Abundance estimates and trends for Antarctic minke whales (*Balaenoptera bonaerensis*) in Antarctic Areas IV and V for the period 1989/90–2004/05

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ABSTRACT

The Japanese Whale Research Programme under Special Permit in the Antarctic (JARPA) conducted sighting surveys during the 1989/90 to 2004/05 austral summer seasons (mainly in January and February), alternating between IWC management Areas IV (70°E–130°E) and V (130°E–170°W), both south of 60°S each (split-)year. These data are analysed to obtain abundance estimates for Antarctic minke whales (*Balaenoptera bonaerensis*) in these Areas. The estimates are calculated by standard line transect analysis methods using the program DISTANCE under the assumption that $g(0) = 1$. Annual rates of increase in abundance are estimated using log-linear models. The analyses take several recommendations from the 2006 JARPA Review Meeting into consideration. Those addressed here aim to: (a) improve the point estimates of abundance and their precision; and (b) evaluate (through sensitivity tests) the effect of different factors associated with the JARPA survey on the estimates of abundance and trend. GLM models are used to adjust for different strata being surveyed at different times of year over the duration of JARPA, with model selection being based on AIC_c. Abundance estimates for Area IV range from 16,562 (CV = 0.542) in 1997/98 to 44,945 (CV = 0.338) in 1999/00, while those for Area V range from 74,144 (CV = 0.329) in 2004/05 to 151,828 (CV = 0.322) in 2002/03. Estimates of the annual rates of increase in abundance are 1.8% with a 95% CI of [–2.5%, 6.0%] for Area IV and 1.9% with a 95% CI of [–3.0%, 6.9%] for Area V. Estimates of these trends are robust to the effects of changes in survey timing, the shapes of the shoulders of detection functions, portions of survey tracklines following the ice edge, parts of the Areas in which no survey took place and poor coverage within some strata. Adjustments to allow for the $g(0)$ being less than 1 are made by the application of a regression model, developed from the results of the Okamura-Kitakado (OK) method estimate of minke whale abundance from the IDCR-SOWER surveys, which provides estimates of $g(0)$ from the statistics of the minke whale school size distribution in a stratum. With this adjustment, abundance estimates increase by an average of 32,333 (106%) for Area IV and 89,245 (86%) for Area V, while the estimates of annual rates of increase and their 95% CIs change slightly to 2.6% [–1.5%,6.9%] for Area IV and 1.6% [–3.4%,6.7%] for Area V.

KEYWORDS: ANTARCTIC; ANTARCTIC MINKE WHALE; JARPA; SIGHTING SURVEY; SURVEY-VESSEL; ABUNDANCE ESTIMATE; TREND

INTRODUCTION

Following a few seasons during which only a small number of Antarctic minke whales (*Balaenoptera bonaerensis*) were taken in the Antarctic, regular commercial harvesting of this species started in the 1971/72 austral summer season and ceased in 1986/87. During this period the average annual catch was around 6,000 whales. The Comprehensive Assessment (CA) of Antarctic minke whales by the IWC Scientific Committee (IWC-SC) took place in 1990 (IWC, 1991). Based on sighting data collected during the IWC-SC's International Decade of Cetacean Research, IDCR (e.g. Matsuoka *et al.*, 2003) from 1982/83 to 1988/89 (the second circumpolar set of surveys – CPII), the circumpolar abundance of Antarctic minke whales south of 60ºS was estimated at 761,000 (IWC, 1991) under the assumption that all schools on the trackline are seen ($g(0) = 1$). Subsequently the IWC-SC has refined the methodology used in 1990 in a number of ways, in particular to make use of models (the SPLINTR approach – Bravington and Hedley, 2012; the OK approach – Okamura and Kitakado, 2012) which allow for the possibility that $g(0) < 1$. Using results from these approaches, the IWC-SC subsequently agreed that 720,000 for CPII (1985/86–1990/91) and 515,000 for CPIII (1991/92–2003/04) represent the best available circumpolar abundance estimates for Antarctic minke whales in the areas surveyed during the IDCR and SOWER (Southern Ocean Whale and Ecosystem Research) programmes (IWC, 2013).

Another important source of sighting data for assessing the abundance and trends of this species in part of the Antarctic is the Japanese Whale Research Programme under Special Permit in the Antarctic (JARPA). Appendix 1 provides more details of JARPA and its main objectives. This Programme, which comprises a combination of sighting and lethal sampling surveys, was conducted in each of the 1987/88 to 2004/05 austral summer seasons. After two (split-)years of feasibility studies, full-scale research began in 1989/90. The JARPA Programme was designed to alternate surveys in Antarctic Areas IV and V in each of the sixteen years of the full-scale research period.

Abundance estimates of Antarctic minke whales based on JARPA data were first estimated using the so-called 'standard methodology' of Branch and Butterworth (2001), and the results (Hakamada *et al.*, 2006) were presented to the 2006 JARPA Review Meeting (JRM) (IWC, 2008a). Several recommendations to improve those estimates were made during the JRM:

(1) re-estimation of detection functions in cases where the number of schools detected is small;
(2) investigation of sensitivities to pooling across vessels to estimate effective search half width and mean school size;

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(3) investigation of a possible 'shoulder' in the detection function;

(4) variance estimation for surveys by the *Sampling and Sighting Vessels* (SSVs[3]) data taking correlation among tracklines into account;

(5) undertaking of sensitivity analyses to examine the effect of portions of the trackline following contours of the ice edge;

(6) abundance estimation taking the whale density in the gaps between the two main survey strata to be zero;

(7) extrapolation of density to the unsurveyed area within a stratum;

(8) consideration of changes over time in order in which strata were surveyed;

(9) estimation of 'additional variance'; and

(10) revision of estimates of the annual rates of increase in abundance and their CVs following suggestions (1)–(9) (IWC, 2008a).

The main objective of this paper is to produce revised estimates of abundance and trends of Antarctic minke whales based on the JARPA sighting data which take these recommendations from the JRM into account.

To facilitate understanding of the analytical procedures and the interpretation of results, details of the JARPA survey procedures are given below. Further details are provided in Appendix 2. The recommendations of the JRM are addressed here in order to: (a) improve the point estimates of abundance and their precision (1, 2, 4 and 9 above); and (b) evaluate the effect (through sensitivity tests) (3, 5, 6, 7, and 8 above) of different aspects of the JARPA survey design on estimates of abundance and trend. Analyses of the IDCR-SOWER surveys results by Okamura and Kitakado (2012) and by Bravington and Hedley (2012) have pointed to values of $g(0)$ being less than 1 for minke whales, especially so for schools of size 1, and shown that possible changes in $g(0)$ over time can be important in estimating trends in abundance. This is investigated here for the JARPA abundance estimates by the application of a regression model, developed from the results of the OK method to estimate Antarctic minke whale abundance from the IDCR/SOWER surveys, which provides estimates of $g(0)$ from the statistics of the minke whale school size distribution in a stratum.

[3]More details of how SSVs operated are given in the 'Sampling and Sighting Vessels (SSVs) and Sighting Vessels (SVs)' section below.

MATERIALS AND METHODS

Sighting survey procedure during JARPA

Survey area and geographical stratification

The main region for full scale research was Antarctic Areas IV (70°E–130°E) and Area V (130°E–170°W) south of 60°S; each of these Areas was divided into smaller strata (Fig. 1). Specifications of the stratification are given in Appendix 2. Distributions of primary sightings of minke whales and of effort in Areas IV and V for each year are shown in Fig. 2.

Monthly coverage and order of the surveys

Although the JARPA research period ranged from the end of November to March in each year, regular research in Areas IV and V was concentrated in January and February (Fig. 3), which coincides with the peak period for the migration of minke whales to their Antarctic feeding grounds (Kasamatsu *et al.*, 1996). The order in which the strata were surveyed within the research period (December–March) each year is shown in Appendix 2 for both Areas. Abundance estimates are based on single coverage of the blocks shown in Fig. 1 in the year concerned.

Trackline design

The trackline was designed to cover the whole research area and was followed consistently throughout the JARPA surveys (Fig. 2). The saw-tooth type trackline for the southern strata was chosen to allow for wide area coverage (see Appendix 2). The starting points of the trackline were selected at random from 1 n.mile intervals on lines of longitude. Trackline way points (where the trackline changes direction) were systematically allocated on the ice edge and

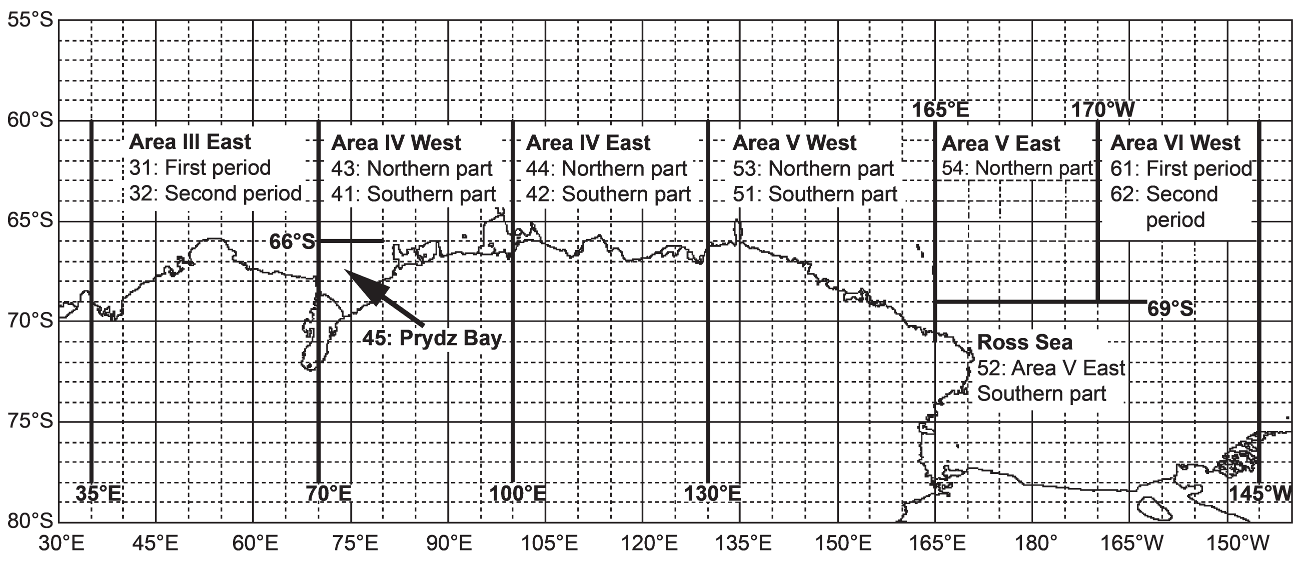

Fig. 1. Stratification of the JARPA research area.

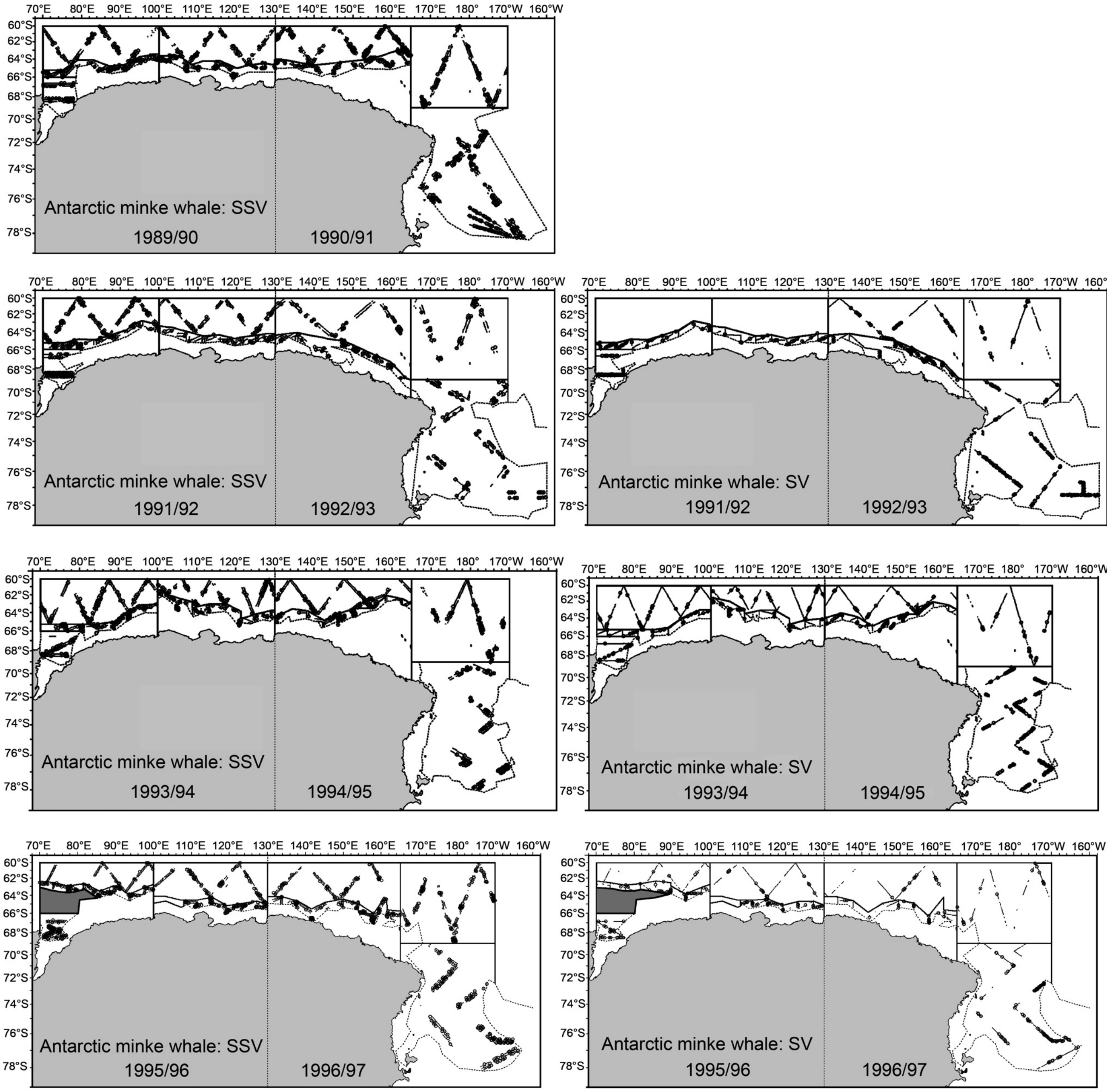

Fig. 2. For caption see next page.

on the locus of points 45 n.miles from that edge in southern strata, and on this locus and the 60°S latitude line in the northern strata. Appendix 2 provides more details.

Sampling and Sighting Vessels (SSVs) and Sighting Vessels (SVs)

JARPA comprised a combination of sighting and sampling surveys. Sighting surveys by Sampling and Sighting Vessels (SSVs) were conducted from the beginning of JARPA. Sighting Vessels (SVs) were introduced in the southern strata in 1991/92, and sighting surveys by SVs have been conducted in all strata since 1992/93. The number of SSVs involved in the survey was three, but this number was reduced to two in the southern strata for 1991/92 and for the whole survey area from 1992/93 to 1994/95 because one of three vessels acted as an SV in those years. Researchers searched for schools until a school was detected, and then proceeded to confirm its species and school size. The procedure used was identical to that of an SV in closing mode (Nishiwaki *et al.*, 2006), except that once this confirmation had been achieved, SSVs attempted to catch Antarctic minke whales targeted within the school in terms of specified procedures (Nishiwaki *et al.*, 2006).

Closing and passing mode

Fundamentally, the survey protocols of JARPA followed those of IDCR/SOWER (Nishiwaki *et al.*, 2006). All sighting surveys were conducted in closing mode until 1996/97; sighting surveys in passing mode were conducted by SVs since 1997/98. Except in 1997/98, a SV surveyed in passing mode (SVP) for the first 8 hours of the day and in closing mode (SVC) during the rest of the day. Therefore, the allocation of effort between passing mode and closing mode was systematic. By comparing abundance estimates for SSV and SVC modes to SVP (which in principle gives less biased results because it avoids the ‘end effects’ introduced by

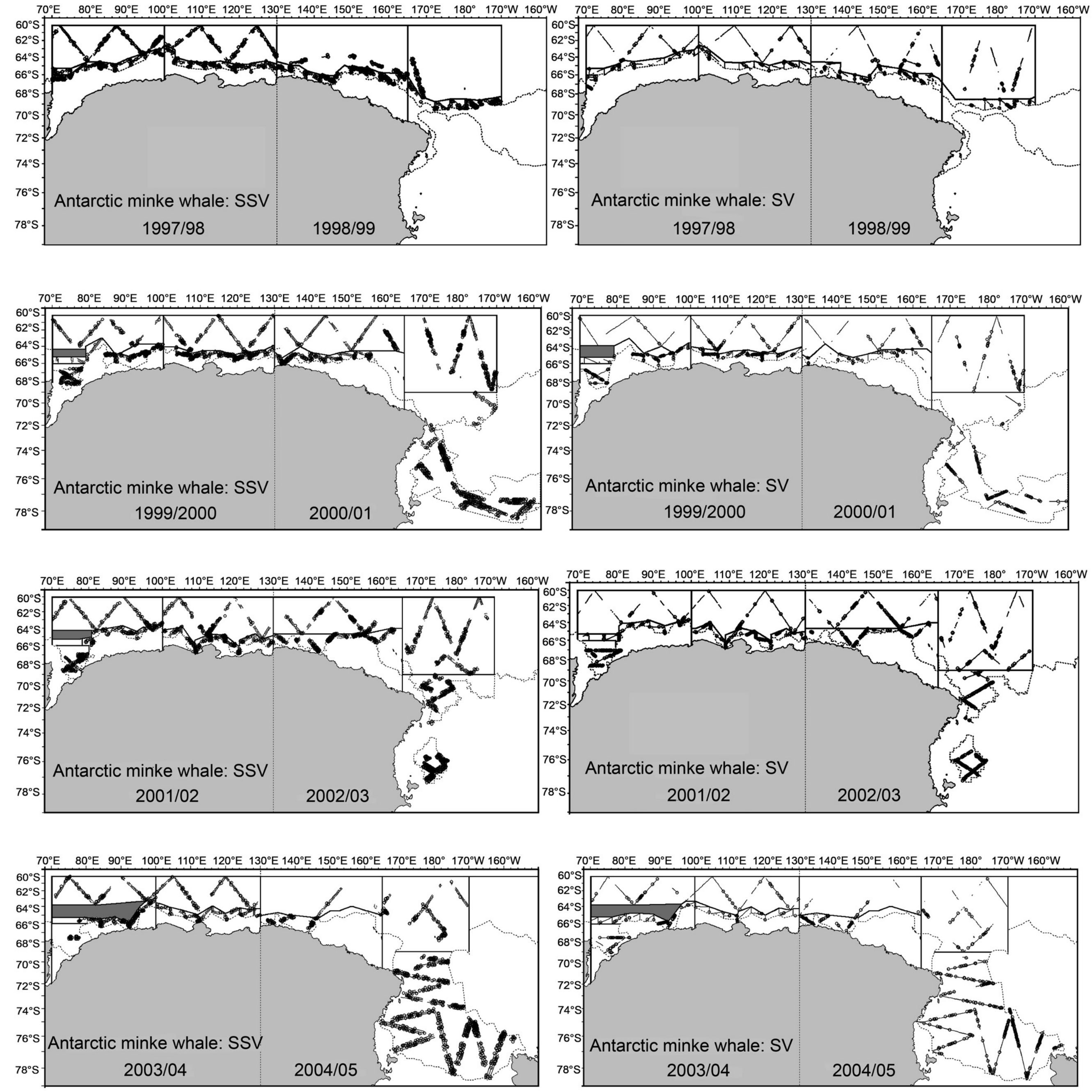

Fig. 2. Primary searching effort (thin lines) and associated primary sightings (circles) of minke whales in Areas IV and V together with the ice edge (dotted) during the 1989/90 to 2004/05 JARPA surveys The areas not surveyed in the 1995/96, 1999/00, 2001/02 and 2003/04 seasons are shaded gray. Abbreviations: SSV = Sighting and sampling vessels, SV = Dedicated sighting vessel.

closure), the effect of survey mode on the abundance estimates can be examined.

