Estimates of abundance and abundance trend of the humpback whale in Areas IIIE-VIW, south of 60ºS, based on JARPA and JARPAII sighting data (1989/90-2008/09)

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

ABSTRACT
Sighting surveys data from the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) and its second phase (JARPA II) are analyzed to obtain abundance estimates for humpback whales (*Megaptera novaeangliae*) in Areas IIIE-VIW, south of 60°S. The surveys were conducted during the 1989/90–2008/09 austral summer seasons (mainly in January and February), alternating between western and eastern sectors of the research area each year. Abundance estimates are obtained from standard line transect analysis methods using the program DISTANCE assuming $g(0)=1$.

	First year			Last year		
Area	Year	Estimate	CV	Year	Estimate	CV
IIIE	1995/96	1,378	0.190	2007/08	11,904	0.261
IV	1989/90	5,325	0.302	2007/08	29,067	0.255
V	1990/91	602	0.343	2008/09	13,894	0.338
VIW	1996/97	1,493	0.185	2008/09	3,609	0.322

These JARPA/JARPAII estimates are similar to estimates obtained from the IDCR-SOWER surveys, which were conducted independently for Area IV in 1978/79, 1988/89 and 1998/99 and for Area V in 1980/81, 1991/92 and 2001/02-2003/04. Abundance increased by an estimated 20.8% (95%CI = 4.1 – 37.6%), 13.6% (95% CI = 8.4- 18.7%), 14.5% (95%CI = 7.6 – 21.5%) and 6.2% (95%CI = -0.9 – 13.4%) per year for Areas IIIE, IV, V and VIW, respectively. These rates in Areas IV and V are also similar to those obtained from the IDCR-SOWER surveys. Estimated additional variance with CV's was 0.635 (Area IIIE) 0.328 (Area IV), 0.416 (Area V) and 0.036 (Area VIW). Results of several sensitivity tests suggest that estimates of abundance and abundance trends are not appreciably affected by factors such as different approaches to deal with survey coverage which in some cases was poor or included gaps. The effects of changes in the order in which survey strata were covered are investigated using a nested GLM approach. A QAIC model selection criterion suggests a preference for not attempting to adjust for such changes; under various approaches in which an adjustment was made, point estimates of increase rates were not greatly affected in Areas IV and V. The JARPA+JARPA II results thus indicate that humpback whales in Area IV and Area V are definitely increasing rapidly.

KEYWORDS: ABUNDANCE ESTIMATE, ANTARCTIC, HUMPBACK WHALE, SURVEY-VESSEL, TRENDS

INTRODUCTION

There are several genetic stocks (genetically differentiated populations within a species) of humpback whales in the Southern Hemisphere. The IWC SC (International Whaling Commission Scientific Committee) has hypothesized a total of seven breeding stocks, which it has called Stock 'A', 'B', …'G'. (IWC, 2005). Currently the IWC SC is working to refine this stock structure hypothesis. A population named Breeding Stock D has its breeding grounds in the waters off western Australia and in summer is distributed mainly in Area IV, south of 60 °S. Another population named Breeding Stock E has its breeding grounds in the waters off eastern Australia and some of the south Pacific islands, and in summer is distributed mainly in Area V south of 60°S.

Humpback whales were heavily exploited during the past century and most of the stocks in the Southern Hemisphere were substantially depleted. Allen (1980) estimated that at the end of commercial whaling, the stocks of this species had been reduced to 2% of its original population of 130,000 animals. More recent evaluations as part of the Comprehensive Assessment of this species have not been finalized, but results reported up until recently, when summed over the seven breeding stocks, suggest an original abundance of about 125,000 whales reduced to a minimum of about 4% of that number by the mid-1960s (IWC, 2009; Jackson *et al*., 2008; Johnston and Butterworth, 2005a, 2005b, 2007; Johnston *et al*., 2008; Zerbini *et al,* 2008). Fortunately signs of recovery are now evident for many of these stocks. In particular the population sizes of Stocks D and E are estimated from the results of low latitude surveys off Australia to be increasing at annual rates of 9.7 % (CV=0.25) (Hedley *et al*., 2011) and 10.9% (95%CI 10.5%-11.3%) (Noad *et al*., 2011), respectively. There is the need for continued monitoring of the abundance and abundance trends of these whale stocks, especially because they provide an excellent opportunity to improve understanding of the dynamics of baleen whale populations recovering from low levels.

Another source of sighting data for assessing the population status of this species in the Antarctic is the JARPA (Japanese Whale Research Program under Special Permit in the Antarctic) and its second phase (JARPA II). This Program has been conducted in every one of the 1987/88 to 2008/09 austral summer seasons. After two seasons of feasibility studies, full-scale research began in 1989/90. The JARPA Program was designed to alternate surveys in Antarctic Areas IV and V in each of the sixteen years of the full-scale research period. The objectives of the JARPA were: a) elucidation of the stock structure of the Antarctic minke whale *Balaenoptera bonaerensis* to improve stock management; b) estimation of biological parameters of the Antarctic minke whale to improve the stock management; c) elucidation of the role of whales in the Antarctic marine ecosystem through whale feeding ecology; and d) elucidation of the effect of environmental change on cetaceans; (Government of Japan, 1987, 1996). In order to address these four objectives, JARPA was comprised of a combination of sighting and sampling surveys. The objectives of the JARPA II were: 1) Monitoring of the Antarctic ecosystem, 2) Modelling competition among whale species and future management objectives, 3) Elucidation of temporal and spatial changes in stock structure and 4) Improving the management procedure for Antarctic minke whale stocks (Government of Japan, 2005).

Sighting data collected by the SVs (dedicated sighting vessels) and SSVs (sighting and sampling vessels) during JARPA have been used to estimate abundance and abundance trends of blue whales (Branch *et al*., 2004) and other large whale species (Kasamatsu *et al*., 2000; Matsuoka *et al*., 2005a, b). Abundance estimates for Antarctic minke and humpback whales were made taking recommendations made at JARPA review meeting (IWC, 2008) into account (Hakamada *et al*., in press; Matsuoka *et al*., 2011) listed in Table 1. Matsuoka *et al*. (2011) suggested that the estimated abundance of humpback whales in Area IV has increased rapidly, although there is also an increase indicated for Area V, it is neither as rapid nor as precisely estimated. Abundance estimates and abundance trends in Areas IV and V are similar to those for IDCR-SOWER surveys (Branch, 2011).

The main objective of this paper is to update humpback whale abundance estimates in Antarctic Areas IIIE, IV, V and VIW based on JARPA and JARPA II sighting data, taking into account the relevant recommendations offered by the IWC SC. Approaches in Matsuoka *et al*. (2011) are applied to JARPA and JARPA II data in order to examine if the abundance estimates and their trends for humpback whales were changed from previous analysis by adding the data obtained during JARPA II surveys (2005/06- 2008/09). To facilitate understanding of the estimation procedures and the interpretation of results, some details of the JARPA and JARPA II survey procedures are provided below, with further details set out in Appendix 2 of Hakamada *et al*. (in press).

Sighting surveys to obtain abundance estimates have been carried out in the waters off both western Australia (Bannister and Hedley, 2001; Paxton *et al*., 2006; Hedley *et al*., 2011)) and eastern Australia (Noad *et al.,* 2006; 2011). A secondary objective of this study is to compare JARPA and JARPA II abundance estimates in the feeding grounds of Areas IV and V with those in the breeding grounds and migratory corridors in the waters off both sides of Australia.

Another secondary objective is to compare abundance estimates in Areas IV and V obtained by JARPA with those obtained by the IDCR (International Decade for Cetacean Research)-SOWER (Southern Ocean Whale and Ecosystem Research) research programmes. Under these programmes, dedicated sighting surveys for assessment purposes had been conducted by the IWC in the Antarctic annually from 1978/79 to 1995/96 (IDCR) and then from 1996/97 to 2009/10 (SOWER) (see overview of IDCR-SOWER surveys in Matsuoka *et al*., 2003). One of the features of JARPA is that, unlike the IDCR-SOWER programmes, surveys have been repeated in the same area and in the same months every second season over a long period. Therefore the JARPA and JARPA II surveys facilitate both estimation of trends and the extent of inter-year variability in local abundance.

SURVEY DESIGN AND DATA COLLECTION

As noted above, JARPA and JARPA II were comprised of a combination of sighting and sampling surveys. In order to obtain biological samples representative of the Antarctic minke whale population, a random sampling method was adopted within a line transect sighting survey design. The sighting and sampling surveys were conducted by two or three SSVs proceeding along predetermined tracklines. A dedicated SV was introduced from the 1991/92 season. The JARPA surveys have been conducted in a generally consistent way every other season in both Areas IV and V since the 1989/90 season. There have been eight full-scale surveys in Area IV: in the 1989/90, 1991/92, 1993/94, 1995/96, 1997/98, 1999/00, 2001/02 and 2003/04 seasons, and eight in Area V: in the 1990/91, 1992/93, 1994/95, 1996/97, 1998/99, 2000/01, 2002/03 and 2004/05 seasons. Details of the surveys' designs and some modifications over time are given in Nishiwaki *et al*. (2006) and in Appendix 2 of Hakamada *et al*. (in press). Implications of some of these modifications to the results for abundance and abundance trends are discussed later.

