

$$\text{Model i)}\ \log\{P_{obs}(y,a)\}=\log\{p_{true}(0,a)\}+\alpha y+\varepsilon_{y,a}+\eta_{y,a} \tag{7}$$

$$\text{Model ii)}\ \log\{P_{obs}(y,a)\}=\log\{p_{true}(0,a)\}+\alpha y+M+\varepsilon_{y,a}+\eta_{y,a} \tag{8}$$

$$\text{Model iii)}\ \log\{P_{obs}(y,a)\}=\log\{p_{true}(0,a)\}+\alpha y+M+T+\varepsilon_{y,a}+\eta_{y,a} \tag{9}$$

$$\text{Model iv)}\ \log\{P_{obs}(y,a)\}=\log\{p_{true}(0,a)\}+\alpha y+M+T+a*T+\varepsilon_{y,a}+\eta_{y,a} \tag{10}$$

where *y* is the year, *a* is the stratum, $P_{obs}(y,a)$ is the observed abundance estimate in stratum a and in year *y* as obtained from the line transect analyses, $P_{true}(y,a)$ is the underlying abundance (i.e. free from the effect of survey mode) which is to be estimated in year *y* and in stratum *a*, *M* is the survey mode factor, *T* is the categorical variable related to survey time as defined below, $a*T$ is an interaction between strata and survey timing, $\varepsilon_{y,a}$ is an error reflecting the sampling error of the survey abundance estimate in year *y* and stratum *a* and $\eta_{y,a}$ is a normally distributed error with mean of 0 and variance of σ^2 associated with "model error."

The middle day of the survey period in each stratum was calculated and categorized into groups as a basis to specify T. Because the estimate of trend *α* might be sensitive to the definition of T, four grouping were considered:

1) T=1: Dec 1–Jan 15, **T=2: Jan 16–31**, T=3: Feb 1–15, T=4 Feb 16–Mar15 (Grouping T1)
2) T=1: Dec 1–Jan 15, **T=2: Jan 16–Feb 15** and T=3: Feb 16–Mar 15 (Grouping T2)
3) T=1: Dec, **T=2: Jan**, T=3: Feb and T=4: Mar (Grouping T3)
4) **T=1: Dec and Jan** and T=2: Feb and Mar (Grouping T4)

The groups in bold letters were included in the intercept of the alternative models considered (i.e. the effect of those groups is set to zero in the calculations). T1–T4 were used as categorical covariates in Models iii) and iv) (equations (9) and (10)) above. The best grouping was selected by comparing the corrected AIC (AIC_c) (Sugiura, 1978; Hurvich and Tsai, 1989; 1991), which can be applied to linear models with normal errors, and is used instead of Akaike Information Criterion (AIC) (Akaike, 1973) for each model.

Correction of nominal abundance estimates and their variance-covariance matrices

Using the estimated coefficients of models i)–iv), nominal abundance estimates for each survey mode can be corrected, and the weighted average of the corrected abundance estimates for each mode were calculated. Among the weighted average of the abundance estimates, that using correction factors based on the best model is treated as 'Base case.' Further details are provided in Hakamada *et al.* (2013).

Sensitivity analyses

There are various possible sources of bias in abundance estimates and their trends, the more important of which were discussed at the IWC SC meeting in 2007 (IWC, 2008; Table 1). In order to examine their possible magnitudes, sensitivity analyses to examine robustness of abundance estimates and trend were conducted.

Table 1

List of the factors for which the sensitivity of abundance estimates and/or trends is examined. Specifications are given for both the base case and the sensitivities, with more details provided in Hakamada *et al.* (2013) and Hakamada and Matsuoka (2014a).

Sensitivity factors	Specification for the base case	Specification for sensitivities
Shoulder of detection function	Estimation by stratum, except that when sample size is less than 15, strata are pooled.	For SSVs, ESW averaged over vessels concerned was used. For SVs the detection function estimation takes account covariates.
Trackline following ice edge contours	Complete tracklines used.	(1) Exclude trackline segments along the ice edge (Option B). (2) Use only transects parallel to lines of longitude (Option C).
Abundance in gaps between northern and southern strata	Assume same density as in stratum to the north.	(1) Assume the density is 0. (2) Assume the same density as in the stratum south.
Interpolation of density in the unsurveyed area within a stratum	Estimated density assumed to apply to complete stratum for JARPA. Interpolation using GLM was used for JARPAII.	Extrapolate based on average ratio of density in the unsurveyed to surveyed area as estimated in other years with complete coverage for JARPA and JARPA II.
‘Skipping’	Assumed not to introduce bias.	Exclude the abundance estimates for years when ‘Skipping’ occurred when estimating trends.
g(0)	Assumed to equal 1.	Adjust for g(0) estimates provided by the regression model.