Unsurveyed areas

Some small parts of Area IV were not surveyed on four of the cruises. These 'gaps' (gray zones in Fig. 2) arose because of the southward retreat of the ice edge after survey of the more northerly of the two strata concerned had been completed, necessitating re-location of the trackline for the more southerly stratum. For the base case analysis, density in these 'gaps' is assumed to be the same as that in the stratum above. Note that such 'gaps' differ from instances where coverage of a survey was poor or incomplete because of shortage of time and/or bad weather. Selection of the potentially more serious cases to examine was guided by inspection of the cruise track plots in Fig. 2, and instances where a review by Wade (2007) suggested coverage to be 'low' in the sense of less than about 50% coverage of the intended trackline. The consequences of each of these effects for abundance estimates are addressed further below under Sensitivity Tests.

Tracklines following contours of the ice edge

At the IWC-SC meeting in 2006 (IWC, 2007), there was a discussion as to whether some lengthy intermediate transects which run nearly parallel to the ice edge might introduce bias, particularly for design-based abundance estimation approaches. The Committee consequently recommended that as a sensitivity analysis, calculations be repeated including only the transects perpendicular to the ice edge, or at least

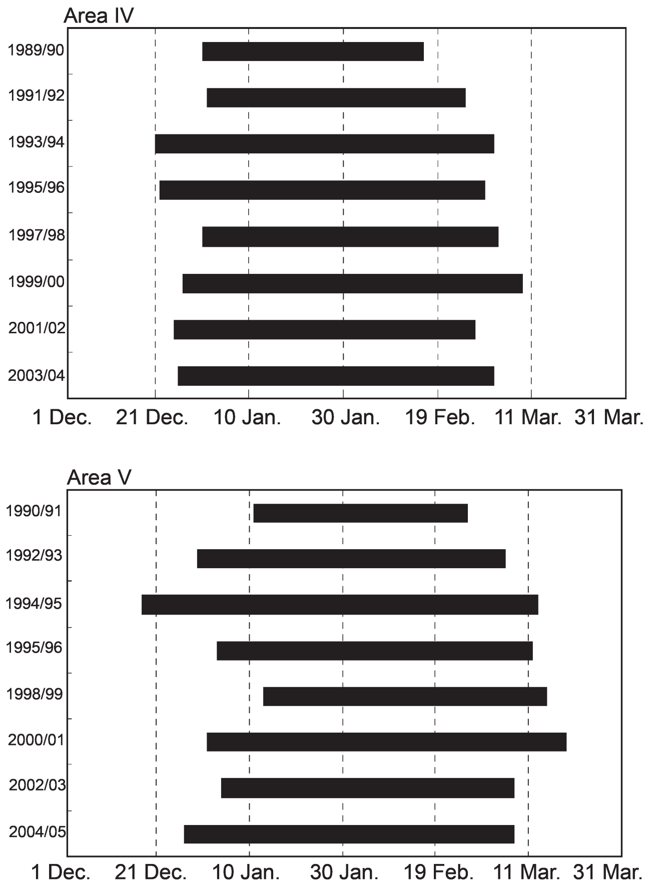

Fig. 3. Start and end dates of JARPA surveys for abundance estimation of the minke whales in Areas IV and V.

exclude segments that appeared to track the contours of the ice edge, to investigate the implications for bias in and precision of the abundance estimates (IWC, 2008b). Having some segments of the tracklines not parallel to lines of longitude could lead to an overestimate of abundance because some of these segments run virtually along the ice edge in strata where saw-tooth shape tracklines designs were used (e.g. the south-west and south-east strata in Area IV and the south-west in Area V). Details of the typical saw-tooth shape trackline are given in Appendix 2.

Pre-determined daily distance coverage

A pre-determined distance for daily movement along the research trackline was calculated so as to cover the survey area within the schedule for JARPA from the 1989/90 to the 1992/93 seasons. On days when this distance was not covered, sighting vessels covered the rest of the distance to the starting point for the next day's survey overnight. This 'skipping' approach was discontinued after the 1992/93 season; thereafter SSVs started their sighting surveys each day from the point where the survey had ended the previous day. More details are provided in Appendix 3.

Analytical procedure

Before explaining the analytical procedures applied in this paper, it is useful to list the five fundamental steps which these involve:

(1) estimate the abundance in stratum for each survey mode using the 'standard methodology' of Branch and Butterworth (2001) for IDCR-SOWER line transect data;

(2) conduct sensitivity tests to investigate whether different treatment of the sighting data might affect substantially the abundance estimates obtained in step (1);

(3) apply a model selection criterion to choose amongst different log-linear models to examine the effects of survey mode and survey timing, and to estimate abundance trends;

(4) examine the sensitivity of estimates of abundance trends by analysing the abundances estimated in step (2);

(5) estimate corrected abundances using the correction factors for the survey mode effect estimated in step (3).

Note that abundances were estimated by survey mode because it has been suggested that these may differ depending on survey mode (Haw, 1991).

Smearing

The data recorded for radial distance and angle are smeared using method II of Buckland and Anganuzzi (1988). The smearing parameter values used in this study are shown in Table 1. After smearing the perpendicular distances were truncated at 1.5 n.miles. This treatment is the same as is employed in abundance estimation from the IWC IDCR-SOWER data (Branch, 2006; Branch and Butterworth, 2001). 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 biases in distance and angle estimation, a distance and angle estimation experiment was conducted on each vessel each year (Nishiwaki *et al.*, 2006). The correction factors estimated for observed angles and distances for each vessel which are listed in Matsuoka *et al.* (2011) have been used for these analyses. More details of the methodology for estimation of these correction factors may be found in Branch and Butterworth (2001).

ABUNDANCE ESTIMATION

The methodology for abundance estimation used in this study is described by Branch and Butterworth (2001) and Branch (2006), and has been termed the 'standard methodology' in the IWC-SC. The programme DISTANCE ver5.0 (Thomas *et al.*, 2006) was used for to provide abundance estimates corresponding to each trackline[4]. 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,

[4]The reason why 'trackline' was used rather than 'vessel' here is because the location of each SSV among the two or three parallel tracklines was changed each day (see Appendix 2).

Table 1

Smearing parameters for each stratum and survey mode used in the abundance estimation. Units for angles are degrees while for radial distances the values given are proportions.

Area IV							
Year	Stratum	Angle	Distance	Angle	Distance	Angle	Distance
		SSV		SVC		SVP	
1989/90	NE	15.165	0.222	–	–	–	–
	NW	11.321	0.400	–	–	–	–
	SE	13.758	0.234	–	–	–	–
	SW	14.220	0.491	–	–	–	–
	PB	9.167	0.308	–	–	–	–
1991/92	NE	18.750	0.333	–	–	–	–
	NW	11.831	0.303	–	–	–	–
	SE	12.632	0.294	12.453	0.308	–	–
	SW	9.167	0.270	12.692	0.321	–	–
	PB	11.688	0.267	13.443	0.286	–	–
1993/94	NE	16.364	0.263	9.767	0.308	–	–
	NW	12.222	0.294	9.767	0.333	–	–
	SE	9.197	0.298	12.632	0.349	–	–
	SW	11.143	0.302	12.558	0.350	–	–
	PB	12.727	0.320	8.727	0.235	–	–
1995/96	NE	11.000	0.314	8.000	0.250	–	–
	NW	16.721	0.389	12.632	0.667	–	–
	SE	16.875	0.261	7.358	0.284	–	–
	SW	11.678	0.276	8.571	0.267	–	–
	PB	12.615	0.257	10.800	0.250	–	–
1997/98	NE	12.889	0.333	15.000	0.333	–	–
	NW	13.548	0.299	12.000	0.200	10.909	0.250
	SE	13.671	0.295	14.595	0.375	16.364	0.333
	SW	13.895	0.259	13.714	0.400	13.333	0.333
	PB	14.894	0.371	13.333	0.500	11.020	0.200
1999/00	NE	15.844	0.328	10.909	0.375	16.981	0.333
	NW	19.646	0.371	10.000	0.500	19.600	0.667
	SE	12.990	0.265	12.995	0.234	11.655	0.184
	SW	12.515	0.264	17.288	0.200	12.649	0.303
	PB	15.472	0.228	13.043	0.248	12.903	0.216
2001/02	NE	12.886	0.255	10.000	0.500	5.185	0.412
	NW	11.667	0.242	10.588	0.667	12.000	0.400
	SE	13.931	0.241	14.483	0.500	8.011	0.261
	SW	12.124	0.207	9.677	0.299	9.251	0.303
	PB	12.062	0.195	15.000	0.292	7.239	0.171
2003/04	NE	12.245	0.224	8.571	0.500	12.000	0.333
	NW	12.212	0.189	8.571	0.667	6.923	0.250
	SE	14.805	0.287	13.333	0.200	13.043	0.400
	SW	11.235	0.183	12.857	0.667	7.021	0.193
	PB	14.286	0.273	8.571	0.500	6.122	0.267

Area V							
Year	Stratum	Angle	Distance	Angle	Distance	Angle	Distance
		SSV		SVC		SVP	
1990/91	NE	12.727	0.310	–	–	–	–
	NW	10.638	0.209	–	–	–	–
	SE	11.150	0.249	–	–	–	–
	SW	15.215	0.280	–	–	–	–
1992/93	NE	16.216	0.421	22.667	0.400	–	–
	NW	11.000	0.280	11.538	0.385	–	–
	SE	12.558	0.311	9.070	0.215	–	–
	SW	10.000	0.318	11.186	0.207	–	–
1994/95	NE	15.484	0.286	13.846	0.333	–	–
	NW	13.846	0.202	13.953	0.286	–	–
	SE	14.498	0.248	13.200	0.226	–	–
	SW	15.349	0.250	10.857	0.316	–	–
1996/97	NE	19.459	0.286	12.632	0.333	–	–
	NW	13.200	0.250	20.000	0.333	–	–
	SE	12.750	0.255	10.169	0.278	–	–
	SW	10.588	0.309	11.020	0.300	–	–
1998/99	NE	17.064	0.304	16.364	0.545	–	–
	NW	15.152	0.259	16.271	0.267	16.364	0.280
	SE	16.239	0.250	12.353	0.286	12.000	0.263
	SW	15.565	0.232	10.957	0.269	11.269	0.280
2000/01	NE	15.488	0.261	6.593	0.381	7.119	0.267
	NW	14.336	0.264	9.474	0.273	8.571	0.273
	SE	11.679	0.230	6.067	0.190	7.003	0.190
	SW	14.836	0.225	7.674	0.400	8.462	0.357
2002/03	NE	6.250	0.126	15.789	0.286	12.527	0.355
	NW	5.797	0.188	8.571	0.400	9.050	0.268
	SE	7.038	0.147	16.667	0.238	10.275	0.207
	SW	7.941	0.152	8.235	0.308	9.161	0.172
2004/05	NE	9.429	0.242	8.750	0.273	8.077	0.273
	NW	12.000	0.500	8.889	0.273	7.200	0.217
	SE	11.640	0.225	7.261	0.251	5.303	0.173
	SW	10.837	0.271	9.677	0.400	5.510	0.184

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 the 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:

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

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:

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

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 trackline is 1). Detections with perpendicular distances of more than 1.5 n.mile were truncated when estimating effective search half-width (ESHW), w. More details of this detection function are given in Buckland *et al.* (1993; 2001).

Stratification of data to estimate ESHW (effective search half width)

In line with JRM recommendation (2), ESHWs 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 JRM recommendation (1). 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 Area IV or V.

Estimated mean school size

Again in line with JRM recommendation (2), mean school sizes were estimated by stratum. Only the primary sightings for which school size was confirmed were used for the estimation. The method for estimation of 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 a distance of 1.5 n.miles was substituted instead in equation (1). If the consequent mean school size estimated was less than 1, then the observed mean school size was substituted instead in equation (1) even if the regression coefficient was statistically significant at this 15% level. Similarly to the analyses for the IDCR-SOWER data (Branch, 2006; Branch and Butterworth, 2001), 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 tracklines (JRM recommendation (4))

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:

$$\mathrm{CV}\left(\frac{n_i}{L_i}\right) = \frac{\sqrt{\left\{\mathrm{var}\left(\frac{n_i}{L_i}\right)\right\}}}{\frac{n_i}{L_i}} \tag{5}$$

where

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

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:

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

where k is the number of transects on each trackline.

Log-linear models to estimate abundance trend considering the effect of survey times

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

Model (i):

$$\log\left(P_{obs}(y,a)\right) = \log\left(P_{true}(0,a)\right) + \alpha y + \varepsilon_{y,a} + \eta_{y,a} \;, \tag{7}$$

Model (ii):

$$\log\left(P_{obs}(y,a)\right) = \log\left(P_{true}(0,a)\right) + \alpha y + M + \varepsilon_{y,a} + \eta_{y,a} \;, \tag{8}$$

Model (iii):

$$\log\left(P_{obs}(y,a)\right) = \log\left(P_{true}(0,a)\right) + \alpha y + M + T + \varepsilon_{y,a} + \eta_{y,a} \;, \tag{9}$$

Model (iv):

$$\log\left(P_{obs}(y,a)\right) = \log\left(P_{true}(0,a)\right) + \alpha y + M + T + a^*T + \varepsilon_{y,a} + \eta_{y,a} \;. \tag{10}$$

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 the survey mode factor,

T is the the categorical variable related to survey time as defined below,

a^*T is an interaction between strata and survey timing,

ε is an error reflecting the sampling error of the survey abundance estimate and in year y and stratum a

η is a normally distributed error with mean of 0 and variance of associated with 'model error'.

To assess sensitivity, models that replace abundance estimates with density estimates were also evaluated to estimate abundance trends.

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

(1) $T = 1$: Dec 15–Jan 15, **$T = 2$: Jan 16–31**, $T = 3$: Feb 1–15, $T = 4$ Feb 16–Mar15 (Grouping $T1$)

(2) $T = 1$: Dec 15–Jan 15, $\boldsymbol{T = 2}$**: Jan 16–Feb 15** and $T = 3$: Feb 16–Mar 15 (Grouping $T2$)

(3) $T = 1$: Dec, $\boldsymbol{T = 2}$**: Jan,** $T = 3$: Feb and $T = 4$: Mar (Grouping $T3$)

(4) $\boldsymbol{T = 1}$**: 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 Akaike Information Criterion (Akaike, 1973) for each model.

Log likelihoods for these models are provided by,

$$LL\left(\theta,\sigma^2\right)=\left(-\frac{n}{2}\right)\log(2\pi)-\frac{\log\left\{\det(V+\sigma^2 I)\right\}}{2} - \frac{{}^{t}(x-\hat{x})(V+\sigma^2 I)^{-1}(x-\hat{x})}{2}. \tag{11}$$

where

θ is the vector of parameters to be estimated,

n is the number of data available to fit the model,

V is the variance-covariance matrix of the abundance estimates,

I is the identity matrix,

X is a vector of log of the observed abundance (density) estimates,

$\hat{x}$ is a vector of log of predicted abundance (density) by one of the models (i) to (iv) (equations (7)–(10)) above, and

t indicates transpose of the vector

The variance-covariance matrices for the estimated parameters $V(\theta)$ were derived from the Information matrix. It should be noted that 'additional variance' as estimated by maximum likelihood using equation (11) is negatively biased.

In cases where sample size is small or the number of parameters is large compared to the sample size, it is known that AIC over-estimates the appropriate number of parameters to be estimated (i.e. AIC has the tendency to select a model that is too complex). Because there may be many such parameters when compared to samples size for Model iv), an adjusted value, AIC_c (Hurvich and Tsai, 1989; 1991; Sugiura, 1978), which can be applied to linear models with normal errors, is used instead of AIC. As AIC_c and AIC are asymptotically equivalent, AIC_c can also be applied in cases of large sample size. AIC_c is defined by:

$$AIC_C = 2\log\left(LL(\hat{\theta},\hat{\sigma})\right)+2(p+1) = AIC+\frac{2(p+1)(p+2)}{n-p-2} \tag{12}$$

where $(\hat{\theta},\hat{\sigma})$ are the parameter values that maximise the log-likelihood, p is the number of parameters estimated in the model concerned.

Correction of nominal abundance estimates and their variance-covariance matrices

When model (i) was selected under AIC_c, the observed abundance estimates from the line transect analyses can be utilised as they stand to calculate estimates averaged over survey modes in the manner described below. Their variance-covariance matrices were derived from a bootstrap approach using equation (13) below. When one of the models (ii) to (iv) was selected however, the nominal abundances from the line transect analyses first needed to be adjusted using factors estimated from the model selected. If models that include the survey time covariate were selected, the nominal abundance estimates were adjusted to correspond to February. This provides total abundance estimates for Areas IV and V for each survey mode. To estimate variance and covariance for these adjusted abundances, resampling techniques were used rather than to attempt to estimate them analytically, because the correlation between adjustment factors and the nominal abundance estimates made the latter approach difficult. A total of 1,000 resamples of abundance were generated for each stratum using a parametric bootstrap approach, and parameters estimated for the selected model to in turn estimate the variance-covariance matrix, as follows:

$$x_{pseudo} \sim N\left(\bar{x},V+\sigma^2 I\right) \tag{13}$$

$$(\theta,\sigma)_{pseudo} \sim N\left((\bar{\theta},\bar{\sigma}),\Sigma_{(\theta,\sigma)}\right) \tag{14}$$

where $\Sigma_{(\theta,\sigma)}$ is variance-covariance matrix of the estimated parameters of models (i) to (iv).

Weighted average of abundance over survey modes

Weighted averages of abundance estimates over survey modes were calculated, where the weights were chosen to minimise the associated variances. Thus the weighted average P_{wa} and its variance $V(P_{wa})$ were obtained from:

$$P_{WA} = wP_{SSV}+(1-w)P_{SVC} \tag{15}$$

$$V(P_{WA}) = w^2V(P_{SSV})+2w(1-w)Cov(P_{SSV},P_{SVC}) + (1-w)^2V(P_{SVC}) \tag{16}$$

where

$w=0$ if $V(P_{SVC}) \le Cov(P_{SSV},P_{SVC})$

$w=1$ if $V(P_{SSV}) \le Cov(P_{SSV},P_{SVC})$

$w=\dfrac{V(P_{SVC})-Cov(P_{SSV},P_{SVC})}{V(P_{SSV})-2Cov(P_{SSV},P_{SVC})+V(P_{SVC})}$ otherwise

for 1992/93–1996/97 and

$$P_{WA} = \frac{aP_{SSV}+bP_{SVC}+cP_{SVP}}{a+b+c}. \tag{17}$$

$$V(P_{WA}) = \frac{a^2V(P_{SSV}) + b^2V(P_{SVC}) + c^2V(P_{SVP}) + 2\{abCov(P_{SSV},P_{SVC}) + bcCov(P_{SVC},P_{SVP}) + caCov(P_{SSV},P_{SVP})\}}{(a+b+c)^2} \quad (18)$$

where

$$a = \{V(P_{SVC}) - Cov(P_{SSV},P_{SVC})\}\{V(P_{SVP}) - Cov(P_{SSV},P_{SVC})\}$$
$$-\{Cov(P_{SVC},P_{SVP}) - Cov(P_{SSV},P_{SVC})\}$$
$$\{Cov(P_{SVC},P_{SVP}) - Cov(P_{SSV},P_{SVC})\}$$

$$b = \{V(P_{SSV}) - Cov(P_{SSV},P_{SVC})\}\{V(P_{SVP}) - Cov(P_{SVC},P_{SVP})\}$$
$$-\{Cov(P_{SSV},P_{SVP}) - Cov(P_{SSV},P_{SVC})\}$$
$$\{Cov(P_{SSV},P_{SVP}) - Cov(P_{SVC},P_{SVP})\}$$

$$c = \{V(P_{SSV}) - Cov(P_{SSV},P_{SVP})\}\{V(P_{SVC}) - Cov(P_{SVC},P_{SVP})\}$$
$$-\{Cov(P_{SSV},P_{SVC}) - Cov(P_{SVC},P_{SVP})\}$$
$$\{Cov(P_{SSV},P_{SVC}) - Cov(P_{SSV},P_{SVP})\}$$

for 1997/98–2004/05. If any of *a*, *b* and *c* was negative, that value would be substituted by 0.