Research area and geographical stratification
In the JARPA II surveys, the main region for full scale research was Antarctic Areas IIIE, IV and V (35°E - 175°E) and Area V and VIW (130°E - 145°W) south of 60ºS; each of these Areas was divided into smaller strata (Figure 1). Specifications of the stratification are given in Figure 1. Distributions of primary sightings of humpback whales and of efforts in Areas IIIE, IV, V and VIW for each year are shown in Figure 2a-2d. Furthermore, each sector was divided into northern (60ºS to 45 n. miles from the ice edge) and southern (from the ice edge to 45 n. miles away) strata. The western sector of Area IV includes a separate Prydz Bay stratum. For this sector, north and south strata were divided at 66°S. The eastern sector of Area V includes the Ross Sea; for this sector, the north and south strata were divided at 69°S.

Monthly coverage
Although the JARPA research period ranged from the end of November to March in each season, regular research in Areas IV and V was concentrated in January and February, which coincide with the peak migration period of humpback whales to Antarctic feeding grounds (Kasamatsu *et al*. 1996). JARPA II research period ranged from December to March in each season (Figure 3). The end date was earlier than usual in 2006/07 due to a fire accident on the research base *Nisshin-Maru* (Nishiwaki *et al*., 2007). Abundance estimates are based on single coverage of the blocks shown in Figure 1 for the year concerned.

Research vessels
Relevant information on research vessels is given in Table 2. *Kyo-maru No.1* (K01), *Toshi-maru No.25* (T25), *Toshi-maru No.18* (T18) operated as SSVs for the surveys from 1989/90 to 1997/1998. *Kyoshin-maru No.2* (KS2) engaged exclusively in sighting surveys (SV) from 1995/96. *Yushin-maru* (YS1) was used from the 1998/1999 cruise replacing the T18, *Yushin-maru No.2* (YS2) was used from the 2001/2002 cruise replacing the T25, *Kaiko-Maru* (KK1) engaged exclusively in sighting surveys (SV) from 2005/06 to 2008/09 and *Yushin-maru No3* (YS3) was used from the 2007/2008 cruise replacing the K01.

Order of the surveys
The order in which strata were surveyed is shown in Figure 4. Abundance estimates are based on single coverage of the blocks shown in the Figure for the season concerned. In the JARPA II period, northern and southern strata were surveyed in the same period (Nishiwaki *et al*., 2014).

Trackline design
The trackline was designed to cover the whole research area and was followed consistently throughout the JARPA surveys (Figure 2a-2d). 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 on the locus of points 45 n.miles from that edge in southern strata, and on this locus and the 60ºS latitude line in the northern strata. There were two modifications in trackline design in JARPA II surveys considering the recommendations at the JRM to improve abundance estimation. One is that the saw-tooth type trackline for the southern strata was chosen to allow for wide area coverage in JARPA but was not chosen in JARPA II. Another is that northern and southern strata were surveyed in the same period (Nishiwaki *et al.*, 2014) to avoid temporal gaps occurring in the survey period of southern and northern strata during JARPA II period.

Sighting survey procedure
There were two or three SSVs traveling in parallel on each predetermined trackline. The distance between their tracklines was 7 n. miles. The SSVs conducted sighting and sampling survey at a standard speed of 11.5 knots. The survey was conducted under optimal research conditions only (i.e. when the wind speed was below 25 knots in the southern strata and below 20 knots in the northern strata, and visibility was over 2 n. miles). During

JARPAII period, SSVs covered south of 62°S whereas SVs covered south of 60°S. Therefore, sighting data obtained by SSVs was not used for abundance estimation in this period.

One of the three SSVs behaved as a SV from the 1991/92 to 1994/95 cruises. From 1995/96, three SSVs and an additional SV (KS2) with closing mode (i.e. NSC as above but without sampling of whales) were allocated to the survey. From 1998/99, the SV (KS2) introduced the passing mode (i.e. NSP in IDCR-SOWER notation i.e. the vessel did not approach whales after the sighting was made and search from the barrel continued uninterrupted, except for some special cases such as sightings of blue whales in which closure was effected once the vessel came abeam of the whale). The sighting surveys (12 hours during the day) were conducted alternating between normal closing mode (4 hours) and passing mode (8 hours) during the day. For the SV, these modes are denoted as SVC and SVP hereafter. The SSVs followed the SV at a distance of over 12 n. miles to avoid any influence of sampling activities on the SV's sighting survey. In the JARPA II period, SSVs and SVs were surveyed independently from each other.

A researcher onboard recorded all the information on the whales sighted. The sighting record included the dates and times of the sightings, the positions of the vessel, a classification of survey mode and sighting (primary or secondary), the angles and distances from the vessel of the initial sighting, the species and school size, the estimated body lengths and other information as for the IDCR-SOWER cruises. More details of these procedures are given in Nishiwaki *et al*. (2006).

ANALYTICAL PROCEDURE

The procedure applied to analyze the sighting data is very similar to that used for the IWC/IDCR-SOWER surveys by Branch and Butterworth (2001a, b). To provide "base case" estimates of abundance: 1) distances and angles are corrected for possible bias by using the results of the distance and angle estimation experiments, 2) the sighting rate is obtained each day, 3) smearing parameters are obtained by Buckland and Anganuzzi's (1988) method II, 4) g (0) is assumed to be 1, and 5) sighting data is pooled each season and across strata to the extent necessary for reliable estimation of the effective search half-width (w_s , using either a hazard rate or half- normal model) and the mean school size (*E(s)*), based on standard line transect analysis methods using the program DISTANCE (Thomas *et al*., 2010).

The material hereunder sets out further assumptions made to obtain base case estimates, followed by descriptions of sensitivity tests in which one or more of the base case specifications and assumptions are varied.

Data selected for the analysis

Size of the research area

The surveys covered the region between the ice edge and 60°S. The open water area for each stratum for each survey was calculated using the *Marine Explore* Geographical Information System version 4 (*Environment Simulation Laboratory Co, Ltd*, Japan). The ice edges and hence boundaries between the northern and southern strata differed for SVs and SSVs because their surveys were not completely synchronous, so the ice edges they encountered differed. This in turn resulted in slightly different stratum areas for the two. For abundance estimates developed combining data over the SSV and SV modes, the averages of the two area sizes of each stratum are used.

Unsurveyed area

Some small parts of Area IV were unsurveyed on four of the cruises, with the proportions not surveyed. These "gaps" arose because of 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 base case abundance estimates, these gaps are treated as having the same density as the more northerly stratum. This is because densities tend to be higher close to the ice edge, and these gap regions are more typical of areas more distant from the ice. 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. The consequences for abundance estimates caused by each of these effects are addressed further below under Sensitivity Tests.

Due to violent action by an anti-whaling non governmental organisation in the research area, the SVs and SSVs could not carry out the research in the planed track line in Area III East (35°E - 70°E), a part of Area IV (90°E - 130°E) and a part of Area V West (130°E - 132°E) in 2009/10 (Nishiwaki *et al*., 2010). Due to violent action by an anti-whaling non governmental organisation in the research area, a sighting survey by SV was not conducted in 2010/11 (IWC, 2012). Therefore, abundance estimates for these years could not be made.

Survey modes

Sighting data collected under SSV, SVC and SVP modes was combined for the estimation of the mean school size and effective search half-width for schools. Although separate estimates are obtained for each of these modes in the case of Antarctic minke whales (Hakamada *et al.* in press), data was pooled here as the limited number of sightings of humpback whales dictated the need to include as many as possible, as in the case of the IDCR-SOWER based abundance estimates for species other than minke whales (Branch and Butterworth, 2001b; Branch, 2011).

Abundance estimation

The methodology used here for abundance estimation is described in Branch and Butterworth (2001a, b), and has been adopted by the IWC SC in the past. The program DISTANCE (Thomas *et al*., 2010) was used to implement this. The basic formula is:

$$P = \frac{AE(s)n}{2w_s L} \qquad (1)$$

where,

P is the estimated abundance in numbers in the stratum,

A is the open ocean area of the stratum,

$E(s)$ is the estimated mean school size,

n is the number of primary sightings of schools,

w_s is the effective strip half-width for schools, and

L is the primary search effort.

The CV of P is calculated using the approximate formula:

$$\mathrm{CV}(P) = \sqrt{\{\mathrm{CV}(\frac{n}{L})\}^2 + \{\mathrm{CV}(E(s))\}^2 + \{\mathrm{CV}(w_s)\}^2} \qquad (2)$$

Under the assumption of distribution log-normality, 95% confidence intervals for the abundance estimates are calculated as (P/C, CP) where C is given by:

$$C = \exp(Z_{0.025}\sqrt{\log_e[1 + \{\mathrm{CV}(P)\}^2]}) \qquad (3)$$

and

$Z_{0.025}$ represents 2.5-percentage point of a standard normal distribution. More details of the analysis methods may be found in Buckland *et al*. (2001) and Branch and Butterworth (2001a, b).

Correction of the estimated angle and distance

To be able to correct for biases in angle and distance observations, experiments using a radar reflecting buoy were conducted by each vessel during each cruise (the experimental methodology is described in Nishiwaki *et al*., 2006). Based on the data obtained, biases were estimated for each platform for each cruise. Linear regression models were used to examine possible differences between observed and true (obtained from radar) distances. In order to correct for such biases, the estimated distance was divided by the estimated slope of a regression through the origin if this slope differed significantly from 1 at the 5% level. The estimated factors in 2005/06 -2008/09 seasons are shown in Table 3a. A similar approach was used for angles. More details of the methodology may be found in Branch and Butterworth (2001a).