RESULTS

This section presents the results of abundance estimate for Antarctic minke whale.

Abundance estimate

Nominal abundance estimates by strata in Areas IIIE, IV, V and VIW in each survey mode (SSV, SVC and SVP) during JARPA/JARPAII were provided in Hakamada *et al.* (2013) and Hakamada and Matsuoka (2014a). Detection functions to estimate ESW for abundance estimation were also provided by these authors. Hakamada and Matsuoka (2014a) shows interpolated abundance estimate for strata where survey coverage was incomplete. Abundance estimates for Areas IV and V for SSV, SVC and SVP survey modes during the JARPA period to apply log-linear models (7)–(10) were referred from Hakamada *et al.* (2013).

Log-linear models to estimate abundance trend

Model i) was selected for both Areas IIIE+IV and V+VIW. These rates of increase (ROI) are 1.1% with a 95% CI of [−2.3%, 4.5%] for Area IIIE+IV and 0.6% with a 95% CI of [−2.2%, 3.3%] for Area V+VIW (Hakamada and Matsuoka, 2014a). The point estimates from the other models range from 1.1% to 4.4% for Area IIIE+IV and from −2.1% to 0.6% for Area V+VIW, so that all lie within the 95% CI for the abundance trend estimate for the model selected (Hakamada and Matsuoka, 2014a).

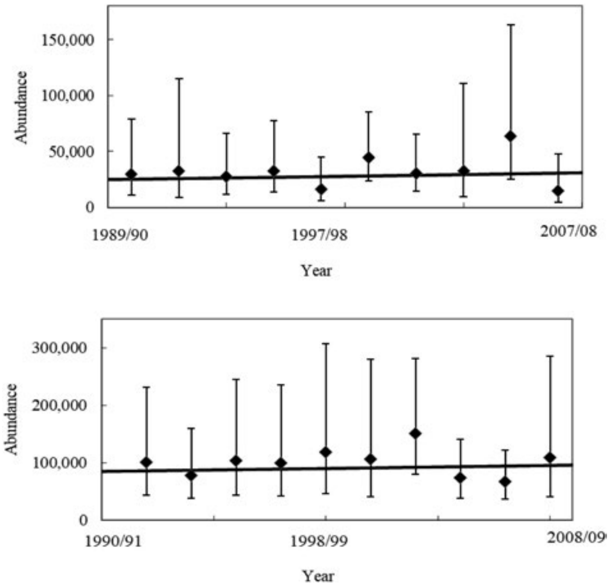

Figure 7. The base case estimates of annual abundance together with their 95% CIs are compared to exponential trend estimated by the AICc-selected model i) of equation (7) for Areas IV (upper panel) and V (lower panel) (from Hakamada and Matsuoka, 2014a).

Abundance estimates averaged over survey modes

The inverse variance weighted averages of abundance estimates over survey modes for Areas IV and V are shown in Figure 7 with their 95% CIs. The point estimates of the weighted average abundance and their CVs (taking into account model error) are shown in Table 2 for Areas IV and V. The CVs for these abundance estimates are all higher than

Table 2
The abundance estimates for the base case scenario for Area IV (left) and Area V (right) (from Hakamada and Matsuoka, 2014a).