Sensitivity tests for abundance and trend estimates

There are various possible sources of bias in abundance estimates and their trends, the most important of which were discussed at JRM and at the IWC-SC meeting in 2007 (Table 2). In order to examine their possible magnitudes, a number of sensitivity analyses were conducted.

The effect of a 'shoulder' in the detection functions (JRM recommendation (3))

For SSVs, the detection function has a clear shoulder in most cases (see Fig. 5a). For cases where *b* in equation (4) is estimated to be 1, however, the detection function would hardly show a shoulder. Estimates of ESHW in those strata were replaced by the average of ESHW for same strata in other years as in this test, which assumed that the CV of the estimated ESHW was the same as before the replacement.

For SVs, although some of the detection functions show a good fit to the data, others do not have a clear shoulder, perhaps related to smaller sample sizes than are typical for the SSVs. In order to examine the detection functions for the SVs further, the MCDS (Multiple Covariates Distance Sampling) module in DISTANCE was used (Thomas *et al.*, 2006). MCDS can incorporate covariates other than perpendicular distance to estimate the scale parameters of detection functions. The data were stratified into Northern strata, Southern strata and Prydz Bay separately, because the ESHW estimate is expected to differ in relation to distance northwards. AIC_c values were compared to select covariates to include in the detection function model below. The hazard rate function was utilised, with the full model described by:

$$f(y) = 1 - \exp\left\{-\left(\frac{y}{a\exp(EW + year)}\right)^{-b}\right\}. \quad (19)$$

where *y* is perpendicular distance, $a > 0$ and $b \geq 1$ are estimable parameters, and *EW* and *year* are categorical covariates for whether the stratum is to the East or the West, and for the year when the survey was conducted, respectively.

Treatment of segments of tracklines following contours of the ice edge (JRM recommendation (5))

To examine the effect of alternative treatments, analyses were conducted for the SE and SW strata in Area IV and the SW stratum in Area V where saw-tooth tracklines designs were used. Abundances were estimated excluding trackline segments that were essentially along the ice edge (Option B), and also for exclusion of tracklines not parallel to lines of longitude (Option C). The results are compared to the base case for which the complete tracklines are used.

Unsurveyed areas (JRM recommendation (6))

Two approaches were pursued to attempt to bound the uncertainty associated with the treatment of 'gaps' in coverage as defined above for the base case estimates. On the 'conservative' side, the abundance contributions from these gaps were set to zero (i.e. whales in such gaps at the time of surveying the more southerly strata were considered to be ones already effectively counted in the earlier survey

Table 2

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 the text.

Sensitivity factors	Specifications for the base case	Specifications for sensitivities
'Shoulder' of detection function	Estimation by stratum, except that when sample size is less than 15, strata are pooled.	For SSVs, ESHW averaged over the vessels concerned was used. For SVs the detection function estimation takes account of covariates.
Trackline following ice edge contours	Complete tracklines used.	(1) Exclude trackline segments along the ice edge (Option B). (2) Use only the 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 to the south.
Extrapolation of density in the unsurveyed area within a stratum	Estimated density assumed to apply to complete stratum.	Extrapolate based on average ratio of density in the unsurveyed to surveyed area as estimated in other years with complete coverage.
'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 detailed in the text.

of the more northerly strata, as these whales would subsequently likely have moved further south). On the liberal side, the density in a gap was assumed to be the same as the higher density in the stratum immediately to the south, rather than that immediately to the north as in the base case.

Incomplete coverage (JRM recommendation (7))

For the base case estimates of abundance, the extrapolated density for the (virtually) unsurveyed portion of a stratum was taken to be the same as that in the surveyed portion. To check sensitivity to an alternative to this assumption, the average of the ratio of the densities in these two portions of the stratum on surveys in other years was evaluated, and this was used instead to extrapolate the density in the surveyed portion to that for the (virtually) unsurveyed portion for the year in question. The development of such averages did not include data from every other cruise, as consideration was also given to similarities of ice-edge configurations amongst the cruises. The strata for which such alternative computations were conducted, together with the other cruises used to develop the average ratio required, are shown in Table 3.

The effect of 'skipping' to cover the pre-determined daily distance

The approach of specifying a pre-determined distance for travel each day was discontinued after 1992/93. In order to eliminate any impact that possible consequent biases in the associated estimates of abundance might have had on the estimated abundance trend, estimates prior to the 1993/94 survey were omitted when implementing models (i) to (iv).

Sensitivity of abundance trend

Models (i) to (iv) were applied to abundance estimates obtained in the sensitivity tests above, under the assumption that the variance-covariance matrix for the abundances was same as that for the base case. Again, the best model was selected using AIC_c.

Table 3

List of the strata for which survey coverage was considered incomplete, together with the other surveys with complete coverage which contributed to calculations of the average density ratio used to extrapolate abundance from the portion of the area covered to that not covered in sensitivity tests.

Year	Stratum	Longitudinal sector	SSV/SV	Other surveys used
Area IV				
1993/94	SW	70°–74°E	SSV	1989/90; 1991/92; 1997/98; 1999/00; 2003/04
1995/96	SE	100°–108°E	SSV/SV	1989/90; 1991/92; 1997/98; 1999/00; 2003/04
1999/00	SW	80°–86°E	SV	1991/92; 1993/94
2001/02	SW	70°–78°E	SSV	1989/90; 1991/92
2001/02	SW	70°–78°E	SSV	1989/90; 1991/92
2003/04	SW	70°–78°E	SSV	1989/90; 1991/92
2003/04	PB	Poor coverage	SSV	1989/90; 1991/92; 1993/94; 1995/96; 1999/00; 2001/02
Area V				
1990/91	SE	69°–71°S	SSV/SV	1992/93; 1994/95; 1996/97; 2004/05
1992/93	NE	68°–69°S	SSV/SV	1990/91; 2002/03; 2004/05
2000/01	NE	165°–170°E	SSV	1992/93; 1996/97; 2002/03
2000/01	SE	69°–71°S	SV	1992/93; 1994/95; 1996/97; 2004/05
2004/05	NW	130°–148°E	SSV/SV	1998/99; 2000/01; 2002/03
2004/05	SW	142°–165°E	SSV/SV	1992/93; 1996/97; 2002/03

Adjustment for g(0) less than 1

The Okamura and Kitakado (2012) and Bravington and Hedley (2012) approaches (known respectively as the 'OK' and 'SPLINTR' methods) for estimating minke whale abundance from the IDCR-SOWER data resulted in estimates of $g(0)$ which were less than 1 for minke whales, especially so for schools of size 1. Furthermore, since school sizes tended to be smaller for later surveys, it was important to take this into account when estimating the extent of possible changes in minke whale abundance over time. Because neither the SSVs nor the SVs participating in the JARPA surveys had Independent Observer Platforms, whose observations are needed to identify the duplicate sightings upon which the OK and SPLINTR methods rely, they cannot be applied directly here.

Instead, noting the key (albeit not exclusive) dependence of the $g(0)$ estimates from these methods on school size, a regression approach was developed. This uses the estimates of $g(0)$ provided by the OK approach for each survey block in their analyses to fit to a linear model whose covariates include the mean and standard deviation of the school size for each block together with other factors readily available such as (Management) *Area* and whether the block concerned adjoined the ice-edge (*S*) or the northern boundary (*N*) of the survey (these co-variates are serving as proxies for the environmental conditions, such as Beaufort sea state, taken into account in the OK analyses). As the JARPA surveys did not include Independent Observers as in IO mode for the IDCR-SOWER surveys, for comparability the OK estimates from those latter surveys which are used here are for closing mode survey which does not have Independent Observers involved in searching for whales. The school size distribution statistics were based on primary sightings in closing mode whose school size had been confirmed. Furthermore to curb undue influence of outlier values arising from the occasional very large school, means above 8 were treated as equal to 8, and similarly standard deviations above 4 were treated as equal to 4. As $g(0)$ cannot exceed 1, making an adjustment along these lines is appropriate anyway. This is because the relationship of $g(0)$ to mean school size cannot continue to be linear but must asymptote as mean school size becomes large. The truncation makes allowance for this in a simple manner in circumstances where there are insufficient data to estimate the further parameters needed to introduce non-linearity into the relationship. In practice only three values were truncated and none were above 9 (Table 11). Because the resulting equation was to be applied to JARPA results for Areas IV and V, only OK estimates of $g(0)$ for these two Areas (a total of 29 estimates) were used in the regression. A number of models were investigated, considering also interactions amongst the factor mentioned above and whether to treat the two Areas separately or jointly; these possibilities included introducing quadratic terms in mean school size and its standard derivation. On the basis of AIC_c, the following model was selected:

$$g(0) = a + b.E(s) + c.sd(s) + NS + Area + NS*Area \quad (20)$$

Table 4

Values of the parameters of the regression model of equation (20) relating OK estimates of $g(0)$ to school size distribution statistics and other covariates for IDCR-SOWER survey blocks in Areas IV and V. The residual standard deviation for the model fit is 0.07.

	Estimate	SE
a	0.590	0.042
b	0.067	0.018
c	–0.088	0.020
NS	–0.111	0.069
Area	–0.032	0.042
*NS*Area*	0.128	0.080

where a, b and c are parameters estimated in the model fit, $sd(s)$ is the standard deviation of the school size distribution for the block, and *NS, Area* and their interactions are categorical variables.

Fig. 4 compares the values of $g(0)$ predicted by this model to the OK estimates; given that school sizes tended to be smaller for the third circumpolar set of surveys (CPIII) than for the second, it is unsurprising that the CPIII points shown tend to reflect higher values of $g(0)$ than do the CPII points. Table 4 lists the estimates of the parameter values of equation (20); given that the relationship between $g(0)$ and school size s must asymptote at $g(0) = 1$ and therefore be non-linear with a negative second derivative, the negative value obtained for the c parameter is to be expected, as larger values of $sd(s)$ reflect the influence of a greater proportion of singleton schools.

RESULTS

Abundance estimates in terms of the 'standard methodology'

Tables 5a–f show abundance estimates by strata in Areas IV and V for SSV, SVC and SVP survey modes. The CVs of the encounter rate in these tables were estimated using equations (5) and (6). For most of the strata, the CV of the encounter rate is larger than those for ESHW and estimated mean school size. These estimates were input to the log-linear models to provide base case results. Detection functions to estimate ESHWs for abundance estimation are shown in Figs 5a–c. By pooling strata where the number of detections is less than 15, the shape of the detection functions seem improved, especially as regards displaying a shoulder.

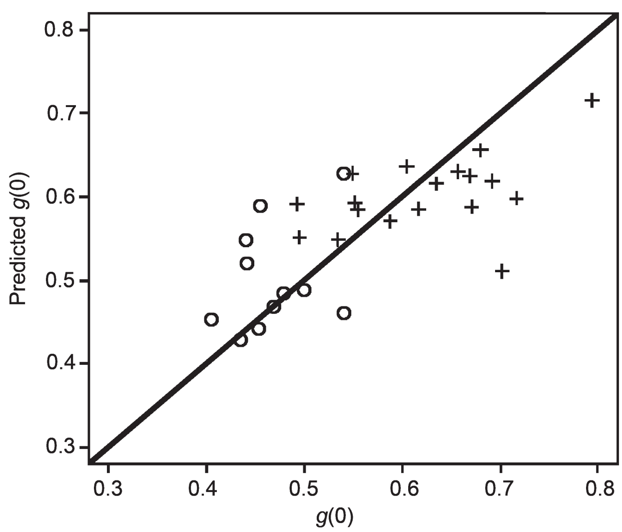

Fig. 4. The values predicted by the regression relationship of equation (20) for g(0) by block for the IDCR-SOWER surveys in Areas IV and V are shown plotted against the estimates obtained by application of the OK approach which were used in fitting this regression model. Values from the second circumpolar cruises (CPII) are shown by (o), and those from CPIII by (+). A 45° line is added to show where points would reflect exact agreement.

The CV of combined encounter rate

Fig. 6 compares the estimated CVs in this paper to those in a previous study (Hakamada *et al.*, 2006) which did not take account of the possible correlation amongst the tracklines for the SSVs as is done in the present approach. Individual estimated CVs are both higher and lower when the correlation is taken into account, but on average the CV increases by 23.1%.

Log-linear models and abundance trend estimates taking 'model error' into account

Table 6 shows AIC_c and its difference from the selected model for each model, and the instantaneous annual rates of increase and 'model error' estimates for Areas IV and V together with their 95% confidence intervals. Model (i) was selected for both Areas IV and V. These rates of increase (ROI) are 1.8% with a 95% CI [–2.5%, 6.0%] for Area IV and 1.9% with a 95% CI [–3.0%, 6.9%] for Area V. The point estimates from the other models range from –0.5% to 2.8% for Area IV and from –2.8% to 1.9% for Area V, so that all lie within the 95% CI for the abundance trend estimate for the model selected. Earlier analyses of these data (Branch, 2006; Branch and Butterworth, 2001; Hakamada *et al.*, 2006; Haw, 1991) have suggested that a survey mode calibration factor should be taken into account in developing composite abundance estimates, but that option was not selected by AIC_c in this instance, possibly as a result of now allowing also for additional variance (model/process error) in the models of equations (7) to (10). Including survey mode in the analysis would not change the point estimate of trend in abundance for Area IV, although that for Area V would decrease by about 1% pa. Estimated coefficients for the log-linear model selected for each Area are shown in Table 7. The model errors (ML estimates of the additional variance parameter σ) and their associated standard errors are 0.682 (SE = 0.072) for Area IV and 0.626 (SE = 0.078) for Area V. These estimates are negatively biased because they were obtained using a standard ML rather than a restricted maximum likelihood (REML) approach (Patterson and Thompson, 1971).

Abundance estimates averaged over survey modes

Because model (i) was selected for Areas IV and V for the base case, adjustment factors were not applied to abundance estimates in Tables 5a–f. Table 8 shows adjusted abundance estimates for each year and survey mode together with their CVs when taking model error estimates into account. The inverse variance weighted averages of abundance estimates over survey modes are shown in Table 9. The CVs for these abundance estimates are all higher than those from a previous analysis (Hakamada *et al.*, 2006) because model error is now taken into account. Table 10 shows the

Table 5a

The abundance estimates from SSV survey mode for minke whales in Area IV (south of 60°S). A = size of research area; n = number of schools sighted on primary effort (truncated at a perpendicular distance of 1.5 n.miles after smearing); L = primary searching distance; *esw* = the effective search half width (hazard rate model estimate, or half normal if shown in italics); E(s) = mean school size; D = estimated density (individuals/100 n.miles^2); P = estimated abundance.

Year	Stratum	Area (n.miles^2)	Period	n	L (n.miles)	n/L*100	CV	*esw* (n.miles)	CV	E(s)	CV	D (ind.)	P (ind.)	CV
1989/90	NW	222,563	2/8–16	49.5	1,987.6	2.489	0.343	0.452	0.399	1.360	0.066	0.037	8,334	0.530
	NE	219,245	1/11–19	49.0	1,964.4	2.494	0.262	0.585	0.121	2.250	0.119	0.048	10,521	0.312
	SW	35,878	1/21–2/1	83.5	2,518.3	3.317	0.114	0.474	0.233	1.963	0.070	0.069	2,463	0.269
	SE	41,143	12/31–1/10	132.3	1,325.5	9.980	0.229	0.698	0.115	2.208	0.060	0.158	6,494	0.263
	PB	36,488	2/3–6	41.6	831.9	4.999	0.453	0.734	0.190	1.756	0.093	0.060	2,181	0.500
	Total	555,317		355.9	8,627.7							0.054	**29,993**	**0.197**
1991/92	NW	219,713	2/15–25	74.6	2,482.7	3.005	0.206	0.438	0.198	1.710	0.108	0.059	12,894	0.305
	NE	216,299	1/1–9	22.3	2,173.9	1.028	0.300	0.504	0.566	1.273	0.106	0.013	2,809	0.649
	SW	37,191	1/27–2/6	56.5	1,199.4	4.713	0.203	0.654	0.235	2.015	0.088	0.073	2,700	0.322
	SE	39,732	1/16–26	38.7	1,357.7	2.847	0.233	0.550	0.199	1.865	0.091	0.048	1,919	0.320
	PB	36,569	2/9–14	61.3	370.4	16.556	0.726	0.577	0.324	2.305	0.099	0.331	12,097	0.801
	Total	549,503		253.4	7,584.1								**32,418**	**0.329**
1993/94	NW	232,794	2/15–3/3	53.1	2,493.3	2.130	0.233	0.567	0.151	1.391	0.072	0.026	6,085	0.287
	NE	163,135	1/5–20	58.6	1,924.7	3.044	0.207	0.482	0.230	1.614	0.082	0.051	8,314	0.320
	SW	40,280	1/22–2/4	101.9	1,352.9	7.535	0.324	0.697	0.178	1.838	0.059	0.099	4,000	0.374
	SE	42,206	12/21–1/4	63.2	1,419.1	4.450	0.283	0.645	0.231	2.516	0.094	0.087	3,661	0.377
	PB	34,506	2/6–14	44.3	599.3	7.390	0.184	0.447	0.275	2.079	0.069	0.172	5,929	0.338
	Total	512,920		321.1	7,789.3								**27,989**	**0.153**
1995/96	NW	153,848	1/10–26	56.5	2,736.9	2.064	0.375	0.883	0.127	1.908	0.085	0.022	3,431	0.405
	NE	230,678	2/10–19	61.8	2,123.5	2.909	0.290	0.482	0.347	1.623	0.090	0.049	11,297	0.461
	SW	85,078	12/22–1/9	140.8	2,137	6.589	0.257	0.638	0.206	1.875	0.052	0.097	8,237	0.334
	SE	33,783	2/20–29	117.1	1,461.5	8.016	0.200	0.767	0.121	2.104	0.067	0.110	3,714	0.243
	PB	25,969	1/27–2/6	87.3	846.6	10.315	0.546	0.794	0.221	1.328	0.046	0.086	2,240	0.591
	Total	529,356		463.6	9,305.5								**28,919**	**0.216**
1997/98	NW	219,550	1/1–15	70.3	2,616.3	2.686	0.401	0.910	0.205	1.914	0.105	0.028	6,204	0.462
	NE	221,192	1/31–2/13	55.7	2,643.3	2.106	0.206	0.641	0.327	1.732	0.166	0.028	6,300	0.421
	SW	32,922	2/14–3/1	82.1	2,645.4	3.103	0.557	0.757	0.178	1.492	0.068	0.031	1,008	0.588
	SE	34,271	1/16–30	80.0	2,370.4	3.374	0.161	0.549	0.289	1.184	0.058	0.036	1,247	0.336
	PB	3,820	2/2–9	67.9	354.9	19.145	1.313	0.383	0.210	2.634	0.101	0.658	2,514	1.333
	Total	511,756		356	10,630.3								**17,272**	**0.301**
1999/00	NW	228,269	12/28–1/13	46.2	1,826.2	2.532	0.304	0.885	0.195	1.174	0.072	0.017	3,832	0.368
	NE	226,325	1/14–27	96.1	2,507.1	3.833	0.254	0.790	0.122	1.212	0.038	0.029	6,651	0.284
	SW	46,682	2/19–3/1, 3/7–9	227.6	1,665.9	13.659	0.285	0.856	0.081	3.019	0.062	0.241	11,245	0.302
	SE	35,018	1/28–2/18	283.1	1,884.8	15.022	0.295	0.830	0.111	4.999	0.084	0.452	15,840	0.326
	PB	20,531	3/2–6	130.6	852.9	15.307	0.297	0.796	0.107	2.677	0.115	0.257	5,284	0.336
	Total	556,825		783.6	8,736.9								**42,852**	**0.160**
2001/02	NW	221,285	12/26–1/10	67.7	2,346.9	2.884	0.810	0.734	0.174	1.400	0.069	0.027	6,085	0.831
	NE	242,188	1/11–26	131.2	2,250.1	5.830	0.769	0.854	0.107	1.444	0.048	0.049	11,937	0.778
	SW	33,562	2/12–22	95.9	1,470.5	6.520	0.224	0.727	0.160	1.386	0.052	0.062	2,087	0.280
	SE	38,128	1/27–2/11	247.4	2,051.6	12.061	0.200	0.827	0.086	1.992	0.060	0.145	5,536	0.226
	PB	28,374	2/23–27	183.6	568.1	32.312	0.187	0.468	0.204	2.114	0.063	0.730	20,710	0.283
	Total	563,537		658.1	5,843.4								**46,355**	**0.263**
2003/04	NW	248,010	12/27–1/11	52.0	2,392.3	2.174	0.198	0.747	0.130	1.228	0.055	0.018	4,431	0.243
	NE	217,430	1/12–24	43.2	2,599.6	1.664	0.334	0.879	0.257	1.318	0.064	0.012	2,712	0.426
	SW	38,491	2/12–28	206.4	1,288.9	16.014	0.643	0.829	0.080	2.374	0.056	0.229	8,819	0.650
	SE	41,349	1/25–2/11	96.4	2,598.5	3.710	0.682	0.523	0.186	1.828	0.082	0.065	2,683	0.712
	PB	37,680	2/29–3/1	20.1	30.0	66.999	0.223	0.597	0.559	1.952	0.109	1.095	41,273	0.611
	Total	582,959		418.1	8,909.3								**59,918**	**0.434**

correlation matrices for the logarithms of the abundance estimates for Areas IV and V. Correlations amongst these estimates are low because no common correction factor was applied.