Truncation distance

The conventional truncation distance for perpendicular distances of sightings that is used for Antarctic minke whales is 1.5 n.miles (Branch and Butterworth, 2001a; Hakamada *et al.*, in press). However, because of their larger bodies and blow sizes, humpback whales can be seen much further from vessels than Antarctic minke whales. The rule of thumb advocated in Buckland *et al*. (2001), of truncating to exclude about 5% of the data, is therefore applied as in Branch and Butterworth (2001b), with results rounded to the nearest 0.3 n. miles. Accordingly the perpendicular distance distributions were truncated at 2.7 n. miles.

Smearing parameters

Smearing parameters were calculated for each cruise to make allowance for errors in estimates of distances and angles. The method used is the same in Branch and Butterworth (2001b). The sightings data is smeared before their truncation to give *n,* and then used in the estimation of the effective search half-width (w_s) and the mean school size ($E(s)$) for input to equation (1). Radial distance and angle data were smeared in the conventional manner by using Method II of Buckland and Anganuzzi (1988) and then grouped into intervals of 0.3 n. miles for estimating w_s values. For Antarctic minke whales, smearing parameters are conventionally estimated separately for each stratum from the data. However, due to the lower number of sightings of humpback whales, some pooling was necessary here to obtain robust estimates from the Buckland and Anganuzzi method. The smearing parameter values reported in Table 3b were thus obtained from pooled sightings (including sightings with both confirmed and unconfirmed school size) separately for each JARPA II cruise.

Effective search half-width

The smeared and truncated sightings data for schools was grouped into intervals of 0.3 n. miles to estimate the detection function A hazard rate model with no adjustment terms and a half-normal model were considered as detection functions. The better model was selected by AIC in each case. *g(0)* was assumed to be 1 (i.e. no schools present on the trackline were missed).

Mean school size

A method regressing the logarithm of school size against the detection *f*(*y*), as described by Buckland *et al.* (2001) was used to estimate mean school size (*E(s)*). If the regression coefficient was not significant at the 15% level, the mean of the observed school size was input to equation (1). Note that pooling across survey modes means use school size estimates for SVP mode which may bias the estimate of *E(s)* downwards. Only sightings for confirmed school size were used to obtain these estimates.

Population rate of increase

To estimate rate of increase in an Area, an exponential trend was assumed with the following error structure:

$$P_y = \beta \exp(\alpha y) + v_y, \quad \hat{P}_y = P_y + u_y, \qquad (4)$$

where

P_y and $\hat{P}_y$ are the true and survey estimated abundances in an Area in season y,

α is the instantaneous increase rate,

β is abundance for season y=0,

u_y reflects survey sampling error, and

v_y is the error associated with additional variance, which arises from an inter-annual variation in the proportion of whales in the surveyed area at the time of the survey.

In order to take the additional variance of abundance estimates (CV_{add}) as well as the survey sampling CV into account, the negative log-likelihood function minimized to estimate α is:

$$l(\alpha, \beta, CV_{add}) = \frac{1}{2}\sum_y \log\left[CV(\hat{P}_y)^2 + CV_{add}^2\right] + \sum_y \frac{\left(\log(\hat{P}_y) - \log(\beta) - \alpha y\right)^2}{2\left[\left\{CV(\hat{P}_y)\right\}^2 + CV_{add}^2\right]} \qquad (5)$$

Estimates of standard errors for α and CV_{add} were obtained from the associated Hessian (Information matrix), with CI estimates assuming a *t*-distribution with 8 degrees of freedom for Areas IV and V and 5degrees of freedom for Areas IIIE and VIW .

Muller and Butterworth (2012) suggested that breeding stock D is near its pristine abundance using the initial population dynamics model. It also examined the annual increase rate being estimated by the Logistic model for Area IV.

$$P_y = \frac{K}{1 + \frac{K - P_0}{P_0} e^{-ry}} \qquad (6)$$

where K is carrying capacity of this population. P_y is abundance estimate in year y. r is instantaneous increasing rate of humpback whales.

Sensitivity tests

Alternative estimates of effective search half-width

The base case selects between the hazard rate and half-normal models of the detection function for cruise-stratum/set-of-strata combination. For sensitivity tests, either all forms are set to half-normal or all to hazard rate.

Inclusion of tracklines that followed the contours of the ice edge

Some of the tracklines were nearly parallel to the ice edge in strata where the saw-tooth type trackline design approach was used (e.g. SW and SE strata in Area IV) during the JARPA survey period. This could lead to overestimation of abundance because of possible higher density close to the ice edge. As sensitivity tests to examine the effect of tracklines that followed the contours of the ice edge, two data sets were developed: one that excluded portions of tracklines that followed the contours of the ice edge (Option B), and the other one that excluded all tracklines not parallel to lines of longitude (Option C). Because of the small number of sightings in the SW and SE strata in Area IV on earlier cruises, only seasons from 1997/98 onwards were considered. No saw-tooth trackline was used in the JARPA II period.

Unsurveyed areas and incomplete coverage

Two approaches are 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 are set to zero (i.e. whales in such gaps at the time of surveying the more southerly strata are considered as ones already effectively counted in the earlier surveying of the more northerly strata, as these whales would subsequently likely have moved further south). On the liberal side, the density in a gap is 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. Because northern and southern strata were surveyed in the same period, such “gaps” did not occur in the JARPA II period.

For cases of incomplete coverage, the approach followed to check sensitivity was as follows. For the base case estimates of abundance, the extrapolated density for the (nearly) unsurveyed portion of a stratum is taken to be the same as that in the surveyed portion of the stratum. As an alternative to this, the average of the ratio of the densities in these two portions of the stratum on other cruises was evaluated (in the case of the humpback analysis, this amounts to considering the ratio of sighting rates, as values of other inputs to the calculation of density as common), and this was used instead to extrapolate the density in the surveyed area to that for the (nearly) unsurveyed portion for the season 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 between the cruises. The strata for which such alternative computations were conducted, together with the other cruises used to develop the average ratio required shown in parenthesis, were as follows:

Area IIIE: 2005/06 IIIEN over 35^{o} – 55^{o}E (2007/08)
Area IIIE: 2005/06 IIIES over 35^{o} – 55^{o}E (2007/08)
Area V: 2006/07 NW over 130^{o} – 159^{o}S (2005/06; 2007/08; 2008/09)
Area V: 2006/07 SW over 130^{o} – 159^{o}S (2005/06; 2007/08; 2008/09)
Area V: 2008/09 NW over 161^{o} – 165^{o}E (2006/07; 2007/08)
Area V: 2008/09 SW over 140^{o} – 150^{o}E (2005/06; 2007/08)

The effect of survey modes and survey timing

To investigate the extent of the effects of the survey modes (i.e. SSV, SVC and SVP) and timing of the survey conducted in each stratum (which differed in some years because of differences in the order in which the strata were surveyed) on estimates of population increase rates, GLM analyses were undertaken. In the Prydz Bay stratum in Area IV and the SE stratum of Area V, no sightings of humpback whales were made for some of the cruises. Hence, a Poisson error structure was assumed for the GLMs. A hierarchy of such models was evaluated for each Area. As discussed in Hakamada *et al*. (in press), since stratum areas vary from season to season as a result of different ice edge locations, it is not immediately obvious whether such approaches should be based on the density or on the abundance in a stratum, and arguments can be offered to support either approach. However, density is perhaps the more obvious choice and furthermore Hakamada *et al* (in press) found little difference in results for the two approaches for minke whales. Accordingly, the analyses here are based only on density.

Model i): $$\log E[n_{obs}(y,a)] = \log\left(\frac{2w_{y,a}L_{y,a}}{E_{y,a}(s)}\right) + \log(D_{true}(0,a)) + \alpha y \qquad (7\text{-}1)$$

Model ii): $$\log E\left[n_{obs}(y,a)\right] = \log\left(\frac{2w_{y,a}L_{y,a}}{E_{y,a}(s)}\right) + \log(D_{true}(0,a)) + \alpha y + M \quad , \qquad (7\text{-}2)$$

Model iii): $$\log E\left[n_{obs}(y,a)\right] = \log\left(\frac{2w_{y,a}L_{y,a}}{E_{y,a}(s)}\right) + \log(D_{true}(0,a)) + \alpha y + M + T \quad , \qquad (7\text{-}3)$$

Model iv): $\log E[n_{obs}(y,a)] = \log\left(\frac{2w_{y,a}L_{y,a}}{E_{y,a}(s)}\right) + \log(D_{true}(0,a)) + \alpha y + M + a*T$, (7-4)

where
y is the season
a is the stratum,
$E[n_{obs}(y,a)]$ is the expected number of sightings in stratum a in season y,
$w_{y,a}$, is the effective search half-width for season y and stratum a,
$L_{y,a}$ *and* is the primary search distance for season y and stratum a,
$E(s)_{y,a}$ is the estimated mean school size for season y and stratum a,
$D_{true}(y,a)$ is the unbiased (i.e. free from the survey mode effect) density for season y and stratum a,
α is the population's exponential rate of increase,
M is the mode factor for SSV and SVC surveys standardized to SVP,
T is a categorical variable related to survey timing that is defined below, and
$a*T$ is an interaction between the stratum a and timing T factors.

The first term on the right-hand-side is known as the offset. It uses values of w_s and $E(s)$ pooled over modes, so that all inputs required are listed in Tables 4b and 4c. The approach used here makes the assumption that the variances of w_s and $E(s)$ are relatively small compared to the variance associated with the observed number of sightings. Additional variance has not been considered in these analyses.