Year	P_{WA}	CV(P_{WA})	Year	P_{WA}	CV(P_{WA})
1989/90	29,993	0.527	1990/91	100,745	0.445
1991/92	32,418	0.720	1992/93	78,919	0.371
1993/94	27,598	0.473	1994/95	104,013	0.458
1995/96	32,970	0.458	1996/97	99,680	0.461
1997/98	16,562	0.542	1998/99	118,779	0.515
1999/00	44,945	0.338	2000/01	106,769	0.524
2001/02	30,807	0.402	2002/03	151,072	0.326
2003/04	32,970	0.682	2004/05	74,030	0.336
2005/06	63,794	0.509	2006/07	67,661	0.308
2007/08	15,088	0.645	2008/09	109,173	0.523

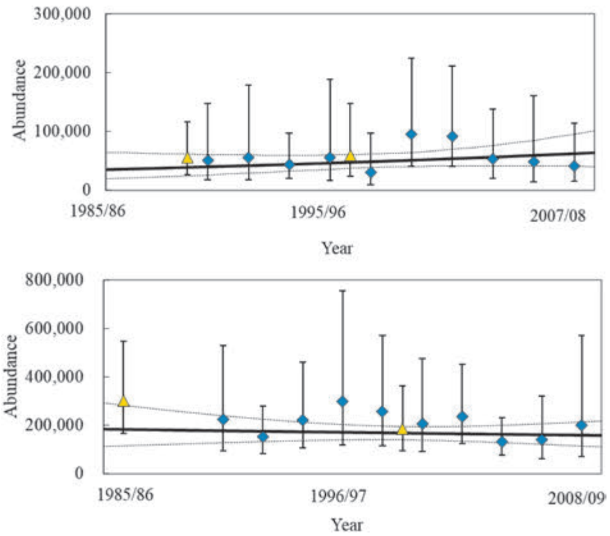

Figure 8. Same plots as for Figure 7, but with the abundance estimates and associated exponential model for the base case replaced by the corresponding g(0)-adjusted results. The IDCR/SOWER estimates for a common northern boundary for CPII and CPIII as agreed by the 2012 IWC SC meeting are shown by the yellow triangles (IWC, 2013); their confidence intervals include allowance for additional variance, as do those for the JARPA and JARPAII surveys. The dashed curves indicate the 95% CIs for the exponential model (from Hakamada and Matsuoka, 2014a).

those from a previous analysis (Hakamada *et al.*, 2006) because model error is now taken into account.

Abundance estimates and trends for the sensitivity tests

Besides the g(0) adjusted scenario, abundance estimates for Areas IV and V do not change substantially for the sensitivities excluding scenarios models other than the model i) (i.e. the best model in the base case) was selected as the best model (Hakamada *et al.*, 2013; Hakamada and Matsuoka, 2014a). These annual abundance rate of increase estimates range over [0.1%, 3.7%] for Area IIIE+IV and [−1.7%, 0.6%] for Area V+VIW for the various sensitivity tests.

When the abundance estimates are g(0)-adjusted, as would be expected the estimates increase by an average of 23,984 (88%) for Area IV and 105,906 (109%) for Area V (Figure 8). The estimates of annual rates of increase and their 95% CIs change to 2.5% [−1.3%,6.3%] for Area IV and −0.6% [−3.9%,2.6%] for Areas V, reflecting 1.5% increase for the former and 1% decrease for the latter, and slightly less precision (an increase in standard error of about 0.02) than when g(0) is assumed to be 1 because of the further variance introduced in estimating the g(0) values (Hakamada and Matsuoka, 2014a).

DISCUSSION

Comparison of the abundance estimates from JARPA and JARPAII with those based on IDCR/SOWER

As shown in Figure 8, abundance estimates for Antarctic minke whales for Areas IV and V based on JARPA and JARPAII agree with the estimates of Okamura and Kitakado (2012) based on IDCR/SOWER (Hakamada *et al.*, 2013; Hakamada and Matsuoka, 2014a).

Application of JARPA and JARPAII abundance trends

As noted earlier, one of the features of JARPA and JARPA II is that, unlike for the IDCR/SOWER program, surveys have been repeated in the same area and in the same months every second year over a long period. Therefore, the JARPA and JARPAII surveys facilitate both estimation of trends and the extent of inter-year variability in local abundance. These abundance series as well as those from IDCR/SOWER can be used to estimate abundance trends using population dynamics models which incorporate catch-at-age data and so integrate information from a number of different sources (Punt *et al.*, 2014; Mori *et al.*, 2006).

Through their use in such population models, the abundance estimates and trends derived from JARPA and JARPAII which are reported in this paper provide information to complement that available to estimate sustainable catch levels for minke whales in Areas IIIE, IV, V and VIW.

It should be noted that the abundance estimates in this study were made on the basis of geographical Areas. These estimates should be made on the basis of biological stocks definition in the future, as such information is already available (Pastene and Goto, 2016).

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