Adjustment for g(0) less than 1

The regression model of equation (20) was applied to school size information for the JARPA survey strata, treating these in exactly the same way as for the OK estimates when developing that regression equation. The resultant values are listed in Table 11. The abundance estimates in Tables 5a–f were then divided by these $g(0)$ values to provide the $g(0)$-adjusted abundance estimates and their trends which are shown in Tables 12 and 13. However, to avoid extrapolation when applying equation (20), in the few cases where the regression estimate lay outside the range of the OK estimates of $g(0)$ used to fit the regression, those estimates were increased or decreased to equal to the lowest or highest value in the set of OK estimates. In computing variances estimates for the $g(0)$-adjusted abundance estimates and trends given in Tables 12 and 13, appropriate account was taken of the co-variances introduced by the use of the common regression relationship of equation (20), although for simplicity the variances and co-variances for the OK estimates of $g(0)$ were overlooked and these were treated as known without error in estimating the regression parameter values.

Table 5b

The abundance estimates from SSV survey mode for minke whales in Area V (south of 60°S). The notation is as for Table 5a.

Year	Stratum	*A* (n.miles^2)	Period	*n*	*L* (n.miles)	*n*/*L**100	CV	*esw* (n.miles)	CV	*E*(*s*)	CV	*D* (ind.)	*P* (ind.)	CV
1990/91	NW	239,688	1/21–31	148.5	2,726.8	5.447	0.199	0.358	0.169	1.572	0.065	0.120	28,692	0.269
	NE	348,822	2/16–26	61.8	2,498.9	2.472	0.373	0.256	0.498	1.562	0.091	0.076	26,342	0.628
	SW	64,431	1/11–20	108.4	1,635	6.629	0.149	0.601	0.188	1.805	0.071	0.100	6,416	0.250
	SE	188,136	2/5–14	211.6	1,670	12.673	0.199	0.557	0.147	1.835	0.055	0.209	39,296	0.254
	Total	841,078		530.3	8,530.7								**100,745**	**0.207**
1992/93	NW	325,234	1/25–2/5	39.0	1,371.2	2.844	0.382	0.451	0.155	1.51	0.075	0.048	15,525	0.419
	NE	348,822	12/30–1/11	33.8	944.2	3.584	0.240	0.696	0.219	1.53	0.100	0.039	13,746	0.340
	SW	59,869	1/15–24,2/8–13	72.1	902.7	7.985	0.309	0.936	0.156	2.69	0.103	0.115	6,879	0.361
	SE	210,194	2/14–3/6	114.5	1,205.6	9.495	0.436	0.668	0.225	2.01	0.066	0.143	29,997	0.495
	Total	944,118		259.4	4,423.7								**66,147**	**0.258**
1994/95	NW	211,503	1/4–19	54.6	2,062.5	2.646	0.333	0.749	0.160	2.36	0.111	0.042	8,803	0.386
	NE	348,822	1/20–2/5,2/13–18	62.0	1,568.0	3.954	0.383	0.661	0.187	2.00	0.037	0.060	20,888	0.428
	SW	41,509	12/18–1/3	82.3	1,584.3	5.195	0.296	0.833	0.210	2.29	0.085	0.071	2,961	0.372
	SE	173,180	2/8–9,2/23–3/11	142.3	606.6	23.454	0.578	0.889	0.104	2.30	0.066	0.304	52,607	0.591
	Total	775,013		341.1	5,821.4								**85,258**	**0.382**
1996/97	NW	285,547	2/5–20	52.2	2,073.0	2.516	0.117	0.536	0.329	1.519	0.074	0.036	10,189	0.357
	NE	337,779	1/5–20	100.9	2,327.3	4.335	0.103	0.657	0.220	1.582	0.057	0.052	17,625	0.249
	SW	56,628	1/21–2/4	109.4	2,432.0	4.496	0.487	0.631	0.235	2.104	0.075	0.075	4,245	0.545
	SE	187,983	2/21–3/12	146.9	1,308.4	11.226	0.448	0.596	0.207	3.240	0.141	0.305	57,356	0.513
	Total	867,936		285.3	8,140.7								**89,415**	**0.336**
1998/99	NW	314,848	1/30–2/3	50.9	833.6	6.100	0.552	0.422	0.259	1.824	0.081	0.132	41,449	0.615
	NE	326,943	1/24–29	45.5	574.1	7.932	0.148	0.503	0.202	2.239	0.103	0.176	57,680	0.271
	SW	48,304	2/4–25	196.6	1,559.0	12.609	0.168	0.517	0.174	2.399	0.068	0.292	14,128	0.251
	SE	26,627	2/26–3/15	115.5	1,183.7	9.754	0.431	0.540	0.145	1.980	0.062	0.179	4,760	0.459
	Total	716,722		310.3	4,150.4								**118,017**	**0.256**
2000/01	NW	272,525	2/10–25	47.6	2,688.7	1.770	1.539	0.571	0.369	1.898	0.137	0.029	8,013	1.588
	NE	348,528	1/2–23	224.7	2,704.8	8.309	0.229	0.625	0.164	1.689	0.044	0.112	39,126	0.286
	SW	78,685	2/27–3/19	197.5	2,267.7	8.707	0.285	0.737	0.166	1.423	0.036	0.084	6,613	0.332
	SE	148,828	1/24–2/9	228.9	1,308.6	17.494	0.332	0.713	0.156	2.636	0.063	0.323	48,102	0.372
	Total	848,567		698.7	8,969.8								**101,854**	**0.243**
2002/03	NW	266,480	2/11–21	104.0	1,837.6	5.659	0.313	0.751	0.099	2.029	0.067	0.076	20,376	0.335
	NE	345,003	1/4–26	128.1	3,573.0	3.587	0.239	0.817	0.198	1.637	0.054	0.036	12,393	0.315
	SW	79,679	2/26–3/8	124.2	764.1	16.251	0.393	0.368	0.281	1.893	0.074	0.418	33,306	0.489
	SE	70,816	1/27–2/9	514.5	734.9	70.008	0.469	0.760	0.065	2.614	0.044	1.204	85,284	0.476
	Total	761,978		870.8	6,909.6								**151,359**	**0.293**
2004/05	NW	278,357	2/19–2/24	5.0	698.2	0.716	1.306	0.513	0.288	1.494	0.061	0.010	2,901	1.339
	NE	336,130	12/27–1/13	81.7	2,288.8	3.569	0.553	0.513	0.288	1.494	0.061	0.053	17,790	0.627
	SW	51,297	2/24–3/8	103.9	485.9	21.391	0.221	1.019	0.121	4.566	0.146	0.483	24,795	0.291
	SE	212,147	1/16–2/15	551.3	5,423.3	10.166	0.135	0.870	0.063	1.849	0.032	0.108	22,939	0.152
	Total	877,931		741.9	4,310.7								**68,425**	**0.238**

Abundance estimates and trends for the sensitivity tests

Table 12 compares abundance estimates and their trends for the sensitivity tests examined. With the exception of the *g*(0)-adjusted estimates, the abundance estimates do not change substantially for any of the sensitivities for Area IV. This is also true for Area V except for the cases of trackline options B and C; in these two cases, model (iv), which allows for the effects of survey mode and survey time together with their interaction, was selected. Table 13 shows estimated instantaneous annual rates of increase for Areas IV and V using the model selected by AIC_c for all the sensitivities examined in this paper. Using density instead of abundance estimates for these calculations does not change the trend estimates substantially. These annual abundance rate of increase estimates range over [0.9%, 3.5%] for Area IV and [–3.5%, 3.7%] for Area V for the various sensitivity tests.

When the abundance estimates are *g*(0)-adjusted, as would be expected, the estimates increase by an average of 32,333 (106%) for Area IV and 89,245 (86%) for Area V. The estimates of annual rates of increase and their 95% CIs change to 2.7% [–1.5%,6.9%] for Area IV and 1.6% [–3.4%,6.7%] for Area V, reflecting a 1% increase in the point estimate for the former, little change for the latter, and slightly less precision (a relative increase inn standard error of about 0.1%) than when *g*(0) is assumed to be 1 because of the further variance introduced in estimating the *g*(0) values.

DISCUSSION AND FUTURE WORK

This paper has provided new estimates of abundance and trend for the Antarctic minke whales in Areas IV and V which take account of the recommendations made at the JRM. The CVs of the estimated abundances and trends were obtained with incorporation of 'model errors'. Recently information on stock structure in Areas IIIE, IV, V and VIW has been provided based on both genetic and non-genetic data from JARPA (Pastene, 2006). The JRM agreed that this showed there to be at least two stocks of Antarctic minke whales present in the JARPA research area, and that the data suggest an area of transition in the region around 150–165ºE within which there is an as yet undetermined level and range of mixing (IWC, 2008a). The annual changes in stock

Table 5c

The abundance estimates from SVC survey mode for minke whales in Area IV (south of 60°S). The notation is as for Table 5a.

Year	Stratum	*A* (n.miles^2)	Period	*n*	*L* (n.miles)	*n*/*L**100	CV	*esw* (n.miles)	CV	*E*(*s*)	CV	*D* (ind.)	*P* (ind.)	CV
1991/92	SW	36,541	1/26–2/6	48.7	1,038.1	4.693	0.238	0.383	0.344	2.240	0.122	0.137	5,011	0.435
	SE	39,732	1/16–24	28.0	924.0	3.027	0.266	0.500	0.507	2.172	0.174	0.066	2,611	0.599
	PB	30,569	2/9–14	76.0	212.6	35.735	0.956	0.868	0.146	4.466	0.495	0.919	28,091	1.086
1993/94	NW	233,784	2/15–3/3	26.0	1,667.4	1.559	0.267	0.295	0.255	1.280	0.106	0.034	7,896	0.384
	NE	164,829	1/5–20	22.4	1,250.4	1.790	0.308	0.401	0.526	1.650	0.166	0.037	6,070	0.632
	SW	39,229	1/22–30	40.0	1,024.8	3.899	0.293	0.634	0.278	1.763	0.132	0.054	2,128	0.425
	SE	40,500	12/21–1/4	59.8	839.8	7.121	0.988	0.477	0.354	2.221	0.111	0.166	6,712	1.055
	PB	34,506	2/6–14	27.0	477.7	5.652	0.514	0.360	0.279	1.381	0.096	0.108	3,740	0.593
	Total	512,848		175.1	5,260.1	3.330							**26,546**	**0.336**
1995/96	NW	144,366	1/10–26	14.8	793.6	1.867	0.386	0.216	0.492	1.540	0.133	0.067	9,611	0.639
	NE	230,267	2/10–18	17.0	856.2	1.986	0.381	0.216	0.492	1.540	0.133	0.071	16,305	0.636
	SW	94,573	12/22–1/9	41.0	714.2	5.741	0.410	0.460	0.224	2.737	0.121	0.171	16,140	0.483
	SE	34,176	2/19–29	52.7	578.4	9.112	0.172	0.526	0.168	2.350	0.133	0.204	6,959	0.275
	PB	25,971	1/27–2/5	25.0	451.6	5.527	0.254	0.375	0.373	1.174	0.132	0.087	2,249	0.470
	Total	529,353		150.5	3,394	4.434							**51,264**	**0.334**
1997/98	NW	215,740	12/31–1/14	20.6	551.5	3.735	0.464	0.982	0.159	2.069	0.128	0.039	8,487	0.507
	NE	218,011	1/30–2/12	10.0	702.6	1.423	0.399	0.982	0.159	2.069	0.128	0.015	3,268	0.448
	SW	30,308	2/13–27	10.3	530.7	1.944	0.526	0.371	0.555	1.750	0.085	0.046	1,388	0.769
	SE	34,477	1/15–29	18.0	602.9	2.986	0.302	0.371	0.555	1.750	0.085	0.070	2,425	0.638
	PB	4,994	3/2–4	2.8	88.6	3.131	0.620	0.371	0.555	1.750	0.085	0.074	368	0.836
	Total	503,529		61.7	2,476.3	2.491							**15,936**	**0.341**
1999/00	NW	230,466	12/27–1/11	2.0	325.5	0.614	0.786	0.313	0.261	1.421	0.135	0.014	3,218	0.839
	NE	226,218	1/11–26	25.0	345.5	7.236	0.312	0.313	0.261	1.421	0.135	0.164	37,193	0.429
	SW	43,042	2/18–3/1,3/6–9	22.6	171.9	13.150	0.396	0.647	0.154	3.346	0.111	0.340	14,642	0.440
	SE	33,331	1/28–2/18	93.2	582.3	16.007	0.343	0.647	0.154	3.346	0.111	0.414	13,802	0.392
	PB	22,045	3/1–6	9.7	101.4	9.570	1.271	0.647	0.154	3.346	0.111	0.248	5,458	1.285
	Total	555,103		152.5	1,526.6	9.991							**74,313**	**0.278**
2001/02	NW	223,614	12/25–1/8	7.3	189.5	3.853	0.428	0.626	0.186	1.303	0.058	0.040	8,967	0.470
	NE	247,653	1/9–25	2.0	211.0	0.948	1.002	0.626	0.186	1.303	0.058	0.010	2,443	1.021
	SW	30,836	2/10–21,27	9.0	198.5	4.534	0.636	0.626	0.186	1.303	0.058	0.047	1,455	0.665
	SE	33,781	1/26–2/8	14.9	197.1	7.570	0.434	0.626	0.186	1.303	0.058	0.079	2,662	0.476
	PB	28,570	2/22–26	40.2	133.7	30.072	0.276	0.626	0.186	1.303	0.058	0.313	8,943	0.337
	Total	564,454		73.4	929.8	7.897							**24,470**	**0.294**
2003/04	NW	239,688	12/26–1/10	5.0	257.1	1.945	0.349	0.567	0.286	2.259	0.207	0.039	9,278	0.496
	NE	218,714	1/11–24	6.0	329.1	1.823	0.566	0.567	0.286	2.259	0.207	0.036	7,937	0.667
	SW	39,461	2/7–25	4.4	257.0	1.720	1.045	0.567	0.286	2.259	0.207	0.034	1,351	1.102
	SE	36,554	1/25–2/7	16.6	242.9	6.836	1.128	0.567	0.286	2.259	0.207	0.136	4,974	1.182
	PB	37,394	2/26–3/2	7.5	235.5	3.183	0.352	0.567	0.286	2.259	0.207	0.063	2,370	0.498
	Total	571,811		39.5	1,321.6								**25,910**	**0.470**

proportions in this region are being investigated using both genetic and non-genetic markers (Kitakado *et al*., 2012). Because the distributions of these two stocks are not identical to the Management Areas, it will be desirable to estimate abundance trends at the stock level, taking account of this recent information on the stock structure of the minke whales.

Clearly the estimates of abundance in this paper are subject to the same uncertainties as those from the IDCR-SOWER surveys as regards minke whales in the unsurveyed areas of sea-ice regions south of the ice edge which was determined as each survey was conducted. At the IWC-SC meeting in 2012, it was recognised that reliable absolute abundance estimates of Antarctic minke whales in these regions (which are comparable in space and time for JARPA and IDCR-SOWER surveys) would be impossible to produce. Accordingly the recommendation was made that relatively simple analyses be conducted to generate abundances using aerial survey data (IWC, 2013). Such abundance estimates using aerial survey data may become available in the future. To the extent that it might prove possible to use these to adjust the IDCR-SOWER abundance estimates, such an adjustment process could also be applied to the abundance estimates of this paper.

Log-linear models

Because stratum areas vary from year to year as a result of different ice edge locations, it is not immediately obvious whether such modeling approaches should be based on the density or on the abundance in a stratum, and arguments can be offered to support either approach. Matsuoka *et al.* (2011) found little difference in results for the two approaches for humpback whales. This is also the case for the Antarctic minke whale abundances and their trends as indicated in Table 13 of this paper. For the selected model, the estimates of abundance trends would not change substantially if abundance were replaced by density in the analyses.

In contrast to previous studies (Branch, 2006; Branch and Butterworth, 2001; Hakamada *et al*., 2006; Haw, 1991), the results from this study do not provide a basis for suggesting that the abundance estimates are affected by the differences in survey mode. This is probably because the variances of these estimates are larger than those for the corresponding

Table 5d

The abundance estimates from SVC survey mode for minke whales in Area V (south of 60°S). The notation is as for Table 5a.