The day halfway through the survey period in each stratum was calculated and categorized into groups as a basis to specify T for models iii) and iv) above. The groups in bold letters below are included in the intercept of the alternative models considered (i.e. the effect of those groups is set to zero in the calculations). Because the estimate of α seemed to be sensitive to the definition of T for Area IV in particular, five groupings were considered:

1) T=1: Dec 15-Jan 15; T=**2: Jan 16-31**; T=3: Feb 1-15; and T=4 Feb 16-Mar15 (Grouping *T*1)
2) T=1: Dec 15-Jan 15; T=**2: Jan 16-Feb 15** and T=3: Feb 16-Mar 15 (Grouping *T*2)
3) T=1: Dec; T=**2: Jan**; T=3: Feb and T=4: Mar (Grouping *T*3)
4) T=**1: Dec and Jan** and T=2: Feb and Mar (Grouping *T*4)

QAIC (Burnham and Anderson, 1998) rather than AIC was used to select amongst these models and alternatives for specifying T because it can be applied to GLMs with over-dispersed Poisson errors. QAIC is defined here as

$$QAIC = -\frac{2\log(L)}{\hat{c}} + 2p \qquad (8)$$

where L is the likelihood of the model without over-dispersion, $\hat{c}$ is the estimated over-dispersion parameter and p is the number of estimable parameters including the over-dispersion parameter.

RESULTS

Abundance estimates

Tables 4a – 4d show abundance estimates (P) of humpback whales in Areas IIIE, IV, V and VIW, respectively, by season and stratum. The tables also show the total number of the primary sightings after truncation (n), open ocean area (A), primary search effort (L), n/L, effective search half width (w_s), estimated mean school size ($E(s)$), estimated whale density (D: whales / 100 n. miles^2) and the CVs for each estimate. The primary effort and associated primary sightings of schools of humpback whales used for these estimates are plotted in Figure 2. Abundance estimates in Area IIIE change from 1,378 (CV=0.190) for the 1995/96 season to 11,904 (CV=0.261) for the 2007/08 season (Table 5a). Abundance estimates in Area IV change from 5,325 (CV=0.302) for the 1989/90 season to 29,067 (CV=0.255) for the 2007/08 season (Table 5b). Abundance estimates in Area V change from 602 (CV=0.343) for the 1990/91 season to 13,894 (CV=0.338) for the 2008/09 season (Table 5c). Abundance estimates in Area VIW change from 1,493 (CV=0.185) for the 1996/97 season to 3,609 (CV=0.322) for the 2008/09 season (Table 5d).Figure 5a and 5b shows the detection probability functions in relation to perpendicular distance from the trackline in nautical miles that were used for the analyses by cruise and stratum (or combination of strata); there are no obvious indications of model mis-specification, nor of any trend towards distributions with sharper peaks near the trackline in the earlier years.

Abundance trends

Figure 6 shows the abundance estimates in Areas IV and V plotted against the survey seasons. For comparative purposes estimates obtained using IDCR-SOWER data (Branch, 2011) have been added to this Figure. An increasing trend in abundance is evident for both Areas IV and V. Annual rate of increase estimates from the JARPA surveys using equation (5) are 20.8% (95%CI = 4.1 – 37.6%), 13.6% (95% CI = 8.4- 18.7%), 14.5% (95%CI = 7.6 – 21.5%) and 6.2% (95%CI = -0.9 – 13.4%) per year for Areas IIIE, IV, V and VIW, respectively in the JARPA and JARPA II period. The estimates for Areas IV and V are clearly significantly positive; the result for Area IIIE is also significantly higher than zero, but not as clearly so as that for Areas IV and V. The additional CVs are estimated as 0.635, 0.328, 0.416 and 0.036 for Areas IIIIE, IV, V and VIW respectively (Table 6).

Logistic regression model

Table 7 shows estimated coefficients of the regression model (6) for Area IV. Carrying capacity was estimated as 29,950 (SE=3,250). Abundance estimates in Area IV and predicted abundance by the model are shown in Figure 7. The estimated model seemed to fit abundance estimates in Area IV except for the first two years. The four latest abundance estimates are close to the carrying capacity estimated by the model (6). These results may suggest that humpback whales in Area IV are close to the carrying capacity, although mixing between breeding stock D and other breeding stocks was not taken into account in this analysis.

Sensitivity tests

Alternative estimates of effective search half-width

The effects on abundance estimates at the Area level, and also on annual rates of increase, compared to the base case for these and the following two sets of sensitivity tests are shown in Tables 5a, 5b, 5c and 5d, with differences in estimates of precision and the associated additional variance shown in Table 6.

There are occasional instances of a large difference, but viewed overall, the average change in the abundance estimates from the base case never exceeds 10% in most of the cases, and any alteration to the rate of increase estimate is below 1% except Area IIIE. For Area IIIE, Change in ROI estimates is some -2% in three sensitivity scenarios. Given the high ROI estimates of 20.8% for the base case in Area IIIE, there is no basis to question the robustness of the abundance trend in Area IIIE.

Inclusion of tracklines that followed the contours of the ice edge

These tests apply only to Area IV, and are somewhat restricted because of insufficient data to allow them to be conducted for the first four seasons of surveys there. For the subsequent years, these alternative treatments make little difference on average to abundance estimates (Table 5b), and also have little impact on the estimated abundance trend (Table 6). Thus there is no definitive indication that including tracklines that followed the contours of the ice edge in estimating humpback whale abundance and trends introduces substantial bias.

Unsurveyed areas and incomplete coverage

Results for these sensitivity tests mirror those that use alternative functional forms to estimate effective search half-width: the average change in the abundance estimates from the base case, except poor coverage corrections in Area IIIE and Area VIW, and any alteration in the rate of increase estimate are small (Table 5a-5d and 6).

The effect of survey modes and survey timing

Table 8a shows the observed number of sightings SSV, SVC and SVP surveys, as used for input to the GLM models of equation (7), by season and stratum. Table 8b shows the QAIC for each model and estimated instantaneous annual rates of increase for Areas IV and V with their 95% confidence intervals. Comparison of the abundance trend estimates in Table 5b, shows broad agreement for Area IV – all point estimates are high and in the 14.1-16.4% range. However, this is not the case for Area V, for which most point estimates in Table 8b are less than that for the base case by 3%-7%. Nevertheless, all the Table 8b estimates fall within the CIs or close to the lower limit for the corresponding base case estimates in Table 6. QAIC selects the more parsimonious models, choosing only survey mode amongst the co-variates considered, and then only for Area IV. This does not necessarily mean that survey timing or the order in which the strata were surveyed has no effect on estimates, but rather that there is insufficient information content in the data to reveal such an effect. Nevertheless for Area IV, even if the (changing) order of surveying strata is taken into account, although the best estimate of the rate of increase drops, the lower 95% confidence limit remains at or above 10% as for the base case. For Area V the results in Table 8b show significant increase, although estimates of the rate of increase is lower than the base case taking survey ordering into account.

Under QAIC, inclusion of survey mode as a factor is selected only for Area IV, but the change to the estimated rate of increase is negligible, and the mode factor estimates themselves suggest SVC and SSV density estimates only slightly (and not significantly) greater than those for SVP. For Area V, a likely reason for non-selection of these factors, which suggest somewhat lower densities in SVC and SSV modes compared to SVP, is their associated high estimated standard errors.

DISCUSSION

Abundance estimates and abundance trend based on JARPA data

As noted earlier the IWC SC has made several suggestions to improve abundance estimation of Antarctic minke and humpback whales from JARPA surveys during previous meetings. Recent discussions on this topic took place during the JARPA review meeting (IWC, 2008). Table 1 shows the recommended work by the workshop and how these suggestions have been addressed in the analyses of this paper, and indicates that all but a few issues (all accorded only medium priority) have been considered, though these few seem unlikely to greatly effect the estimates of abundance and trends presented here as suggested in previous analysis (Matsuoka *et al*, 2011).

The results of sensitivity analyses provide no basis to question the pooling of the data across survey modes (SSV, SVC and SVP) for the base case abundance estimation, though the information content of this data to determine inter-mode differences is poor. The same conclusion follows for the effect of including data from tracklines that followed the contours of the ice edge in the analyses. The impact on the overall estimates of abundance and trends of the choice of functional form for the detection function, and of some instances of survey gaps and poor coverage, are small.

The point estimates of the annual increase rate are high given the estimate of Clapham *et al*. (2006) of a maximum demographically plausible annual increase rate for humpback whales of 10.6%. However the lower 95% CIs for this rate for the base case and sensitivities in Table 6 are all below this figure, though only barely so for some cases.

A high annual increasing rate was estimated for Area IIIE. Given that the abundance estimate in Area IV is suggested to be near its carrying capacity, a possible shift from breeding stock D to breeding stock C could be the cause of the high estimate in Area IIIE.

Comparison with IDCR-SOWER estimates

As is readily evident from the list of JARPA and IDCR-SOWER estimates of abundance in Table 9a, and the corresponding plot in Figure 6, results from the two sets of surveys are entirely consistent.

Rates of increase in Areas IV and V as estimated from JARPA and IDCR-SOWER results are also similar (Table 9b). Rates of increase estimated from JARPA data are 13.6% (95% CI = 8.4- 18.7%) in Area IV and 14.5% (95%CI = 7.6 – 21.5%) in Area V, which compare with rates estimated from IDCR-SOWER data of 14.9% (95% CI 10.0-19.7%) and 12.8% (95% CI 6.7–17.4%) for those two Areas respectively (Branch, 2011). However Branch’s estimates of precision are based on estimates of additional variance of zero; if instead the estimates determined in this paper are used, though the IDCR-SOWER estimates change only slightly, their CIs do expand (Table 9b). They nevertheless still reflect somewhat greater precision than do the JARPA estimates. The reason for this is that the IDCR-SOWER surveys extend over a longer period of time. Importantly though, the greater frequency of the JARPA surveys makes realistic (and reasonably precise – Table 6) estimates of additional variance achievable – something that is scarcely possible for the lesser numbers of IDCR-SOWER surveys, and this has important implications for reliable estimation of precision.