Year	Stratum	*A* (n.miles^2)	Period	*n*	*L* (n.miles)	*n*/*L**100	CV	*esw* (n.miles)	CV	*E*(*s*)	CV	*D* (ind.)	*P* (ind.)	CV
1992/93	NW	326,061	1/25–2/5	46.7	923.0	5.058	0.294	0.434	0.188	1.565	0.076	0.091	29,732	0.357
	NE	348,822	12/30–1/11	15.0	717.3	2.091	0.617	0.453	0.233	2.562	0.329	0.059	20,646	0.737
	SW	59,030	1/15–24,2/8–13	105.3	1,004.7	10.483	0.283	0.482	0.266	2.899	0.102	0.315	18,612	0.401
	SE	210,194	2/14–3/6	172.4	1,048.0	16.450	0.367	0.484	0.143	1.915	0.071	0.325	68,367	0.400
	Total	944,107		339.4	3693	9.191							**137,356**	**0.247**
1994/95	NW	208,477	1/4–19	47.6	1,166.9	4.078	0.576	0.479	0.396	1.435	0.138	0.061	12,744	0.713
	NE	348,822	1/20–2/14	21.7	986.1	2.200	0.251	0.397	0.446	1.381	0.144	0.038	13,329	0.531
	SW	38,313	12/18–1/3	88.0	884.7	9.946	0.270	0.774	0.151	3.918	0.109	0.252	9,642	0.328
	SE	173,180	2/15–3/13	191.7	686.4	27.931	0.257	0.840	0.100	4.057	0.104	0.674	116,762	0.295
	Total	768,792		349	3,724.1								**152,477**	**0.239**
1996/97	NW	290,846	2–4/20	14.8	711.6	2.076	0.342	0.362	0.207	2.929	0.353	0.084	24,429	0.533
	NE	337,779	1–3/20	16.0	806.1	1.985	0.414	0.362	0.207	2.929	0.353	0.080	27,127	0.582
	SW	51,292	1/21–2/3	16.4	563.3	2.914	0.660	0.899	0.525	2.742	0.327	0.044	2,279	0.904
	SE	187,983	2/20–3/12	107.5	790.1	13.603	0.447	0.729	0.132	3.694	0.106	0.345	64,764	0.478
	Total	867,900		154.7	2,871.1								**118,599**	**0.338**
1998/99	NW	314,708	1/14–2/2	8.9	185.4	4.806	0.521	0.476	0.550	2.217	0.170	0.112	35,266	0.776
	NE	328,037	1/13–23	15.8	652.8	2.416	0.126	0.476	0.550	2.217	0.170	0.056	18,476	0.589
	SW	48,361	2/3–21	14.0	86.9	16.110	1.072	0.178	1.305	3.462	0.294	1.566	75,727	1.714
	SE	24,791	2/24–3/12	1.5	116.5	1.327	1.235	0.178	1.305	3.462	0.294	0.129	3,197	1.820
	Total	715,898		40.23	1,041.6								**132,667**	**1.040**
2000/01	NW	269,652	2/10–23	2.0	254.9	0.785	0.742	0.157	1.442	5.692	0.569	0.143	38,460	1.718
	NE	348,541	1/1–23	13.3	333.9	3.970	0.427	0.157	1.442	5.692	0.569	0.722	251,516	1.608
	SW	80,503	2/25–3/18	10.0	210.8	4.744	0.948	0.271	0.710	1.439	0.130	0.126	10,156	1.192
	SE	148,828	1/24–2/7	18.7	225.0	8.328	0.449	0.271	0.710	1.439	0.130	0.221	32,958	0.850
	Total	847,524		43.99	1,024.6								**333,090**	**1.394**
2002/03	NW	266,894	2/11–20,3/5–7	15.6	183.3	8.526	0.432	0.407	0.356	2.231	0.177	0.234	62,349	0.587
	NE	345,003	1/5–25	15.4	408.3	3.783	0.505	0.474	0.436	1.636	0.149	0.065	22,534	0.683
	SW	79,072	2/21–3/4	27.0	203.0	13.300	0.346	1.074	0.131	2.000	0.147	0.124	9,790	0.398
	SE	68,928	1/27–2/9	26.4	148.3	17.770	0.373	0.632	0.332	1.800	0.128	0.253	17,429	0.516
	Total	759,896		84.43	942.9								**112,102**	**0.365**
2004/05	NW	278,204	2/11–21	1.0	69.7	1.435	0.860	0.452	0.667	1.556	0.140	0.025	6,873	1.098
	NE	336,130	1/4–26	16.7	297.5	5.615	0.569	0.452	0.667	1.556	0.140	0.097	32,498	0.888
	SW	51,449	2/26–3/8	13.0	69.6	18.618	0.404	0.625	0.257	1.802	0.079	0.268	13,806	0.485
	SE	212,214	1/27–2/9	62.4	714.3	8.737	0.219	0.625	0.257	1.802	0.079	0.126	26,724	0.347
	Total	877,997		93.07	1151.1								**79,901**	**0.448**

Table 5e

The abundance estimates from SVP survey mode for minke whales in Area IV (south of 60°S). The notation is as for Table 5a.

Year	Stratum	*A* (n.miles^2)	Period	*n*	*L* (n.miles)	*n*/*L**100	CV	*esw* (n.miles)	CV	*E*(*s*)	CV	*D* (ind.)	*P* (ind.)	CV
1997/98	NW	215,740	12/31–1/14	4.8	199.4	2.404	0.394	0.978	0.155	2.069	0.128	0.025	5,488	0.443
	SW	30,308	2/13–27	8.0	256.4	3.120	0.697	0.978	0.155	1.750	0.085	0.028	846	0.719
	SE	34,477	1/15–29	6.0	222.6	2.695	0.637	0.978	0.155	1.750	0.085	0.024	832	0.661
	PB	4,994	3/2–4	21.6	46.5	46.426	0.215	0.978	0.155	1.750	0.085	0.415	2,075	0.279
1999/00	NW	230,466	12/27–1/11	4.0	673.6	0.594	0.490	0.561	0.178	1.421	0.135	0.008	1,732	0.538
	NE	226,218	1/11–26	31.4	698.2	4.504	0.236	0.561	0.178	1.421	0.135	0.057	12,895	0.325
	SW	43,042	2/18–29,3/6	84.5	498.9	16.933	0.361	1.031	0.106	3.346	0.111	0.275	11,831	0.392
	SE	33,331	1/28–2/18	50.6	237.2	21.344	0.278	0.961	0.130	3.346	0.111	0.372	12,391	0.327
	PB	22,045	3/1–6	33.2	290.4	11.426	0.385	1.051	0.343	3.346	0.111	0.182	4,009	0.527
	Total	533,057		203.7	2,398.3								42,858	**0.194**
2001/02	NW	223,614	12/25–1/8	7.0	507.2	1.390	1.110	0.313	0.224	1.303	0.058	0.029	6,459	1.134
	NE	247,653	1/9–25	41.9	810.5	5.175	0.585	0.313	0.224	1.303	0.058	0.108	26,634	0.629
	SW	30,836	2/10–21,27	116.1	652.8	17.783	0.354	0.875	0.065	1.303	0.058	0.132	4,080	0.364
	SE	33,781	1/26–2/8	175.3	636.5	27.543	0.223	0.517	0.091	1.303	0.058	0.347	11,732	0.247
	PB	28,570	2/22–26	173.8	331.9	52.371	0.133	1.051	0.342	1.303	0.058	0.325	9,271	0.372
	Total	535,884		514.2	2,938.9								58,176	**0.336**
2003/04	NW	239,688	12/26–1/10	23.4	587.2	3.981	0.513	0.372	0.547	2.259	0.207	0.121	28,998	0.778
	NE	218,714	1/11–24	8.7	809.8	1.075	0.328	0.372	0.547	2.259	0.207	0.033	7,144	0.671
	SW	39,461	2/7–25	75.7	729.3	10.382	0.438	0.883	0.119	2.259	0.207	0.133	5,237	0.499
	SE	36,554	1/25–2/7	13.0	791.8	1.639	0.320	0.883	0.119	2.259	0.207	0.021	766	0.400
	PB	37,394	2/26–3/2	34.8	243.0	14.306	0.792	0.883	0.119	2.259	0.207	0.183	6,839	0.827
	Total	571,811		155.5	3,161.1								**48,984**	**0.562**

Table 5f

The abundance estimates from SVP survey mode for minke whales in Area V (south of 60°S). The notation is as for Table 5a.

Year	Stratum	*A* (n.miles^2)	Period	*n*	*L* (n.miles)	*n*/*L**100	CV	*esw* (n.miles)	CV	*E*(*s*)	CV	*D* (ind.)	*P* (ind.)	CV
1998/99	NW	314,708	1/14–2/2	42.8	811.6	5.268	0.457	0.536	0.239	2.217	0.170	0.109	34,276	0.543
	SW	48,361	2/3–21	86.4	560.6	15.414	0.232	0.526	0.277	3.462	0.294	0.507	24,534	0.466
	SE	24,791	2/24–3/12	30.0	260.8	11.503	0.398	0.487	0.202	3.462	0.294	0.409	10,137	0.535
2000/01	NW	269,652	2/10–23	18.0	651.9	2.761	0.595	0.452	0.254	5.692	0.569	0.174	46,904	0.861
	NE	348,541	1/1–23	31.4	902.4	3.475	0.331	0.320	0.589	5.692	0.569	0.309	107,811	0.884
	SW	80,503	2/25–3/18	34.0	674.4	5.042	0.272	0.396	0.316	1.439	0.130	0.092	7,381	0.437
	SE	148,828	1/24–2/7	152.2	7,21.3	21.101	0.270	0.945	0.119	1.439	0.130	0.161	23,924	0.323
	Total	847,524		265.6	3,210.8								**186,019**	**0.637**
2002/03	NW	266,894	2/11–20,3/5–7	82.5	714.8	11.542	0.320	0.499	0.296	2.231	0.177	0.258	68,909	0.470
	NE	345,003	1/5–25	39.9	1065.7	3.740	0.272	0.651	0.232	1.636	0.149	0.047	16,218	0.387
	SW	79,072	2/21–3/4	213.6	491.2	43.487	0.262	0.548	0.118	2.000	0.147	0.794	62,777	0.323
	SE	68,928	1/27–2/9	335.0	704.0	47.585	0.281	0.514	0.126	1.800	0.128	0.833	57,448	0.334
	Total	759,896		936.5	6,186.5								**205,352**	**0.211**
2004/05	NW	278,204	2/19–3/8	3.0	202.1	1.484	0.405	0.401	0.554	1.556	0.140	0.029	8,010	0.701
	NE	336,130	12/26–2/14	21.4	738.9	2.891	0.580	0.401	0.554	1.556	0.140	0.056	18,852	0.814
	SW	51,449	2/24–3/7	90.2	301.2	29.937	0.307	0.592	0.233	1.802	0.079	0.455	23,427	0.393
	SE	212,214	1/16–2/13	263.8	1,901.6	13.874	0.235	0.766	0.110	1.802	0.079	0.163	34,640	0.272
	Total	877,997		1,314.9	3,143.8								**84,930**	**0.276**

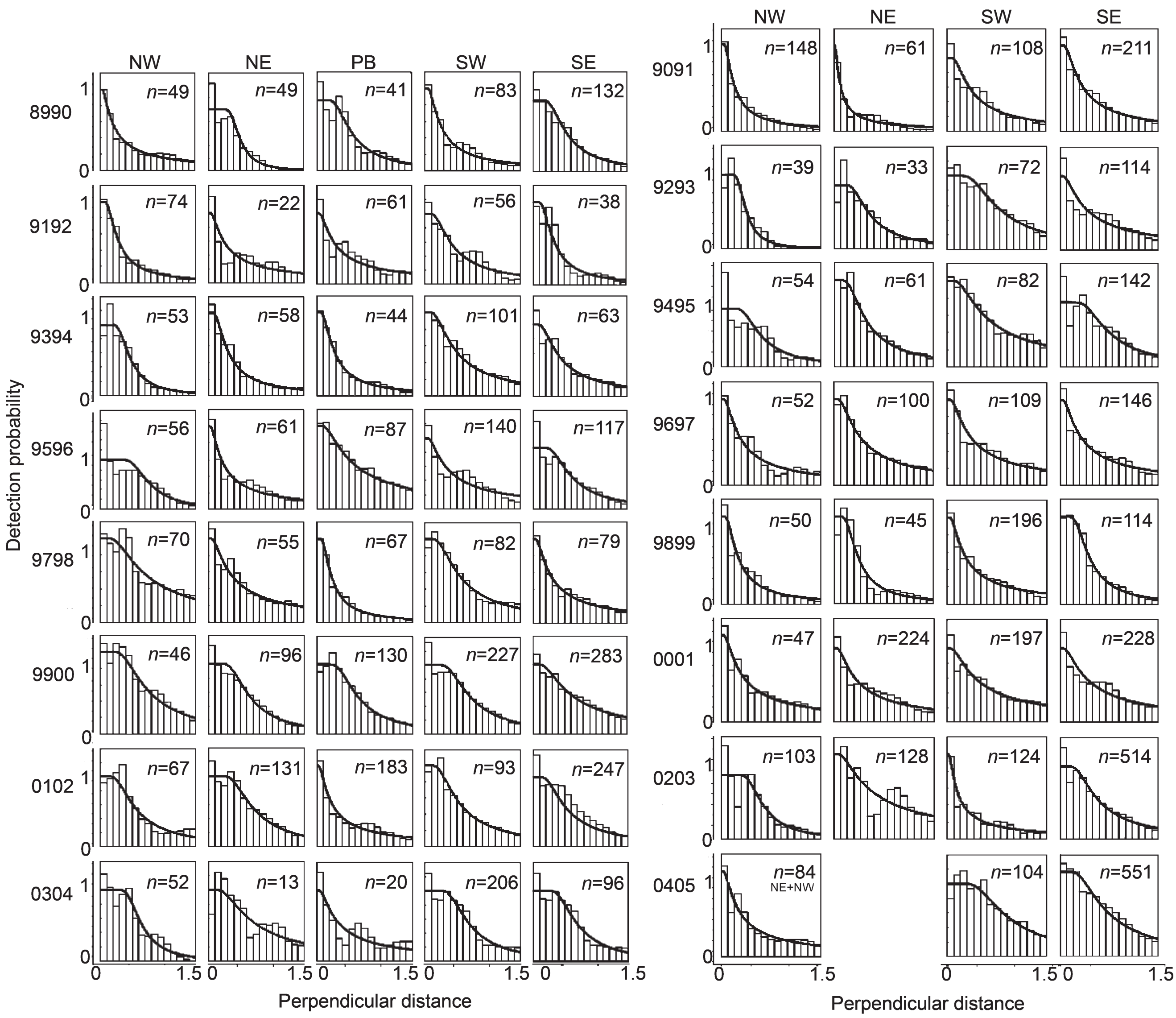

Fig. 5a. Histograms of the smeared perpendicular distance (in n.miles) distributions of minke school sightings with fitted detection functions for each stratum in Areas IV and V for SSV data. *n* is the number of the sightings used in estimation of the detection function.

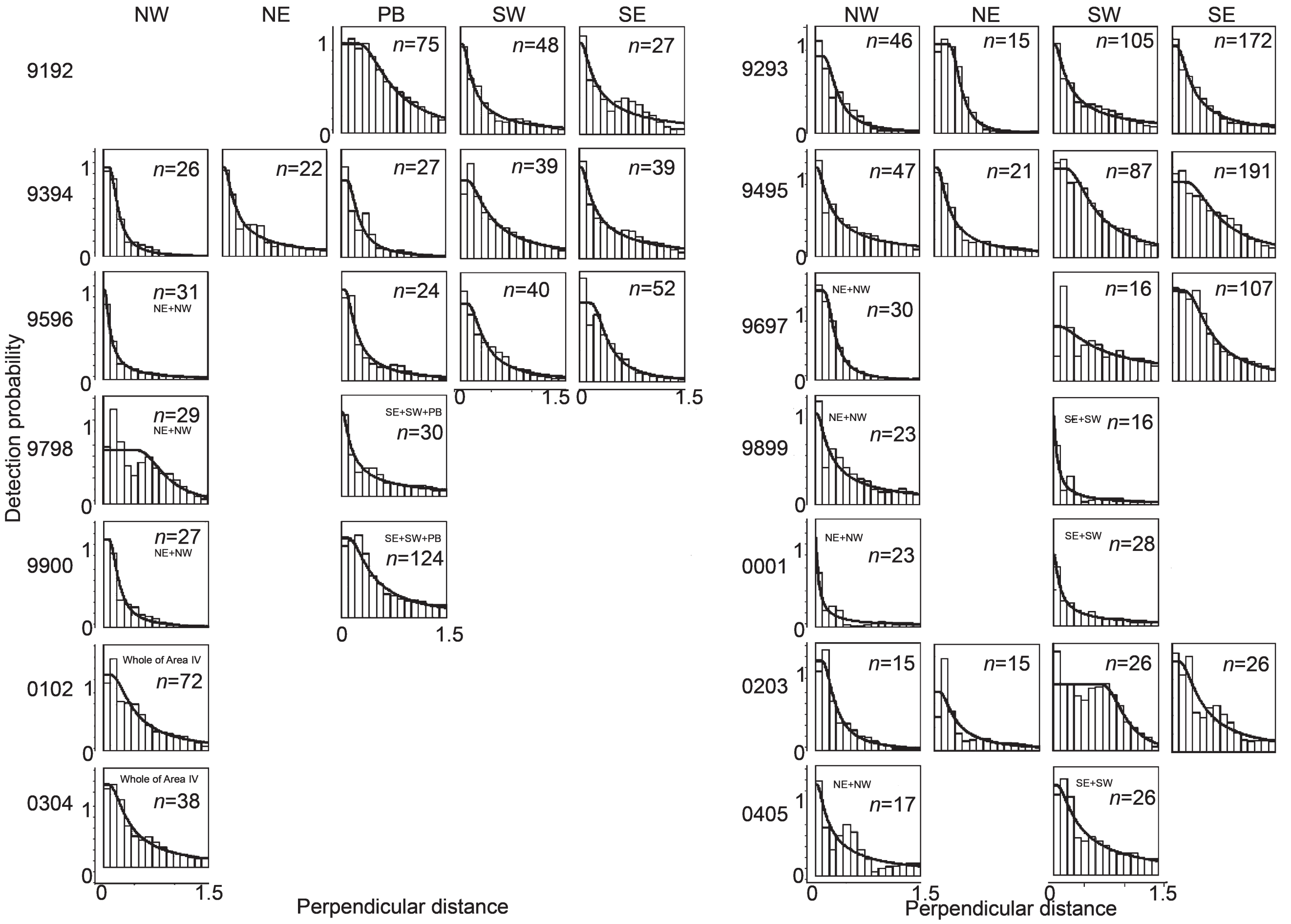

Fig. 5b. Histograms of the smeared perpendicular distance (in n.miles) distributions of minke school sightings with fitted detection functions for each stratum in Areas IV and V for SVC data. *n* is the number of the sightings used in estimation of the detection function.

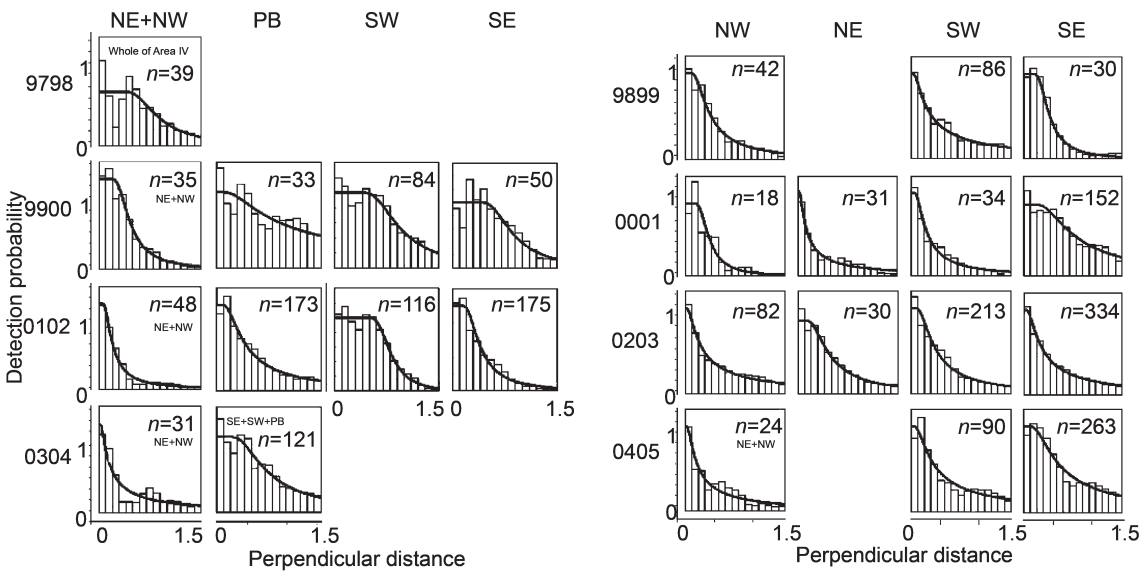

Fig. 5c. Histograms of the smeared perpendicular distance (in n.miles) distributions of minke school sightings with fitted detection functions for each stratum in Areas IV and V for SVP data. *n* is the number of the sightings used in estimation of the detection function.

previous analyses (Hakamada *et al.*, 2006) as model error is now taken into account. This weakens the power of these data to detect such effects. For humpback whales, similarly no significant effect of survey mode and survey timing was detected (Matsuoka *et al.*, 2011). Table 5 shows abundance trend estimates for equation (7)–(10) in base case. For equation (8) (i.e. Model (ii)) which takes account of the possible effect of survey mode, these estimates are 0.018 (unchanged) for Area IV and 0.009 (about 1% less) for Area V, respectively, so that the possible size of the effect is well within the overall trend estimation uncertainty (standard errors of about 2%).

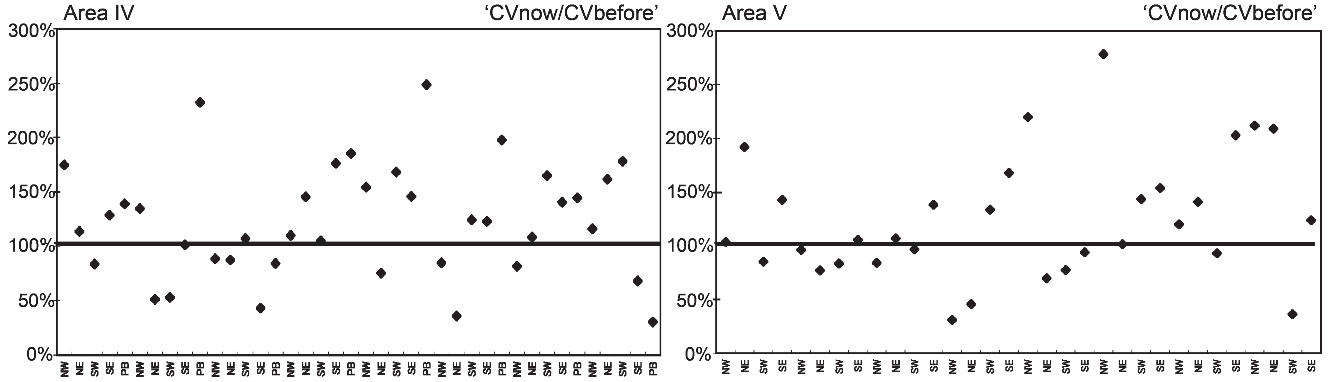

Fig. 6 Comparison estimated CV of encounter rate for each stratum in this study with that in previous study which did not make allowance for correlations amongst parallel tracklines. The horizontal lines indicate where the CVs from this study and the previous study would be the same.

Table 6

AIC$_c$, estimated instantaneous annual rates of increase (α) and estimated additional variance (σ) the various log–linear models applied to estimate α for Areas IV and V where the minke whale abundance estimates input to those models are for the base case (i.e. the estimates shown in Tables 5a–f). Values shown in bold below are for the model selected on the basis on minimum AICc.

Model	AIC$_c$	ΔAIC$_c$	α	SE(α)	α95%*LL*	α95%*UL*	σ	SE(σ)
Area IV								
(i)	**77.549**	**0.00**	**0.018**	**0.021**	**–0.025**	**0.060**	**0.682**	**0.072**
(ii)	82.468	4.92	0.018	0.023	–0.027	0.064	0.681	0.072
(iii) with T1	85.740	8.19	0.019	0.023	–0.027	0.064	0.648	0.071
(iii) with T2	87.158	9.61	0.018	0.023	–0.028	0.065	0.675	0.072
(iii) with T3	78.804	1.26	0.018	0.022	–0.026	0.061	0.620	0.069
(iii) with T4	83.204	5.65	0.014	0.023	–0.031	0.059	0.666	0.072
(iv) with T1	104.569	27.02	–0.005	0.039	–0.084	0.074	0.582	0.068
(iv) with T2	99.223	21.67	0.028	0.036	–0.044	0.100	0.652	0.070
(iv) with T3	87.496	9.95	0.016	0.025	–0.033	0.065	0.588	0.067
(iv) with T4	89.065	11.52	0.021	0.026	–0.030	0.072	0.640	0.070
Area V								
(i)	**59.000**	**0.00**	**0.019**	**0.021**	**–0.030**	**0.069**	**0.626**	**0.078**
(ii)	61.257	2.26	0.008	0.022	–0.042	0.058	0.606	0.077
(iii) with T1	65.122	6.12	0.002	0.022	–0.046	0.050	0.575	0.076
(iii) with T2	63.541	4.54	0.005	0.022	–0.043	0.054	0.580	0.077
(iii) with T3	62.179	3.18	0.001	0.022	–0.046	0.049	0.556	0.075
(iii) with T4	61.586	2.59	0.001	0.022	–0.049	0.050	0.589	0.077
(iv) with T1	78.787	19.79	–0.022	0.030	–0.085	0.040	0.503	0.072
(iv) with T2	74.516	15.52	–0.011	0.030	–0.074	0.052	0.555	0.075
(iv) with T3	62.454	3.45	–0.021	0.026	–0.077	0.034	0.489	0.072
(iv) with T4	61.001	2.00	–0.028	0.027	–0.086	0.031	0.535	0.074

Table 7

Estimated coefficients of the log–linear models selected on the basis of AICc to provide estimates of the rate of increase in minke whale abundance, α.

Area IV			Area V		
Parameter	Estimate	SE	Parameter	Estimate	SE
factor(S)SW	8.176	0.263	factor(S)SW	9.256	0.274
factor(S)SE	8.215	0.263	factor(S)SE	10.194	0.277
factor(S)NW	8.625	0.274	factor(S)NW	9.694	0.271
factor(S)NE	8.788	0.278	factor(S)NE	9.935	0.277
factor(S)PB	8.391	0.277	α	0.019	0.021
α	0.018	0.021	σ	0.626	0.078
σ	0.682	0.072			

Survey timing

In order to understand the effect of survey timing better, the relationship between the ice edge, abundance estimates and migration patterns of the minke whales need to be investigated further in future. JARPA II (Government of Japan, 2005) has conducted sighting surveys in the northern and southern parts of the survey area simultaneously, similarly to the IDCR-SOWER surveys. Thus it is expected that any interaction between survey timing and the order in which the strata are surveyed will be better estimated when JARPA II data become available to use in addition in these analyses.

Underestimation of additional variance

In principle, additional variance (the size of model error) should be estimated using REML rather than MLE to avoid

Table 8

Abundance estimates for Areas IV and V based upon data for each survey mode separately. The CVs are estimated by a parametric bootstrap approach (see text for details).

Area IV							Area V						
Year	P_{SSV}	CV(P_{SSV})	P_{SVC}	CV(P_{SVC})	P_{SVP}	CV(P_{SVP})	Year	P_{SSV}	CV(P_{SSV})	P_{SVC}	CV(P_{SVC})	P_{SVP}	CV(P_{SVP})
1989/90	29,993	0.527					1990/91	100,745	0.445				
1991/92	32,418	0.720					1992/93	66,147	0.488	137,356	0.503		
1993/94	27,989	0.539	26,546	0.909			1994/95	85,258	0.655	152,477	0.586		
1995/96	28,919	0.579	51,264	0.703			1996/97	89,415	0.640	118,599	0.657		
1997/98	17,272	0.763	15,936	0.776			1998/99	118,017	0.537	132,667	2.335		
1999/00	42,852	0.495	74,312	0.739	42,858	0.555	2000/01	101,854	0.566	333,090	4.043	186,019	1.172
2001/02	46,355	0.660	24,471	0.579	58,176	0.744	2002/03	151,359	0.572	112,102	0.690	205,352	0.439
2003/04	59,918	1.031	25,910	0.969	48,984	1.050	2004/05	68,425	0.461	79,901	0.802	84,930	0.571

Table 9

Weights (w) (see text) and the weighted average over survey modes to provide a minke whale abundance estimate (P_{WA}) for each year. The reason why w_{SVC} is zero for 2000/01 is explained in the text.

Area IV						Area V					
Year	W_{SSV}	W_{SVC}	W_{SVP}	P_{WA}	CV(P_{WA})	Year	W_{SSV}	W_{SVC}	W_{SVP}	P_{WA}	CV(P_{WA})
1989/90	1.00	–	–	29,993	0.527	1990/91	1.00	–	–	100,745	0.445
1991/92	1.00	–	–	32,418	0.720	1992/93	0.82	0.18	–	78,919	0.371
1993/94	0.73	0.27	–	27,598	0.473	1994/95	0.72	0.28	–	104,013	0.458
1995/96	0.82	0.18	–	32,970	0.458	1996/97	0.65	0.35	–	99,680	0.461
1997/98	0.47	0.53	–	16,562	0.542	1998/99	0.95	0.05	–	118,779	0.515
1999/00	0.53	0.07	0.41	44,945	0.338	2000/01	0.94	0.00	0.06	106,991	0.523
2001/02	0.16	0.76	0.08	30,807	0.402	2002/03	0.33	0.39	0.28	151,072	0.326
2003/04	0.11	0.74	0.15	32,970	0.682	2004/05	0.62	0.14	0.24	74,030	0.336

Table 10

Variance-covariance matrices for the logarithm of minke whale abundance estimates when weighted over survey modes for Areas IV and V.

Area IV	1989/90	1991/92	1993/94	1995/96	1997/98	1999/00	2001/02	2003/04
1989/90	0.245							
1991/92	–0.017	0.418						
1993/94	–0.002	–0.008	0.202					
1995/96	–0.003	0.004	0.013	0.190				
1997/98	0.008	–0.009	0.008	0.005	0.258			
1999/00	0.003	0.002	–0.001	–0.008	–0.006	0.108		
2001/02	0.004	0.014	0.009	–0.001	–0.006	–0.002	0.149	
2003/04	–0.013	–0.016	–0.018	–0.004	–0.001	0.002	0.013	0.382
Area V	1990/91	1992/93	1994/95	1996/97	1998/99	2000/01	2002/03	2004/05
1990/91	0.181							
1992/93	–0.003	0.126						
1994/95	0.001	0.004	0.188					
1996/97	0.004	–0.001	0.001	0.194				
1998/99	–0.002	0.004	–0.001	0.009	0.236			
2000/01	0.003	–0.003	–0.004	0.010	0.006	0.243		
2002/03	–0.005	–0.009	0.006	–0.005	–0.008	0.007	0.100	
2004/05	–0.007	–0.004	0.004	–0.001	0.002	–0.001	0.004	0.107

negative bias, but this would lead to difficulties in model selection. This is a matter which merits future investigation. However the quantitative consequences seem likely to be rather small, as the standard linear model adjustment for loss of degrees of freedom through estimation of additional parameters associated with the co-variates included in the model chosen here would increase the standard errors of estimates by no more than some 3–4%.

Abundance trend estimates from JARPA

Fig. 7 compares the exponential trend estimated by model (i) with the estimates of abundance by year for the base case model for each of Area IV and V which are given in Table 12.

For all the models and sensitivities examined, the point estimates of the abundance trend in Area IV fall within the 95% confidence intervals for the model selected. For Area V, the trend estimates are not substantially different among the sensitivities examined except in two cases. For these a different log-linear model was selected. Even so, these two point estimates fall within the 95% CI for the base case model for Area V. The provision of more data from JARPA II should see an improvement in precision and greater power to detect the possible effects of survey timing and mode.

Adjustment for g(0) < 1 and comparison with the minke whale abundance estimates derived from IDCR-SOWER

Fig. 8 repeats Fig. 7 with the base case estimates of abundance replaced by $g(0)$-adjusted estimates. Other than an approximate doubling of abundance in absolute terms, these figures are very similar. Fig. 8 also shows the IWC-SOWER estimates for Areas IV and V from the second and third circumpolar cruises as agreed at the 2012 IWC-SC meeting (IWC, 2013). In three of the four cases there is very good agreement between the IWC-SOWER point estimates and the exponential trend estimated from applying model (i) to the JARPA data. The exception is the point estimate for the 1985/86 CPII estimate for Area V which is appreciably larger than the following JARPA and CPIII estimates.

Table 11

The values of $g(0)$ predicted by the regression model of equation (20) and mean school size $E(s)$ for the various JARPA strata. Instances where these fall below or above the lowest (0.794) or highest (0.405) OK values used in developing the regression relationship are shown in italics. When calculating $g(0)$-adjusted abundance estimates for the JARPA surveys using the values below, those values in italics have been replaced by the appropriate bounding OK value. Note also, as specified in the text, that values of $E(s)$ below that are greater than 8 were set equal to 8 when applying the regression model to calculate $g(0)$.

Area IV SSV			Area IV SVC			Area V SSV			Area V SVC		
Strata	$g(0)$	$E(s)$	Strata	$g(0)$	$E(s)$	Strata	$g(0)$	$E(s)$	Strata	$g(0)$	$E(s)$
8990NW	0.514	1.321	9192SW	0.556	3.543	9091NW	0.477	2.277	9293NW	0.608	1.565
8990NE	0.467	2.250	9192SE	0.560	2.769	9091NE	0.600	2.167	9293NE	0.759	8.059
8990SW	0.612	1.988	9192PB	0.627	5.805	9091SW	0.566	2.706	9293SW	0.506	4.479
8990SE	0.577	2.700	9394NW	0.505	1.280	9091SE	0.505	2.429	9293SE	0.442	3.535
8990PB	0.617	1.767	9394NE	0.482	1.650	9293NW	0.615	1.500	9495NW	0.465	3.627
9192NW	0.460	1.729	9394SW	0.419	2.700	9293NE	0.600	1.543	9495NE	0.583	1.958
9192NE	*0.274*	2.208	9394SE	0.518	3.328	9293SW	0.447	3.613	9495SW	0.503	3.875
9192SW	0.624	2.271	9394PB	0.635	1.545	9293SE	0.579	2.342	9495SE	0.490	4.239
9192SE	0.623	1.842	9596NW	0.498	2.353	9495NW	0.565	2.414	9697NW	0.486	3.929
9192PB	0.581	2.507	9596NE	0.445	2.222	9495NE	0.584	1.631	9697NE	0.582	1.933
9394NW	0.512	1.375	9596SW	0.604	2.800	9495SW	0.534	2.780	9697SW	0.682	7.100
9394NE	0.468	1.767	9596SE	0.480	3.322	9495SE	0.565	2.256	9697SE	0.623	6.223
9394SW	0.520	2.266	9596PB	0.579	1.960	9697NW	0.599	1.683	9899NW	0.604	3.500
9394SE	0.562	2.843	9798NW	0.497	2.824	9697NE	0.601	1.903	9899NE	0.556	2.150
9394PB	0.652	2.049	9798NE	0.509	1.800	9697SW	0.524	3.079	9899SW	0.483	4.143
9596NW	0.490	2.344	9798SW	*0.359*	1.806	9697SE	0.413	3.101	9899SE	0.483	4.143
9596NE	0.442	1.882	9798SE	*0.359*	1.806	9899NW	0.604	1.865	0001NW	0.633	6.118
9596SW	0.598	2.268	9798PB	*0.359*	1.806	9899NE	0.574	2.744	0001NE	0.633	6.118
9596SE	0.515	2.535	9900NW	0.501	1.381	9899SW	0.512	4.575	0001SW	0.536	1.727
9596PB	0.625	1.465	9900NE	0.501	1.381	9899SE	0.581	2.235	0001SE	0.588	2.250
9798NW	*0.323*	2.632	9900SW	0.618	2.600	0001NW	0.573	1.872	0203NW	0.599	2.231
9798NE	0.415	1.708	9900SE	0.650	6.140	0001NE	0.531	1.984	0203NE	0.613	1.636
9798SW	0.525	2.011	9900PB	0.568	4.917	0001SW	0.409	3.038	0203SW	0.565	2.000
9798SE	0.590	1.742	0102NW	*0.365*	1.627	0001SE	0.431	3.365	0203SE	0.567	1.931
9798PB	0.545	3.065	0102NE	*0.365*	1.627	0203NW	0.570	2.189	0405NW	0.597	1.526
9900NW	0.510	1.208	0102SW	0.476	1.627	0203NE	0.578	1.931	0405NE	0.597	1.526
9900NE	0.513	1.314	0102SE	0.476	1.627	0203SW	0.419	3.196	0405SW	0.593	2.357
9900SW	0.497	3.865	0102PB	0.476	1.627	0203SE	0.472	2.691	0405SE	0.532	2.219
9900SE	0.775	8.737	0304NW	*0.375*	3.710	0405NW	0.578	2.200			
9900PB	0.461	2.821	0304NE	*0.375*	3.710	0405NE	0.585	1.543			
0102NW	0.503	1.368	0304SW	0.486	3.710	0405SW	0.742	8.391			
0102NE	*0.337*	2.027	0304SE	0.486	3.710	0405SE	*0.366*	2.393			
0102SW	0.594	1.741	0304PB	0.486	3.710						
0102SE	0.548	2.036									
0102PB	0.500	3.077									
0304NW	0.513	1.373									
0304NE	0.447	1.574									
0304SW	0.507	2.717									
0304SE	0.586	1.856									
0304PB	0.639	1.966									

However, when the confidence intervals for both the CPII estimate and the exponential trend are considered (see Fig. 8), together with the fact that considerable backward extrapolation of that trend is needed for comparison with the IDCR-SOWER estimate during a period when the actual (log-)population trend might not have been linear, there appears no obvious inconsistency. Nevertheless, comparison of Area V estimates on a finer spatial scale to identify the main source of this difference would seem desirable to aid understanding. Both the JARPA and IDCR-SOWER CIs shown in Fig. 8 incorporate additional variance (σ^2 – see equations (7)–(10) and the text following). The CIs for the JARPA surveys are notably larger, arising from a σ value of about 0.65 which is larger than that for the IDCR-SOWER surveys. This additional variance arises from differing proportions of the overall population in a particular region surveyed from one season to another; the reasons for the larger values for the JARPA surveys merit further investigation, but may relate to the fact that these surveys extended over a longer period than the IDCR-SOWER surveys (typically about three to about two months respectively), hence allowing for more movement of minke whales into and out of the Areas while these were under survey.

The approach used here to adjust for $g(0)$ is novel and the fit of the regression model to the IDCR-SOWER $g(0)$ estimates shown in Fig. 4 is not ideal, so that some improvement should be sought, Clearly there is scope to attempt this, particularly by investigating the inclusion of other co-variates, such as those related to sighting conditions such as Beaufort sea state. The regression approach may introduce bias, as the form of the detection function for the OK approach differs from that assumed for this analysis in equation (19); the size of this bias could be investigated by applying the methods of this paper to the IDCR-SOWER data and comparing the results to those obtained using the OK method of Okamura and Kitakado (2012). Furthermore, in JARPA II, the SVs use Closing mode and Passing mode

Table 12

Minke whale abundance estimates when weighted over survey modes for the various sensitivity tests. For estimating the annual rate of increase (α), the best log-linear model in terms of AICc was selected separately for each sensitivity test. Percentage changes are relative to the base case. For the base case the CV of each estimate is shown in parentheses.