Comparison with Western and Eastern Australia estimates

The abundance estimate of humpback whales off western Australia based on an aerial survey conducted in 2005 is 13,145 (95% CI 4,984–38,726) (Paxton *et al*., 2006). The annual rate of increase for this population has been estimated at 9.7% (CV=0.25) (Hedley *et al*., 2011). Off eastern Australia the abundance estimate based on data collected in 2004 is 7,090 (SE=660) and the rate of increase is estimated at 10.9% (95%CI =10.5 -11.3%) (Nord *et al*., 2011). These quite high estimates of rates of increase are consistent among surveys conducted in breeding areas and migratory corridors, and those carried out in Antarctic feeding areas (IDCR-SOWER and JARPA/JARPA II).

Estimates of abundance in absolute terms off western and eastern Australia of 28,830 in 2008 (Hedley *et al*., 2011) and 14,522 in 2010 (Nord *et al*., 2011) are similar to the latest abundance estimates for Antarctic Areas IV and V, respectively.

In summary, humpback whales in Area IV and Area V are definitely increasing rapidly.

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REFERENCES

Allen, K. R. (ed.). 1980. *Conservation and management of whales*. A Washington Sea Grant Publication. Seattle, USA, 107pp.

Bannister, J. L. and Hedley, S. L. 2001. Southern Hemisphere Group IV humpback whales: their status from recent aerial survey. *Mem. Qld. Mus.* 47(2):587-598.

Branch, T.A., and Butterworth, D.S. 2001a. Southern Hemisphere minke whales: standardised abundance estimates from the 1978/79 to 1997/98 IDCR/SOWER surveys. *J. Cetacean. Res. Manage*. 3(2): 143-174.

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

Branch, T.A., Matsuoka, K. and Miyashita, T. 2004. Evidence for increases in Antarctic blue whales based on bayesian modelling. *Mar. Mammal Sci.* 20 (4): 726-754.

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

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

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. 2001. Introduction to d*istance sampling. Estimating Abundance of Biological Populations.* Oxford University Press, New York, USA. 431 pp.

Burnham, K.P. and Anderson, D.R. 1998. Model selection and multimodel inference. A practical information – Theoretic approach. Second edition, Springer-Verlag, New York NY. 488pp.

Clapham, P., Wade, P. and Zerbini, A. 2006. Plausible rates of population growth in humpback whales revisited. IWC Paper SC/58/SH4 submitted to the IWC Scientific Committee, 2006 (unpublished). 12pp. [Available from the Office of this Journal].

Government of Japan. 1987. The research plan for the Feasibility Study on "The Program for Research on the Southern Hemisphere Minke Whale and for Preliminary Research on the Marine Ecosystem in the Antarctic. Paper SC/D87/1 submitted to the IWC Scientific Committee, 1987 (unpublished). 57pp. [Available from the Office of this Journal].

Government of Japan. 1996. The 1996/97 research plan for the Japanese Whale Research Program under Special Permit in the Antarctic. Paper SC/48/SH3 submitted to the IWC Scientific Committee, 1996 (unpublished). 11pp. [Available from the Office of this Journal].

Government of Japan. 2005. Plan for the Second Phase of the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA II) - Monitoring of the Antarctic Ecosystem and Development of New Management Objectives for Whale Resources. Paper SC/57/O1 submitted to IWC Scientific Committee, 2005 (unpublished). 99pp.

Hakamada, T., Matsuoka, K., Nishiwaki, S. and Kitakado, T. Abundance estimates and trends for Antarctic minke whales (*Balaenoptera bonaerensis*) in Antarctic Areas IV and V based on JARPA sighting data. *J. Cetacean Res. Manage*. (in press).

Hedley, S. L., Dunlop, R.A. and Bannister J.L. 2011. Evaluation of WA Humpback surveys 1999, 2005, 2008: Where to from here? Report to the Australian Marine Mammal Centre. Project 2009/23.

International Whaling Commission. 2005. Report of the Scientific Committee, Annex H. Report of the Sub-Committee on Other Southern Hemisphere Whale Stocks. *J. Cetacean. Res. Manage. (Suppl.),* 7:235-246.

International Whaling Commission. 2008. Report of the Intersessional Workshop to Review Data and Results from Special Permit Research on Minke Whales in the Antarctic, Tokyo 4-8 December 2006. *J. Cetacean. Res. Manage. (Suppl.),* 10:411-445.

International Whaling Commission. 2009. Report of the Scientific Committee, Annex H. Report of the Sub-Committee on Other Southern Hemisphere Whale Stocks. *J. Cetacean. Res. Manage. (Suppl.),* 11:220-247.

International Whaling Commission. 2012. Report of the Scientific Committee. *J. Cetacean Res. Manage*. (*Suppl.*) 13 :1-75.

Jackson, J.A., Zerbini, A., Clapham, P., Constantine, R., Garrigue, C., Hauser, N., Poole, M.M. and Baker, C.S. 2008. Progress on a two-stock catch allocation model for reconstructing population histories of east Australia and Oceania. Paper SC/60/SH14. submitted to the IWC Scientific Committee, 2008 (unpublished). 12pp.[Available from the Office of this Journal].

Johnston, S.J. and Butterworth, D.S. 2005a. A Bayesian assessment of Breeding Stocks B, C and G of Southern Hemisphere humpback whales using a prior for growth rate from analyses for stocks D and E. Paper SC/57/SH16. submitted to the IWC Scientific Committee, 2005 (unpublished). 14pp.[Available from the Office of this Journal].

Johnston, S.J. and Butterworth, D.S. 2005b. A Bayesian assessment of the West and East Australian breeding populations (stocks D and E) of Southern Hemisphere humpback whales. Paper SC/57/SH15. submitted to the IWC Scientific Committee, 2005 (unpublished). 25pp. [Available from the Office of this Journal].

Johnston, S.J. and Butterworth, D.S. 2007. Corrected assessment results for Southern Hemisphere humpback whales from Breeding Stocks D and G. SC/59/SH2. submitted to the IWC Scientific Committee, 2007 (unpublished). 5pp. [Available from the Office of this Journal].

Johnston, S.J., Zerbini, A.N. and Butterworth, D.S. 2008. A Bayesian approach to assess the status of Southern Hemisphere humpback whales (*Megaptera novaengliae*) with an application to breeding stock G. [This volume].

Kasamatsu, F., Joyce, G.G., Ensor, P. and Mermoz, J. 1996. Current occurrence of baleen whales in the Antarctic. *Rep. Int. Whal. Commn.* 46: 293- 304.

Kasamatsu, F., Matsuoka, K. and Hakamada, T. 2000. Interspecific relationships in density among the whale community in the Antarctic. *Polar Biology* 23:466-473.

Matsuoka, K., P. Ensor, T. Hakamada, H. Shimada, S. Nishiwaki, F. Kasamatsu, and H. Kato. 2003. Overview of minke whale sightings surveys conducted on IWC/IDCR and SOWER Antarctic cruises from 1978/79 to 2000/01. *J. Cetacean. Res. Manage*. 5(2):173-201.

Matsuoka, K., Hakamada, T., Kiwada, H., Nishiwaki, S. and Ohsumi, S. 2005a. Distribution and abundance of sperm whales in the Antarctic Areas IIIE, IV, V and VIW (35°E -145°W). Paper A&D7 presented to the Cachalot Assessment research Planning (CARP) Workshop, Marine Biological Laboratory, Swope Center, Woods Hole, MA, 1-3, March. [Available from the Office of this Journal].

Matsuoka, K., Hakamada, T., Kiwada, H., Murase, H. and Nishiwaki, S. 2005b. Abundance increases of large baleen whales in the Antarctic based on the sighting survey during Japanese Whale Research Program (JARPA). *Glob. Environ. Res.*, 9(2): 105–115.

Matsuoka, K., Hakamada, T., Kiwada, H., Murase, H. and Nishiwaki, S. 2011. Abundance estimates and trends for humpback whales (*Megaptera novaeangliae*) in Antarctic Areas IV and V based on JARPA sighting data. *J. Cetacean Res. Manege.* (SPECIAL ISSUE) 3, 75-94.

Muller, A. and Butterworth, D. S. 2012. Initial population model fits to the humpback breeding stocks D, E1 and Oceania. Paper SC/64/SH29 submitted to IWC Scientific Committee, 2012 (unpublished). 18pp.

Nishiwaki, S., Ishikawa, H. and Fujise, Y. 2006. Review of general methodology and survey procedure under the JARPA. IWC Paper SC/ D06/ J2. presented to the IWC workshop on JARPA review. (unpublished). 47pp.[Available from the Office of this Journal].

Nishiwaki, S., Ogawa, T., Matsuoka, K., Mogoe, T., Kiwada, H., Konishi, K., Kanda, N., Yoshida, T., Wada, A., Mori, M., Osawa, T., Kumagai, S., Oshima, T., Kimura, K., Yoshimura, I., Sasaki, T., Aki, M., Matsushita, Y., Ito, H., Sudo, S. and Nakamura, G. 2007. Cruise report of the second phase of the Japanese Whale Research Program under special permit in the Antarcitic (JARPA Ⅱ) in 2006/2007 -feasibility study-. Paper SC/63/O4 Paper submitted to IWC Scientific Committee, June 2007. (unpublished). 23pp.