Area IV – Year	1989/90	1991/92	1993/94	1995/96	1997/98	1999/00	2001/02	2003/04	Average of change	ROI	Change from base case
Base case	**29,993** **(0.527)**	**32,418** **(0.720)**	**27,598** **(0.473)**	**32,970** **(0.458)**	**16,562** **(0.542)**	**44,945** **(0.338)**	**30,807** **(0.402)**	**32,970** **(0.682)**	–	**1.8%**	–
Alternative detection functions	26,765 –10.8%	30,542 –5.8%	27,373 –0.8%	27,441 –16.8%	20,658 24.7%	50,426 12.2%	41,307 34.1%	45,757 38.8%	– 9.5%	3.5%	1.7%
Trackline option B	28,907 –3.6%	32,601 0.6%	25,216 –8.6%	29,200 –11.4%	18,395 11.1%	38,708 –13.9%	34,273 11.2%	25,408 –22.9%	– –4.7%	0.9%	–0.9%
Trackline option C	29,537 –1.5%	30,922 –4.6%	31,592 14.5%	32,017 –2.9%	19,217 16.0%	34,803 –22.6%	33,146 7.6%	57,104 73.2%	– 10.0%	2.4%	0.6%
Gap density = 0	29,993 –	32,419 –	27,542 –	30,191 –8.4%	16,457 –	45,748 1.8%	32,162 4.4%	30,722 –6.8%	– –2.3%	1.7%	–0.1%
Gap density = stratum to the south	29,993 –	32,419 –	27,579 –	32,629 –1.0%	16,585 –	52,439 16.7%	29,434 –4.5%	33,745 2.3%	– 3.4%	2.1%	0.3%
Extrapolation for incomplete coverage	29,993 –	32,419 –	27,663 0.2%	33,827 2.6%	16,600 0.2%	44,605 –0.8%	32,119 4.3%	35,873 8.8%	– 2.6%	1.7%	0.0%
Skipping correction (ignoring the first two surveys)	– –	– –	27,598 –	32,970 –	16,562 –	44,945 –	30,807 –	32,970 –	– –	1.7%	0.0%
g(0) adjustment	57,548 91.9%	63,180 94.9%	52,515 90.3%	71,184 115.9%	36,127 118.1%	80,576 79.3%	73,310 138.0%	72,490 119.9%	106.0%	2.7%	0.9%
Area V – Year	**1990/91**	**1992/93**	**1994/95**	**1996/97**	**1998/99**	**2000/01**	**2002/03**	**2004/05**	**Average of change**	**ROI**	**Change from base case**
Base case	**100,745** **(0.445)**	**78,919** **(0.371)**	**104,013** **(0.458)**	**99,680** **(0.461)**	**118,779** **(0.515)**	**106,991** **(0.523)**	**151,072** **(0.326)**	**74,030** **(0.336)**	–	**1.9%**	–
Alternative detection functions	85,107 –15.5%	73,144 –7.3%	105,176 1.1%	90,845 –8.9%	105,911 –10.8%	109,851 2.7%	152,529 1.0%	75,098 1.4%	– –4.5%	2.3%	0.4%
Trackline option B	100,746 –	79,098 0.2%	105,837 1.8%	102,864 3.2%	118,871 0.1%	107,204 0.2%	143,917 –4.7%	81,630 10.3%	– 1.6%	2.7%	0.7%
Trackline option C	100,746 –	82,452 4.5%	104,202 0.2%	105,673 6.0%	120,056 1.1%	108,502 1.4%	151,934 0.6%	75,707 2.3%	– 2.3%	1.9%	0.0%
Extrapolation for incomplete coverage	99,613 –1.1%	88,677 12.4%	110,070 5.8%	101,298 1.6%	118,846 0.1%	107,829 0.8%	149,881 –0.8%	96,626 30.5%	– 6.2%	2.9%	1.0%
Skipping correction			104,013 –	99,680 –	118,779 –	106,991 –	151,072 –	74,030 –	– –	3.7%	1.8%
g(0) adjustment	193,162 91.7%	134,375 70.3%	173,201 66.5%	200,064 100.7%	223,921 88.5%	240,718 125.0%	250,012 65.5%	136,766 84.7%	86.6%	1.6%	–0.3%

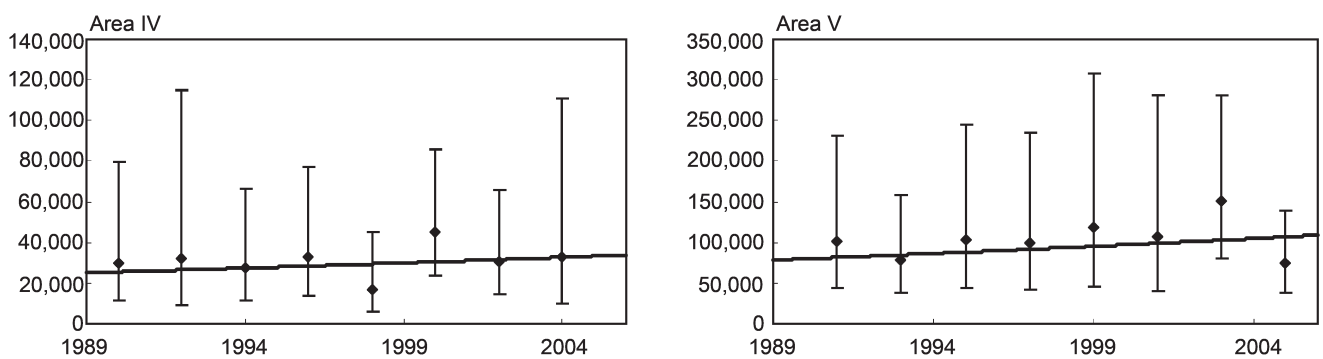

Fig. 7. The base case estimates of annual abundance from Table 12 together with their 95% CIs are compared to exponential trend estimated by the AIC_c-selected model (i) of equation (7) for Areas IV and V.

where the latter now includes an Independent Observer (Matsuoka *et al.*, 2012). The availability of data on duplicate sightings will allow the application of methods such as OK and SPLINTR to estimate *g*(0) directly, which will hopefully reduce variance compared to the *g*(0)-adjusted estimates of this paper and hence improve estimates of trends in

Table 13

Estimated annual rates of increase in minke whale abundance (α), together with their standard errors and 95% confidence intervals, as provided by the log-linear model selected by AICc for the base case and sensitivities for Areas IV and V. σ is the standard deviation of the 'model error' distribution associated with the logarithms of the abundance estimates.

Base_P: Base case (based on abundance). Base_D: Base case but using density instead of abundance. TB: Trackline option B. TC: Trackline option C. DF: Alternative detection function. *G*0: Density in Gap = 0. GB: Density in Gap is as in stratum to the south. IC: Extrapolation in incomplete coverage area. SK: Omit years when skipping occurred.

Sensitivity	α	SE(α)	α95%*LL*	α95%*UL*	σ	SE(σ)	Selected model
Area IV							
Base_P	0.018	0.021	–0.025	0.060	0.682	0.072	(i)
Base_D	0.020	0.020	–0.021	0.060	0.629	0.067	(i)
TB	0.009	0.022	–0.036	0.054	0.731	0.075	(i)
TC	0.024	0.021	–0.018	0.067	0.679	0.072	(i)
DF	0.035	0.022	–0.008	0.078	0.690	0.073	(i)
G0	0.017	0.021	–0.025	0.059	0.672	0.071	(i)
GB	0.021	0.022	–0.022	0.063	0.689	0.072	(i)
IC	0.017	0.021	–0.025	0.059	0.668	0.071	(i)
SK	0.028	0.031	–0.033	0.090	0.709	0.079	(i)
g(0) adjusted	0.027	0.021	–0.015	0.069	0.662	0.069	(i)
Area V							
Base_P	0.019	0.021	–0.030	0.069	0.626	0.07	(i)
Base_D	0.022	0.020	–0.024	0.069	0.562	0.070	(i)
TB	–0.023	0.027	–0.081	0.035	0.526	0.073	(iv) with T4
TC	–0.035	0.027	–0.093	0.023	0.531	0.073	(iv) with T4
DF	0.023	0.021	–0.028	0.073	0.639	0.079	(i)
IC	0.029	0.021	–0.020	0.078	0.614	0.075	(i)
SK	0.037	0.032	–0.039	0.114	0.674	0.089	(i)
g(0) adjusted	0.016	0.021	–0.034	0.067	0.641	0.079	(i)

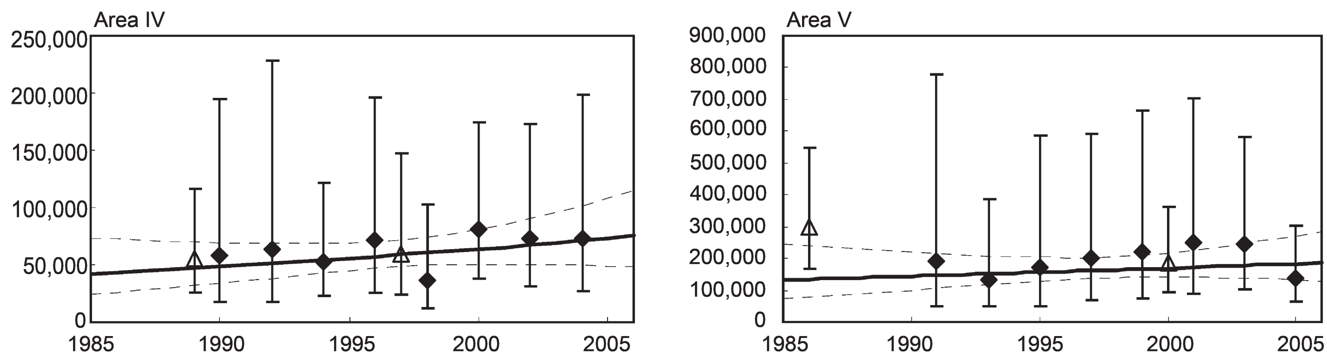

Fig. 8. Plots as for Figure 7, but with the abundance estimates and associated exponential model for the base case replaced by the corresponding g(0)-adjusted results. The IDCR-SOWER estimates for a common northern boundary for CPII and CPIII as agreed by the 2012 IWC SC meeting are shown by the open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

abundance for the minke whales based on JARPA and JARPA II information in combination.

Application of JARPA abundance trend

One of the features of JARPA is that, unlike for the IDCR-SOWER programme, surveys have been repeated in the same area and in the same months every second year over a long period. Therefore the JARPA 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 (Mori *et al.*, 2006; Punt *et al.*, 2012). Through their use in such population models, the abundance estimates and trends derived from JARPA which are reported in this paper provide information to complement that available to estimate the productivity of Antarctic minke whales in Areas IV and V.

ACKNOWLEGEMENTS

We would like to express our gratitude to Doug Butterworth, Sharon Hedley and Paul Wade for their valuable comments to improve the manuscript, though naturally the interpretations offered in the paper are those of its authors and are not necessarily held by reviewers. We would like to express our gratitude to anonymous reviewers for their useful comments to improve this manuscript, to Hiroshi Okamura for kindly providing *g*(0) estimates from and school size data used for the OK model as well as his useful suggestions to improve the manuscript. In addition we thank Luis Pastene for improving an earlier version of this paper, and Hiroshi Kiwada, Atsushi Wada, Tomoko Hasegawa and Kazuhiro Oshima for their assistance in dealing with sighting data for the analyses and producing the figures for this paper. Naturally this work would not have been possible without the considerable and appreciated efforts of all the researchers, Captains, officers and crew members who have participated in the JARPA surveys.

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Appendix 1

THE JARPA SURVEYS AND THEIR MAIN OBJECTIVES

The JARPA (Japanese Whale Research Programme under Special Permit in the Antarctic) was a large-scale and long-term monitoring program using line-transect surveys with catches of Antarctic minke whales taken under permits issued by the Government of Japan under Article VIII of the International Convention for the Regulation of Whaling (ICRW). In parallel with lethal sampling surveys, a variety of non-lethal surveys, e.g. oceanographic surveys, photo identification and biopsy sampling for large baleen whales, and prey species surveys were conducted. These surveys were carried out in a broadly consistent way every other year in Areas IV and V commencing with the 1987/88 survey during the austral summer season (Hatanaka *et al.*, 2006; Nishiwaki *et al.*, 2006). Table A1 provides a summary of the JARPA surveys.

The main objectives of JARPA were: (a) estimation of

Table A1

Summary of the JARPA surveys from the 1987/88 to 2004/05 seasons (Area, period, vessel and number of samples of Antarctic minke whales). Area IIIE: (35°E–70°E), IV: (70°E–130°E), V: (130°E–170°W), VIW: (170°W–145°W).

		IWC Area					Research vessel			Number of minke whales sampled				
No.	Year	IIIE	IV	V	VIW	Research period (days)	RBS	SSV	SV	IIIE	IV	V	VIW	Total***
1	1987/88	–	∧*	–	–	1988.1.17–1988.3.26 (70)	NM3	K01/T25	–	–	273	–	–	273 (1)
2	1988/89	–	–	∧*	–	1989.1.12–1989.3.31 (79)	NM3	K01/T25/T18	–	–	–	241	–	241 (5)
3	1989/90	–	○	–	–	1989.12.6–1990.3.12 (97)	NM3	K01/T25/T18	–	–	330	–	–	330 (3)
4	1990/91	–	–	○	–	1990.12.19–1991.3.22 (94)	NM3	K01/T25/T18	–	–	–	327	–	327 (4)
5	1991/92	–	○	–	–	1991.12.5–1992.3.25 (112)	NM	K01/T25/T18	**	–	288	–	–	288
6	1992/93	–	–	○	–	1992.12.3–1993.3.24 (112)	NM	K01/T25/T18	**	–	–	330	–	330 (3)
7	1993/94	–	○	–	–	1993.12.3–1994.3.19 (107)	NM	K01/T25/T18	**	–	330	–	–	330
8	1994/95	–	–	○	–	1994.12.3–1995.3.21 (109)	NM	K01/T25/T18	**	–	–	330	–	330
9	1995/96	○	○	–	–	1995.11.26–1996.3.22 (118)	NM	K01/T25/T18	KS2	110	330	–	–	440
10	1996/97	–	–	○	○	1996.11.30–1997.3.13 (103)	NM	K01/T25/T18	KS2	–	–	330	110	440
11	1997/98	○	○	–	–	1997.12.7–1998.3.14 (98)	NM	K01/T25/T18	KS2	110	328	–	–	438
12	1998/99	–	–	○	○	1999.1.13–1999.3.31 (78)	NM	YS1/K01/T25	KS2	–	–	329	60	389
13	1999/00	○	○	–	–	1999.12.5–2000.3.10 (97)	NM	YS1/K01/T25	KS2	109	330	–	–	439
14	2000/01	–	–	○	○	2000.12.11–2001.3.20 (100)	NM	YS1/K01/T25	KS2	–	–	330	110	440
15	2001/02	○	○	–	–	2001.11.29–2002.3.8 (100)	NM	YS1/K01/T25	KS2	110	330	–	–	440
16	2002/03	–	–	○	○	2002.12.2–2003.3.8 (97)	NM	YS1/K01/T25	KS2	–	–	330	110	440
17	2003/04	○	○	–	–	2003.11.30–2004.3.3 (95)	NM	YS1/YS2/K01	KS2	110	330	–	–	440
18	2004/05	–	–	○	○	2004.12.7–2005.3.8 (92)	NM	YS1/YS2/K01	KS2	–	–	330	110	440

Abbreviations: RBS: research base vessel; SSV: sighting and sampling vessel; SV: dedicated sighting vessel. NM3: *Nisshin-maru No.3*; NM: *Nisshin-maru*; K01: *Kyo-maru No.1*; T25: *Toshi-maru No.25*; T18: *Toshi-maru No.18*; KS2: *Kyoshin-maru No.2*; YS1: *Yusin-maru*; YS2: *Yusin-maru No.2*.
*The feasibility surveys. A part of Areas IV and V was surveyed. **One of the SSVs was allocated as the SV. ***Sampled number of dwarf minke whales is in parentheses.

biological parameters of the Antarctic minke whale to improve stock management; (b) elucidation of the role of whales in the Antarctic marine ecosystem through whale feeding ecology; (c) elucidation of the effect of environmental change on cetaceans; and (d) elucidation of the stock structure of the Antarctic minke whale to improve stock management (Government of Japan, 1987; 1995; 1996). The third and the fourth objectives were added in the 1995/96 and the 1996/97 seasons, respectively. In order to address the first objective, JARPA comprised a combination of sighting and sampling surveys. JARPA contributed to monitoring of whales stocks in the surveyed areas (IWC, 2008).

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Appendix 2

SIGHTING SURVEY PROCEDURES DURING JARPA

This Appendix details the sighting survey procedures which were applied during JARPA as they relate to abundance estimation for Antarctic minke whales. It is based on Nishiwaki *et al.* (2006).

Stratification of the research area

Following results from the first two years of research (which were feasibility studies, and suggested different densities with segregation by sex and maturity of Antarctic minke whales by region), the main area selected for the full scale research comprised Antarctic Area IV (70°E–130°E) and Area V (130°E–170°W) south of 60°S, with each of these Areas divided into smaller strata (see Fig. 1 of main text). Area IV was divided into two sectors, east and west, by the 100°E line of longitude. These sectors were then divided further into two strata, a south stratum extending from the ice edge to a locus 45 n.miles from the edge, and a north stratum extending from the northern boundary of the south stratum to the northern boundary at 60°S. The southern boundary of the West-south stratum between 70°E and 80°E was fixed at 66°S, and the

Prydz Bay stratum was defined as the area south of this boundary. Area V was divided into east and west sectors at 165°E. The west sector was further divided into north and south strata in the same manner as Area IV. The southern boundary of the East-north stratum was fixed at 69°S and the East-south stratum (the Ross Sea) was defined as the area south of this boundary.

Seasonal and spatial coverage

Some experimental research areas were specified in Areas IV and V during the JARPA surveys. These additional areas were surveyed principally before and/or after the regular surveys of Areas IV and V, so that the regular survey in the Antarctic summer season (the peak migration period for Antarctic minke whales) was not disturbed. Fig. 2 of the main text shows the research periods for the regular surveys used for the abundance estimation for each year.

Double coverage of the entire Area (1989/90–1991/92)

From 1989/90 to 1991/92, Areas IV and V were covered twice at different times to analyse the changes of population density of whales by season and area. This indicated that the peak migration season for Antarctic minke whales corresponded to the latter half of the first period and the first half of the second period of the surveys concerned (i.e. roughly the start of January to the end of February). From the 1992/93 season, the research area was covered once each year.

The order in which strata were surveyed

Abundances south of 60°S are estimated using sighting data collected during the peak migration season, mainly January and February, and are based on single coverage of each stratum for the survey concerned. The orders in which strata were surveyed on JARPA surveys in Areas IV and V are shown in Fig. A1a and A1b, and differed from year to year. The rationale for these changes at the time was to make sure that each stratum was not always surveyed in the same month from year to year, which it was thought might introduce a bias in the estimation of absolute abundance.

Design of the trackline

JARPA maintained basically the same design of the research trackline in each stratum of Areas IV and V, although with some modification over time. Fig. A2 shows the typical trackline in each stratum of Areas IV and V. It was designed to cover the whole research area in the same manner during all JARPA surveys. The following concepts were incorporated into the trackline design.