Nishiwaki, S., Ogawa, T., Bando, T., Isoda, T., Wada, A., Kumagai, S., Yoshida, T., Nakai, K., Kobayashi, T., Koinuma, A., Mori, M., Yoshimura, I., Ohshima, T., Takamatsu, T., Konagai, S., Aki, M. and Tamura, T. 2010. Cruise Report of the Japanese Whale Research Program under Special Permit in the Antarctic-Second Phase (JARPA II) in 2009/2010. Paper SC/63/O3 submitted to IWC Scientific Committee, June 2010. (unpublished). 13pp.

Nishiwaki, S., Ishikawa, H., Matsuoka, K., Goto, M. and Tamura, T. 2014. Review of general methodology and survey procedure under the JARPA II. Paper SC/F14/J2 submitted to JARPA II review meeting. (unpublished)

Noad, M., Cato, D.H., Paton, D. 2006. Absolute and relative abundance estimates of Australian east coast humpback whales. Paper SC/A06/HW27 presented to IWC Workshop on the comprehensive assessment of Southern Hemisphere humpback whales, 4–7 April 2006, Hobart, Australia (unpublished). 15pp. [Available from the Office of this Journal].

Noad, M.J., Dunlop, R.A., Paton, D. and Kniest, H. 2011. Abundance estimates of the east Australian humpback whale population: 2010 survey and update. Paper SC/63/SH22 presented to the IWC Scientific Committee, June 2011, Tromsø, Norway (unpublished). 12pp. [Paper available from the Office of this Journal].

Paxton, C.G.M., Bannister, J.L. and Hedley, S.L. 2006. Group IV humpback whales: their status from aerial and landbased surveys off Western Australia, 2005. Paper SC/A06/HW3 presented to IWC Workshop on the comprehensive assessment of Southern Hemisphere humpback whales, 4–7 April 2006, Hobart, Australia (unpublished). 22pp. [Available from the Office of this Journal].

Thomas, L., S.T. Buckland, E.A. Rexstad, J.L. Laake, S. Strindberg, S.L. Hedley, J.R.B. Bishop, T.A. Marques, and K.P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47: 5-14.

Zerbini, A.N., Ward, E.J., Kinas, P.G., Engel, M.H. and Andriolo, A. 2008. A Bayesian assessment of the Conservation of Humpback Whales (*Megaptera novaengliae*) in the Western South Atlantic Ocean. [This volume].

Table 1. List of recommendations for improvements to estimates of abundance of humpback whales from the JARPA surveys from the IWC Scientific Committee (IWC, 2008) and priority assigned by the Advisory Group.

Tasks	Priority	Remarks
1. Estimation of detection function（re-estimate in the cases where the number of detection is small ）	H	Addressed Table 5a-5d (Abundance) Table 6 (Trend)
2. Investigation of sensitivities to pooling all vessels to estimate effective strip width and mean school size.	M	For humpback whales, data had already been pooled for all vessels.
3. Variance estimation from the SSV data	M	To be addressed in future work
4. Sensitivity analysis with appropriate weighting and/or bootstrapping	M	Addressed Tables 5a, 5b and 6
5. Abundance estimates treating as if abundance in gaps between two strata were 0.	L	Addressed Table 5b and 6
6. Extrapolation of density into unsurveyed areas	H	Addressed Table 5a-5d and 6
7. Abundance estimates accounting for change in order that the strata were surveyed	H	Addressed Table 8b
8. Estimation of additional variance	M	Partially addressed Table 6 and 9b, Future analyses will utilize GLM
9. Revised estimates of annual increase rate and its CV following suggestions 1-8	M	Addressed Table 6 and 9b.

Table 2. Specifications of the research vessels used for the JARPA and JARPA II surveys.

	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

Table 3a. Estimated observer bias (expressed as multiplicative correction factors) in distance and angle estimation for JARPA surveys from 2005/06 to 2008/09.

Year	Vessel	Platform			
		Barrel		Upper bridge	
		Distance	Angle	Distance	Angle
2005/06	KS2	1.043	0.914	n.s.	n.s.
	KK1	1.049	n.s.	n.s.	n.s.
2006/07	KS2	n.s.	n.s.	n.s.	n.s.
	KK1	n.s.	n.s.	n.s.	n.s.
2007/08	KS2	n.s.	0.961	n.s.	0.950
	KK1	n.s.	n.s.	0.839	n.s.
2008/09	KS2	n.s.	0.918	n.s.	n.s.
	KK1	1.055	0.963	n.s.	0.949

*n.s. indicates not significant at 5% level.

Table 3b. Smearing parameters for each year used in abundance estimation. Units for angles are degrees, while for distances the values given are proportions.

Year	angle	distance
2005/06	5.244	0.154
2006/07	9.278	0.154
2007/08	7.826	0.333
2008/09	5.379	0.14

Table 4a. Abundance estimates for humpback whales in Area IIIE (south of 60°S) from the 1995/96 to 2007/08 JARPA and JARPA II cruises. *A*: size of research area, *n*: number of schools sighted on primary effort (truncated at a perpendicular distance of 2.7 n. miles after smearing), *L*: primary searching distance, w_s: 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	*A* (n.mile ^{2})	*n*	*L* (n.mile)	*n / L* * 10^2	CV	*w s* (n.mile)	CV	*E (s)*	CV	*D* (ind.)	*P* (ind.)	CV
1995/96	IIIE	250,272	54.0	5,646.8	0.956	0.174	*1.291*	*0.108*	1.480	0.063	**0.546**	**1,378**	**0.190**
1997/98	IIIE	267,522	26.0	6,704.0	0.388	0.211	1.480	0.172	1.923	0.493	**0.251**	**671**	**0.360**
1999/2000	IIIE	354,053	141.0	3,679.7	3.832	0.122	*0.946*	*0.065*	1.681	0.030	**3.412**	**12,081**	**0.130**
2001/02	IIIE	355,694	102.0	4,822.9	2.115	0.198	1.320	0.078	1.681	0.042	**1.347**	**4,791**	**0.200**
2003/04	IIIE	330,467	194.0	4,844.9	4.004	0.096	*1.437*	*0.059*	1.747	0.030	**2.435**	**8,045**	**0.100**
2005/06	IIIEN	332,409	55.5	674.2	8.228	0.362	*1.999*	*0.127*	2.017	0.064	0.042	13,797	0.389
	IIIES	51,635	2.0	675.0	0.294	0.587	1.999	0.127	2.017	0.064	0.001	76	0.604
	Total	384,043	57.5	1,349.2	4.259						**0.036**	**13,874**	**0.387**
2007/08	IIIEN	228,382	80.3	931.4	8.620	0.270	*1.660*	*0.098*	1.678	0.096	0.044	9,946	0.303
	IIIES	50,431	77.0	1,126.2	6.839	0.327	1.615	0.098	1.833	0.168	0.039	1,958	0.380
	Total	278,813	157.3	2,057.6	7.645						**0.043**	**11,904**	**0.261**

Table 4b. Abundance estimates for humpback whales in Area IV (south of 60°S) in the 2005/06 and 2007/08 JARPA II cruises. The notation is as for Table 4a.

Year	Stratum	*A* (n.mile ^{2})	*n*	*L* (n.mile)	*n / L* * 10^2	CV	*w s* (n.mile)	CV	*E (s)*	CV	*D* (ind.)	*P* (ind.)	CV
2005/06	NW	228,919	149.9	1,131.4	13.245	0.431	*2.218*	*0.060*	1.973	0.172	5.890	13,483	0.468
	NE	213,660	59.8	1,450.3	4.124	0.279	*2.169*	*0.130*	1.713	0.086	1.628	3,479	0.320
	SW	47,117	131.3	859.4	15.275	0.424	1.665	0.076	2.040	0.143	9.356	4,408	0.454
	SE	37,228	230.1	865.5	26.589	0.253	*1.736*	*0.059*	1.609	0.066	12.323	4,588	0.268
	PB	31,689	0.0	381.1	0.000	0.851	2.700	0.000	1.706	0.038	0.000	0	0.852
	Total	577,386	1359.6	13,392.0	10.152	0.077	-	-	-	-	**4.496**	**25,958**	**0.263**
2007/08	NW	213,311	141.6	958.9	14.768	0.314	*1.376*	*0.193*	1.600	0.082	0.086	18,318	0.378
	NE	216,236	63.7	1,332.4	4.782	0.425	*1.891*	*0.117*	1.857	0.077	0.023	5,078	0.448
	SW	39,787	205.9	847.5	24.299	0.282	2.021	0.068	1.833	0.078	0.110	4,384	0.301
	SE	36,277	73.7	819.8	8.987	0.415	*2.027*	*0.113*	1.600	0.153	0.035	1,287	0.457
	PB	-	-	-	-	-	-	-	-	-	-	-	-
	Total	577,386	1359.6	13,392.0	10.152	0.077	-	-	-	-	**5.034**	**29,067**	**0.255**

Table. 4c. Abundance estimates for humpback whales in Area V (south of 60°S) in the 2006/07 and 2008/09 JARPA II cruises. The notation is as for Table 4a.