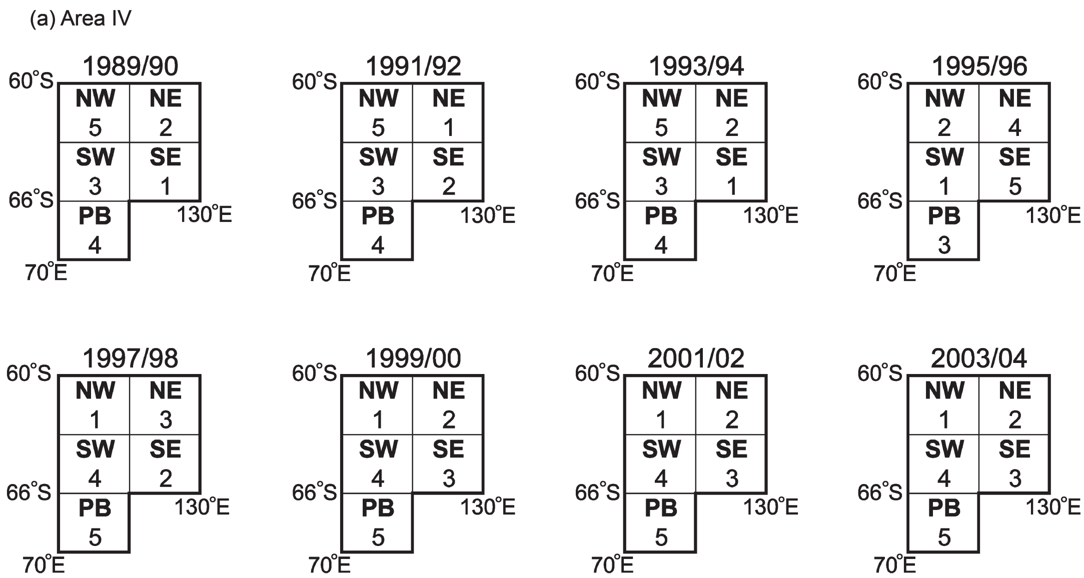

Fig. A1a. Survey order by strata in Antarctic Area IV for the JARPA cruises from 1989/90 to 2003/04.

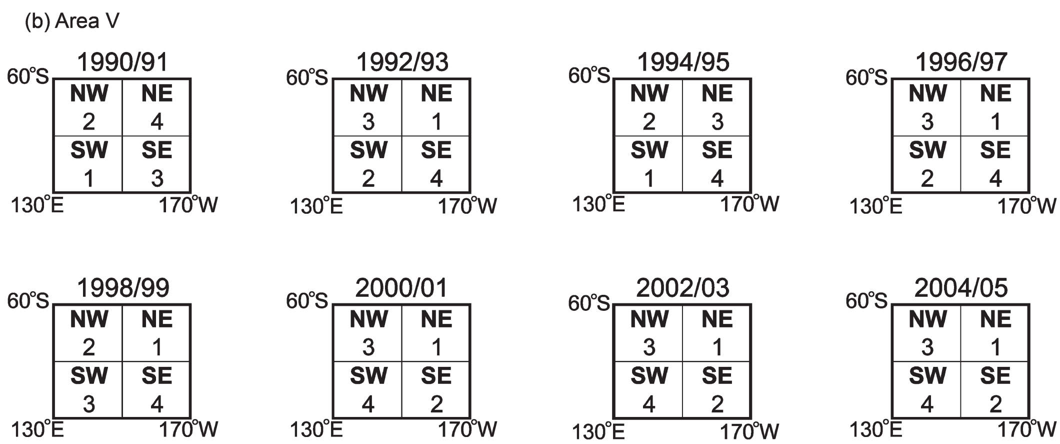

Fig. A1b. Survey order by strata in Antarctic Area V for the JARPA cruises from 1990/91 to 2004/05.

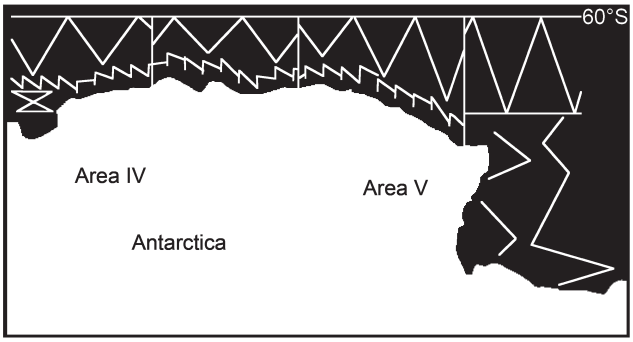

Fig. A2. Conceptual design of research tracklines in JARPA.

(1) South strata in Area IV and the South-west stratum in Area V

A saw-tooth (right triangles) shaped trackline was set at intervals of four degrees longitude. Southern waypoints (turning points) were set on the ice edge and northern waypoints (northern boundary) were set on the locus 45 n.miles from the edge. As the longitude of the first southern waypoint was set randomly, the latitude of the starting point on the boundary of the area was also determined randomly for each south stratum.

The latitude of each southern (ice edge) waypoint was estimated in advance based on the latest ice information, e.g. a pack ice survey in advance, a photograph from a meteorological satellite and/or information from the National Ice Center (formerly the NAVY/NOAA Joint Ice Center). When the ice edge was encountered prior to reaching an estimated waypoint, the SV and SSV stopped the sighting (and sampling) survey and continued along the ice edge until the survey could be resumed on the planned trackline. When the ice edge was not encountered on reaching an estimated southern waypoint, the SV and SSVs stopped the sighting (and sampling) survey and moved south on the line of longitude of the waypoint until the vessels encountered the ice edge. Then the research vessels turned around and resumed the survey northward (Fig. A3a).

(2) North strata in Areas IV and V

A zigzag trackline was set at intervals of 15 degrees longitude in the same style as for the IDCR/SOWER surveys (the length of the trackline was determined from days allocated for research and expected searching distance per day). Southern waypoints were set on the locus 45 n.miles from the ice edge (northern boundary of the south strata). The latitude of the starting point was set at random on the starting line of longitude for each north stratum.

(3) Prydz Bay in Area IV

Prydz Bay was divided into north and south zones, with a trackline of fixed latitude located in each. These two tracklines were diagonally connected and formed a z- or hourglass-shaped line. The southern east-west line was selected at random among the lines of constant latitude at intervals of 15 minutes of latitude intervals between 67°30’S and the ice edge. The northern east-west line was 90 n.miles northwards of the southern east-west line.

(4) South-east stratum in Area V (the Ross Sea)

The basic design comprised two longitudinal zigzag tracklines as adopted for the IDCR-SOWER surveys. The length of the line was determined based on the number of research days allocated, the expected searching distance per day and the amount of open water anticipated in the Ross Sea. When the ice edge was encountered prior to reaching a planned waypoint, the research vessel(s) stopped the sighting (and sampling) survey and followed the ice edge until the survey could be resumed on the planned trackline. When the ice edge was not encountered on reaching an estimated ice edge waypoint, the survey was continued on a bisector line. After the vessel(s) reached the waypoint on the ice edge (the true waypoint), the sighting (and sampling) survey was stopped and the vessel(s) moved back to the estimated waypoint. When the time elapsed from the estimated waypoint to the true waypoint was over two hours, a revised trackline was set from the true waypoint and the next one on the northern boundary (Fig. A3b). Dependent upon the ice conditions in the Ross Sea, modification of the tracklines occurred in some years.

Sighting survey procedure

JARPA maintained its unique sighting and sampling method during all the surveys. In order to try to obtain biological samples representing the whole population in the research area, a random sampling method within the overall line transect sighting survey design was adopted.

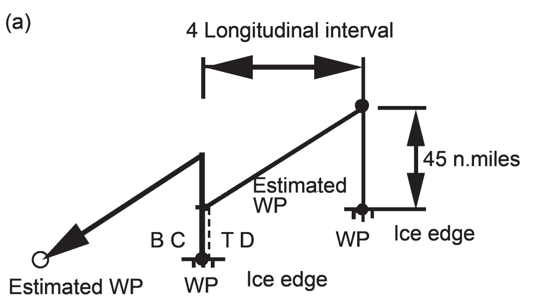

Fig. A3a (left). When the ice edge was not encountered on reaching a planned southern waypoint (estimated WP), the research vessels stopped survey and moved south (TD) on the line of longitude of the WP until the vessels encountered the ice edge. Then the research vessels turned around and resumed the survey (BC) northward.

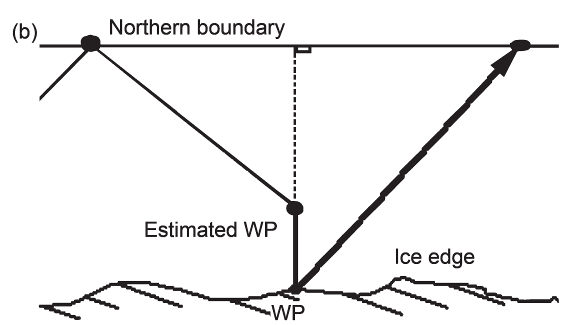

Fig. A3b (right). In the case of surveys in the Ross Sea, the survey was continued on a bisector line after reaching an estimated southern WP. When the time elapsed from the estimated WP to the true WP on ice edge was over two hours, a revised trackline was set from the true WP to the next one on the northern boundary.

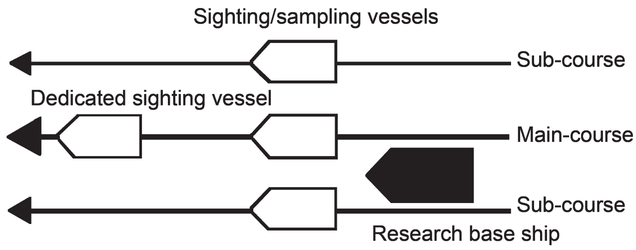

Fig. A4. Configuration of the SV and the three SSVs. The research base ship followed the SV and SSVs so as not to affect the sighting and sampling surveys.

Two or three sighting/sampling vessels (SSVs) conducted the sighting and sampling surveys on the predetermined trackline with parallel track lines 7 n.miles apart at a standard speed of 11.5 knots. The survey operated only under 'optimal' research conditions (when the wind speed was below 25 knots in the south strata or 20 knots in the north strata, and visibility was over 2 n.miles), which ensured good sightability for minke whales.

The location of each SSV amongst the two or three parallel tracklines was changed each day to avoid any possible sighting bias that may have resulted from fixing these locations. Sightings of whales were classified into primary and secondary sightings. Primary sightings were those seen in normal searching mode (three observers searched from the top barrel of the vessel on the predetermined trackline). Secondary sightings were those seen when not in normal searching mode (e.g. during closing or chasing whales, no observer in the top barrel or the vessel engaged in other work) or outside research time. Effectively, the sighting surveys by SSVs were conducted under closing mode (NSC: when a sighting of an Antarctic minke whale was made on the predetermined trackline, the vessel turned to approach it and species and school size were confirmed).

A dedicated sighting vessel (SV) was introduced from the 1991/92 season (see Table A1). One of the three SSVs was allocated as the SV from the 1991/92 to 1994/95 seasons. An additional SV (KS2) was introduced from the 1995/96 season. The sighting survey by the SV was conducted under limited closing mode (ASP: same protocol as NSC but without sampling of whales) and passing mode (NSP: even if a sighting was made on the predetermined trackline, the vessel did not approach the whale directly and searching from the barrel was uninterrupted). NSP mode was introduced from the 1998/99 season on the SV. The SSVs followed the SV by a distance of over 12 n.miles to avoid any influence of the sampling activity on the sighting survey by the SV (Fig. A4).

In addition to the sightings of Antarctic minke whales, or whales suspected to be Antarctic minke whales, the SV approached blue whales (*Balaenoptera musculus*), southern right whales (*Eubalaena australis*) and humpback whales (*Megaptera novaeangliae*) to conduct e.g. photo-ID and biopsy sampling.

A researcher on board recorded all the sightings of whales. The sighting record includes the date and time of the sighting, the position of the vessel, classification of the survey mode and sighting (primary or secondary), the angle and distance from the vessel, the species and school size, and the estimated body length. Further details of the sighting survey procedure are provided in Nishiwaki *et al*. (2006).

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Appendix 3

'SKIPPING' IN SIGHTING SURVEYS DURING THE EARLY JARPA CRUISES

Fig. A5 illustrates the movement of a sighting/sampling vessel (SSV) in a day. The SSV started from point A in the morning and planned to proceed to point C that day. A school was detected and the sighting survey was interrupted at point D_1. The SSV closed on the school detected to confirm species and school size. If the school detected was identified to comprise Antarctic minke whales, the SSV chased a targeted minke whale to sample it. After this sampling, the SSV transported the whale to the Research Base Ship, returned to point E_1 on the trackline and resumed the sighting survey. As a result, the portion of the trackline between D_1 and E_1 was skipped. The same situation occurred between D_3 and E_3. However, sometimes none of the trackline was skipped as in the case of the trackline between D_2 and E_2, as D_2 and E_2 are the same position. When the time to end the daily survey was reached, the SSV had arrived at the point B. If the SSV did not reach point C, it moved without surveying from point B to point C for the start of the survey the next day. Conversely, if the SSV reached point C, the SSV stayed there until the next morning. This pre-determined distance per day requirement applied until the end of the 1992/93 season.

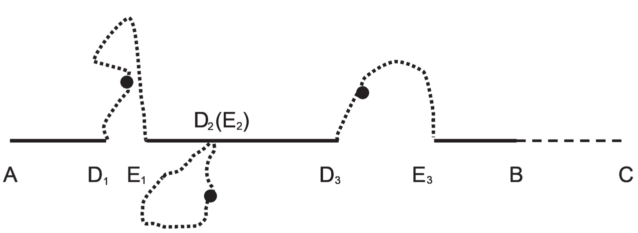

Fig. A5. An illustrative example of the movement of a SSV over a day with skipping of types A and C.

The skipping that occurred during the JARPA surveys is classified into four types as follows (Hakamada *et al*., 2006).

A: Skipping occurring after the end of the daily survey (proceeding along the trackline at night without any sighting survey), in order to achieve the pre-determined distance per day.

B: Skipping to catch up with the schedule within a stratum. When time became short during the survey of a stratum, vessels skipped some segments of the planned trackline.

Table A2

Pre-determined daily distance coverage for the 1989/90 to 1992/93 surveys.

1989/90	Distance (n.miles)	1990/91	Distance (n.miles)
Northwest (NW)	170	Northwest (NW)	160
Northeast (NE)	170	Northeast (NE)	160
Southwest (SW)	100	Southwest (SW)	100
Southeast (SE)	100	Southeast (SE)	140
Prydz Bay (PB)	120		
1991/92	**Distance (n.miles)**	**1992/93**	**Distance (n.miles)**
Northwest (NW)	150	Northwest (NW)	140
Northeast (NE)	150	Northeast (NE)	140
Southwest (SW)	Not applied*	Southwest (SW)	100
Southeast (SE)	Not applied*	Southeast (SE)	140
Prydz Bay (PB)	Not applied*		

*Same distance as SV proceeded in the day.

C: Skipping accompanied by the detection of whales due to closing on a detected school and chasing a targeted minke whale.

D: Skipping due to bad weather conditions.

Skipping type A

The pre-determined distance per day governs the daily movement of the vessels on the research trackline (Table A2). This applied to JARPA from the 1989/90 to the end of the 1992/93 season. The SSVs had to steam during the night to the starting point for the next day when they had not achieved the pre-determined distance during daytime. This type of skipping occurred because only a short searching distance had been achieved during a day due to bad weather conditions and/or sampling activity in an area with a high density of minke whales. A concern was that such skipping might cause bias in abundance estimation because the SSVs tended to skip a greater distance in high- rather than low-density areas as a result of the sampling activities during a day (IWC, 1998). However, the pre-determined distance per day approach was no longer applied from the beginning of the 1993/94 season because the total distance planned for the trackline in a survey was reduced. The surveys in Areas IV or V covered those regions only once during the peak migration season for minke whales from the beginning of the 1992/93 season, whereas prior to this the SSVs surveyed the whole of Area IV or V twice in a year. Type A skipping is represented as segment BC which is illustrated as a broken line in Fig. A5. The pre-determined distance was less in south than in north strata because it was expected that whale density would be higher in the former. The effect of this type of skipping on the estimation of trends in abundance was examined by running a sensitivity test (see main text).

Skipping type B

Beginning in the 1993/94 season, pre-determined daily distances were not set. Even if a survey vessel covered a shorter distance than expected, it would not skip along the trackline at night. However, in circumstances where it became difficult to finish the survey in a stratum within the planned schedule, segments of the planned trackline would be skipped during the night to catch up with that schedule. Compared to type A skipping, the daily distance lost to this skipping tended to be much less, as shown in Table A2. Therefore, this type of skipping should not affect abundance estimates substantially.

Skipping type C

This type of skipping occurs accompanied with the detection of minke whales. For a dedicated sighting vessel (SV), it is caused by closing to confirm the species and school size of the school detected. However, for SSVs, it is caused by the closing, chasing and sampling of a targeted minke whale. Type C skipping is the union of the segments D_1E_1 and D_3E_3. It should be noted that type C skipping is the same kind of skipping that occurred in the IDCR/SOWER surveys and was examined in Haw (1991). The effects of this type of skipping are identical to the closing *vs* passing 'survey mode' effects in abundance estimation.

Skipping type D

Skipping due to bad weather is reasonably assumed to be independent of the density of the minke whales. Hence type D skipping should not affect abundance estimates and is therefore not discussed here.

Fig. A5 illustrates examples of skipping types A and C. Type C skipping is the union of the segments D_1E_1 and D_3E_3. Type A skipping is the segment BC of the planned sighting survey on segment AC. If there had been no detection on the day, the survey vessel could have proceeded to point C. The bold line segments represent the parts of the trackline actually surveyed, The vessel follows the dotted curves to close on a detected school and to chase a targeted whale. The dashed line indicates the segment of the trackline skipped in the night.

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Appendix 4

SPECIFICATIONS OF THE RESEARCH VESSEL IN JARPA SURVEYS

Table A3 below summarises the specifications of the research vessels involved in the JARPA surveys. *Kyo-maru No.1* (K01), *Toshi-maru No.25* (T25) and *Toshi-maru No.18* (T18) operated as SSVs for the surveys from 1989/90 to 1997/98. *Kyoshin-maru No.2* (KS2) was engaged from the 1995/96 season exclusively in sighting surveys (SV). *Yushin-maru* (YS1) was used from the 1998/99 season replacing T18. *Yushin-maru No.2* (YS2) was used from the 2001/02 season replacing T25**.**

	Kyo-maru No.1	*Toshi-maru No.25*	*Toshi-maru No.18*	*Yushin-maru*	*Yushin-maru No.2*	*Kyoshin-maru No.2*
Call sign	JKNG	8JCG	JPMQ	JLZS	JPPV	JFHR
Register length (m)	69.15	68.37	63.20	69.61	69.60	68.18
Molded breadth (m)	10.30	9.90	9.90	10.40	10.80	10.80
Gross register tonnage	812.08	739.92	758.33	720.00	747.00	372.00
Barrel height (m)	18.00	18.00	18.00	18.00	18.00	17.00
IOP height (m)	–	–	–	13.50	13.50	10.50
Upper bridge height (m)	10.00	10.00	10.00	10.00	10.00	8.00
Bow height (m)	6.40	6.00	6.20	6.50	6.50	-
Maximum continuous output (hp)	5,000	3,600	3,500	5,280	5,280	2,100