Year	Stratum	*A* (n.mile ^{2})	*n*	*L* (n.mile)	*n / L* * 10^2	CV	*w s* (n.mile)	CV	*E (s)*	CV	***D*** (ind.)	***P*** (ind.)	CV
2005/06	NW	238,068	15.3	613.8	2.489	0.45	*1.661*	0.11	1.629	0.06	0.012	2,905	0.47
	SW	49,999	49.5	652.6	7.584	0.39	*1.661*	0.11	1.629	0.06	0.037	1,859	0.41
2006/07	NW	351,072	5.5	97.2	5.683	0.339	*1.670*	*0.115*	1.864	0.046	0.032	11,135	0.361
	NE	340,889	44.9	2,107.7	2.130	0.196	*1.670*	*0.115*	1.864	0.046	0.012	4,052	0.232
	SW	38,198	8.0	136.2	5.872	0.305	*1.670*	*0.115*	1.864	0.046	0.033	1,252	0.329
	SE	139,575	0.0	2,272.9	0.000						0.000	0	-
	Total	869,734	58.4	4,614.1	-	-	-	-	-	-	**1.890**	**16,438**	**0.266**
2007/08	NW	275,376	35.3	1148.1	3.072	0.27	1.201	0.21	1.473	0.06	0.019	5,189	0.34
	SW	43,609	14.0	864.9	1.619	0.32	1.201	0.21	1.473	0.06	0.010	433	0.39
2008/09	NW	224,275	23.0	1,144.7	2.009	1.068	*1.255*	*0.092*	1.718	0.046	0.014	3,085	1.073
	NE	324,889	56.6	1,369.5	4.132	0.405	*1.775*	*0.115*	1.889	0.059	0.022	7,145	0.425
	SW	64,901	48.0	638.1	7.522	0.330	*1.255*	*0.092*	1.718	0.046	0.052	3,343	0.345
	SE	277,209	6.0	2,757.8	0.218	0.328	*1.775*	*0.115*	1.889	0.059	0.001	321	0.353
	Total	891,274	133.6	5,910.1	-	-	-	-	-	-	**1.559**	**13,894**	**0.338**

Table 4d. Abundance estimates for humpback whales in Area VIW (south of 60°S) from the 1996/97 to 2008/09 JARPA and JARPA II cruises. The notation is as for Table 4a.

Year	Stratum	*A* (n.mile ^{2})	*n*	*L* (n.mile)	*n / L* * 10^2	CV	*ws* (n.mile)	CV	*E (s)*	CV	*D* (ind.)	*P* (ind.)	CV
1996/97	VIW	215,064	62.5	6,464.2	0.967	0.164	*1.229*	*0.154*	1.768	0.045	**0.697**	**1,493**	**0.185**
1998/99	VIW	29,908	5.0	1,114.5	0.449	0.672	0.664	0.233	1.707	0.046	**0.543**	**171**	**0.721**
2000/01	VIW	289,954	48.7	4,383.6	1.111	0.163	*1.012*	*0.203*	1.533	0.056	**0.842**	**2,440**	**0.196**
2002/03	VIW	318,055	48.1	5,950.2	0.808	0.216	1.132	0.174	1.402	0.058	**0.493**	**1,614**	**0.235**
2004/05	VIW	278,538	35.8	3,954.7	0.905	0.233	*0.823*	*0.460*	1.460	0.078	**0.803**	**2,237**	**0.353**
2006/07	VIWN	220,818	18.3	756.4	2.426	0.375	*2.700*	*0.224*	2.039	0.117	0.009	2,022	0.452
	VIWS	31,008	7.0	721.2	0.970	0.638	2.700	0.224	2.039	0.117	0.004	114	0.686
	Total	251,826	25.3	1,477.6	1.715						**0.008**	**2,136**	**0.437**
2008/09	IIIEN	166,610	25.6	721.6	3.549	0.358	*1.538*	*0.125*	1.490	0.070	0.017	2,863	0.386
	IIIES	76,255	20.0	990.1	2.020	0.249	1.538	0.125	1.490	0.070	0.010	746	0.287
	Total	242,865	45.6	1,711.7	2.664						**0.015**	**3,609**	**0.322**

Table 5a.Abundance and annual rate of increase (ROI) estimates for Area IIIE for the base case and sensitivities.

Year		1995/96	1997/98	1999/00	2001/02	2003/04	2005/06	2007/08	Average % of change	ROI (%)	Change from base case (%)
Base case		1,378	671	12,081	4,791	8,045	13,874	11,904	-	20.8	-
		-	-	-	-	-	-	-	-	-	-
Hazard rate model		1,163	620	10,703	4,299	7,527	13,296	11,311	-	19.8	-1.0
		-16%	-8%	-11%	-10%	-6%	-4%	-5%	-9%	-	-
Half-normal model		1,378	671	12,081	4,791	8,045	13,874	11,904	-	20.8	0.0
		0%	0%	0%	0%	0%	0%	0%	0%	-	-
Trackline Option B *		1,378	671	11,252	4,791	8,045	13,874	11,904	-	18.9	-1.9
		-	-	-7%	-	-	-	-	-7%	-	-
Trackline Option C *		1,378	671	12,542	4,791	8,045	13,874	11,904	-	18.9	-1.9
		-	-	4%	-	-	-	-	4%	-	-
Poor coverage corrections **		1,378	671	5,108	4,791	8,045	8,861	11,904	-	18.6	-2.2
		-	-	-58%	-	-	-36%	-	-47%	-	-

*: Saw-tooth design was used in 1999/00 season.
**: 1999/00 and 2005/06 seasons.

Table 5b. Abundance and annual rate of increase (ROI) estimates for Area IV for the base case and sensitivities.

Year	1989/90	1991/92	1993/94	1995/96	1997/98	1999/00	2001/02	2003/04	2005/06	2007/08	Average % of change	ROI (%)	Change from base case (%)
Base case	5,325	5,408	2,747	8,066	10,657	16,751	31,134	27,783	25,958	29,067	-	13.6	-
	-	-	-	-	-	-	-	-	-	-	-	-	-
Hazard rate model	5,325	5,666	2,331	8,051	10,537	17,233	31,108	25,818	25,591	30,162	-	13.6	0.0
	0%	5%	-15%	0%	-1%	3%	0%	-7%	-1%	4%	-1%	-	-
Half-normal model	4,041	5,183	2,747	8,066	11,205	12,632	32,844	27,708	27,327	25,626	-	14.0	0.5
	-24%	-4%	0%	0%	5%	-25%	5%	0%	5%	-12%	-5%	-	-
Trackline Option B *	5,325	5,408	2,747	8,066	10,705	14,685	30,713	29,376	25,958	29,067	-	13.7	0.1
	-	-	-	-	0%	-12%	-1%	6%	-	-	-2%	-	-
Trackline Option C *	5,325	5,408	2,747	8,066	11,034	14,146	30,484	34,224	25,958	29,067	-	13.9	0.3
	-	-	-	-	4%	-16%	-2%	23%	-	-	2%	-	-
Gap abundance =0 **	5,325	5,408	2,747	7,467	10,657	16,479	30,359	24,924	25,958	29,067	-	13.5	-0.1
	-	-	-	-7%	-	-2%	-2%	-10%	-	-	-5%	-	-
Gap abundance = stratum below **	5,325	5,408	2,747	8,578	10,657	18,145	31,730	31,905	25,958	29,067	-	13.8	0.2
	-	-	-	6%	-	8%	2%	15%	-	-	8%	-	-
Poor coverage corrections ***	5,325	5,408	2,747	8,279	10,657	16,751	31,134	27,783	25,958	29,067	-	13.6	0.0
	-	-	-	3%	-	-	-	-	-	-	3%	-	-

*: Due to the small number of sightings, there were insufficient data to evaluate options B and C for the 1989/90 to 1995/96 seasons; the averages quoted for these sensitivities refer to the 1997/98 to 2003/04 seasons.
**: 1995/96, 1999/00, 2001/02 and 2003/04 seasons.
*** Line under the table to read: SE stratum in 1995/96 season

Table 5c. Abundance estimates and annual rates of increase for Area V for the base case and sensitivities.

Year	1990/91	1992/93	1994/95	1996/97	1998/99	2000/01	2002/03	2004/05	2006/07	2008/09	Average % of change	ROI (%)	Change from base case (%)
Base case	602	4,388	3,678	1,474	3,831	5,127	2,873	9,342	16,438	13,894	-	14.5	-
	-	-	-	-	-	-	-	-	-	-	-	-	-
Hazard rate model	523	5,396	3,592	1,460	3,994	4,734	2,873	9,067	14,401	14,838	-	14.5	0.0
	-13%	23%	-2%	-1%	4%	-8%	0%	-3%	-12%	7%	-1%	-	-
Half-normal model	602	4,388	3,785	1,474	2,302	4,824	3,415	9,342	16,438	13,894	-	14.9	0.4
	0%	0%	3%	0%	-40%	-6%	19%	0%	0%	0%	-2%	-	-
Poor coverage corrections *	770	4,386	3,678	1,474	3,831	5,518	2,873	11,466	15,837	12,498	-	13.7	-0.8
	28%	0%	-	-	-	8%	-	23%	-4%	-10%	7%	-	-

*: SE stratum in 1990/91, NE stratum in 1992/93, SE stratum in 2000/01, NW and SW strata in 2004/05 seasons.

Table 5d. Abundance estimates and annual rates of increase for Area VIW for the base case and sensitivities.

Year	1996/97	1998/99	2000/01	2002/03	2004/05	2006/07	2008/09	Average % of change	ROI (%)	Change from base case (%)
Base case	1,493	171	2,440	1,614	2,237	2,136	3,609	-	6.2	-
	-	-	-	-	-	-	-	-	-	-
Hazard rate model	1,505	193	2,440	1,614	2,237	2,139	3,410	-	5.8	-0.4
	1%	13%	0%	0%	0%	0%	-6%	1%	-	-
Half-normal model	1,493	171	2,086	1,443	1,362	2,136	3,609	-	5.4	-0.8
	0%	0%	-15%	-11%	-39%	0%	0%	-9%	-	-
Poor coverage corrections *	1,493	223	2,440	1,614	2,237	2,136	3,609	-	6.1	-0.1
	-	23%	-	-	-	-	-	23%	-	-

*: VIW in 1998/99.

Table 6. Estimated annual instantaneous rates of exponential increase, together with their standard errors and 95% confidence intervals, for base case and other detection function selections for Areas IIE, IV, V and VIW, respectively. α is the instantaneous rate of increase. CV_{add} is the CV corresponding to the additional variance associated with abundance estimates.

Area IIIE

	α	se(α)	95%CILL	95%CIUL	CVadd	se(CVadd)
Base case	0.208	0.065	0.041	0.376	0.635	0.194
hazard rate	0.198	0.060	0.045	0.352	0.529	0.188
half-normal	0.208	0.065	0.041	0.376	0.635	0.194
opt B	0.189	0.058	0.041	0.337	0.503	0.184
opt C	0.189	0.061	0.031	0.346	0.547	0.194
poor coverage corrections	0.186	0.030	0.108	0.263	0.134	0.150

Area IV

	α	se(α)	95%CILL	95%CIUL	CVadd	se(CVadd)
Base case	0.136	0.022	0.084	0.187	0.328	0.093
hazard rate	0.136	0.024	0.080	0.192	0.372	0.100
half-normal	0.140	0.022	0.089	0.192	0.328	0.092
opt B	0.137	0.022	0.086	0.188	0.324	0.093
opt C	0.139	0.023	0.087	0.191	0.335	0.095
Gap abun=0	0.135	0.022	0.084	0.185	0.320	0.092
Gap abun=below	0.138	0.023	0.085	0.191	0.344	0.096
poor coverage corrections	0.136	0.022	0.084	0.187	0.328	0.093

Area V

	α	se(α)	95%CILL	95%CIUL	CVadd	se(CVadd)
Base case	0.145	0.030	0.076	0.215	0.416	0.138
hazard rate	0.145	0.031	0.075	0.215	0.424	0.147
half-normal	0.149	0.028	0.084	0.214	0.369	0.139
poor coverage corrections	0.137	0.030	0.068	0.206	0.411	0.135

Area VIW

	α	se(α)	95%CILL	95%CIUL	CVadd	se(CVadd)
Base case	0.062	0.028	-0.009	0.134	0.036	0.582
hazard rate	0.058	0.026	-0.010	0.125	0.002	0.374
half-normal	0.054	0.033	-0.032	0.140	0.086	0.394
poor coverage corrections	0.061	0.026	-0.007	0.129	0.002	0.339

Table 7. Coefficients and their SE for logistic regression model (6). SE of P_0 estimate was very high.

	Estimate	SE
K	29,950	3,250
P_0	674	498.3
r	0.440	0.023

Table 8a. Observed number of sightings (truncated at 2.7 n. miles perpendicular distance after smearing) by survey mode used as input in the GLMs of equation (7) in Areas IV and V.

Area IV by SSV

Year	Stratum	n_{obs}
1989/90	NW	21
	NE	20
	SW	10
	SE	1
	PB	2
1991/92	NW	42
	NE	16
	SW	13
	SE	10
	PB	0
1993/94	NW	34
	NE	17
	SW	17
	SE	6
	PB	3
1995/96	NW	101
	NE	33
	SW	35
	SE	21
	PB	0
1997/98	NW	150
	NE	80
	SW	130
	SE	18
	PB	2
1999/00	NW	41
	NE	94
	SW	76
	SE	86
	PB	0
2001/02	NW	195
	NE	179
	SW	261
	SE	52
	PB	0
2003/04	NW	175
	NE	199
	SW	294
	SE	280
	PB	0

Area IV SVC

Year	Stratum	n_{obs}
1991/92	SW	7
	SE	6
	PB	1
1993/94	NW	10
	NE	11
	SW	7
	SE	1
	PB	1
1995/96	NW	21
	NE	13
	SW	20
	SE	7
	PB	0
1997/98	NW	29
	NE	25
	SW	18
	SE	5
	PB	0
1999/00	NW	4
	NE	23
	SW	8
	SE	21
	PB	0
2001/02	NW	16
	NE	18
	SW	30
	SE	1
	PB	0
2003/04	NW	33
	NE	28
	SW	32
	SE	39
	PB	1
2005/06	NW	36
	NE	23
	SW	24
	SE	49
	PB	0
2007/08	NW	40
	NE	14
	SW	48
	SE	13

Area IV SVP

Year	Stratum	n_{obs}
1997/98	NW	9
	NE	1
	SW	21
	SE	1
	PB	0
1999/00	NW	10
	NE	43
	SW	21
	SE	58
	PB	3
2001/02	NW	41
	NE	40
	SW	97
	SE	10
	PB	0
2003/04	NW	33
	NE	53
	SW	64
	SE	128
	PB	1
2005/06	NW	114
	NE	38
	SW	106
	SE	181
	PB	0
2007/08	NW	101
	NE	50
	SW	158
	SE	61

Table 8a (Cont.).

Area V by SSV

Year	Stratum	n_{obs}
1990/91	NW	1
	NE	1
	SW	22
	SE	1
1992/93	NW	5
	NE	3
	SW	1
	SE	3
1994/95	NW	6
	NE	10
	SW	27
	SE	3
1996/97	NW	1
	NE	13
	SW	8
	SE	6
1998/99	NW	3
	NE	17
	SW	16
	SE	30
2000/01	NW	29
	NE	24
	SW	12
	SE	0
2002/03	NW	6
	NE	40
	SW	15
	SE	2
2004/05	NW	9
	NE	46
	SW	15
	SE	9

Area V SVC

Year	Stratum	n_{obs}
1992/93	NW	0
	NE	6
	SW	4
	SE	1
1994/95	NW	8
	NE	17
	SW	15
	SE	2
1996/97	NW	0
	NE	1
	SW	9
	SE	0
1998/99	NW	5
	NE	5
	SW	3
	SE	0
2000/01	NW	5
	NE	8
	SW	4
	SE	0
2002/03	NW	1
	NE	3
	SW	2
	SE	0
2004/05	NW	6
	NE	7
	SW	0
	SE	0
2005/06	NW	4
	SW	5
2006/07	NW	1
	NE	10
	SW	2
	SE	0
2007/08	NW	14
	SW	1
2008/09	NW	4
	NE	18
	SW	14
	SE	5

Area V SVP

Year	Stratum	n_{obs}
1998/99	NW	4
	NE	0
	SW	12
	SE	4
2000/01	NW	9
	NE	12
	SW	15
	SE	0
2002/03	NW	5
	NE	15
	SW	2
	SE	1
2004/05	NW	5
	NE	23
	SW	2
	SE	1
2005/06	NW	11
	SW	44
2006/07	NW	4
	NE	35
	SW	6
	SE	0
2007/08	NW	22
	SW	13
2008/09	NW	19
	NE	39
	SW	35
	SE	1

Table 8b. QAIC and estimated annual instantaneous rate of exponential increase in Areas IV and V. $\hat{c}$ is the estimated over-dispersion parameter. The line in **bold** indicates the model selected by QAIC.

Area IV

Model	$\hat{c}$	QAIC	ΔQAIC	α	se(α)	α 95%LL	α 95%UL
i)	18.69	135.23	135.23	0.141	0.014	0.114	0.168
ii)	**19.00**	**131.36**	**131.36**	**0.159**	**0.017**	**0.125**	**0.192**
iii) with T1	19.76	131.50	131.50	0.162	0.018	0.127	0.197
iii) with T2	19.54	131.70	131.70	0.158	0.017	0.124	0.192
iii) with T3	16.47	139.21	139.21	0.164	0.017	0.131	0.197
iii) with T4	19.13	132.17	132.17	0.162	0.017	0.127	0.196
iv) with T1	14.41	159.70	159.70	0.155	0.020	0.115	0.194
iv) with T2	14.50	152.88	152.88	0.160	0.018	0.125	0.195
iv) with T3	14.12	156.40	156.40	0.148	0.016	0.116	0.180
iv) with T4	15.62	144.96	144.96	0.143	0.017	0.110	0.175

Area V

Model	$\hat{c}$	QAIC	ΔQAIC	α	se(α)	α 95%LL	α 95%UL
i)	**12.32**	**92.66**	**92.66**	**0.117**	**0.026**	**0.066**	**0.167**
ii)	12.21	93.10	93.10	0.085	0.029	0.027	0.144
iii) with T1	11.31	104.25	104.25	0.070	0.031	0.008	0.132
iii) with T2	11.41	102.01	102.01	0.073	0.032	0.010	0.136
iii) with T3	10.55	107.54	107.54	0.077	0.027	0.022	0.131
iii) with T4	12.49	93.35	93.35	0.086	0.031	0.026	0.147
iv) with T1	7.98	141.80	141.80	0.094	0.031	0.033	0.155
iv) with T2	7.81	137.49	137.49	0.095	0.027	0.040	0.150
iv) with T3	6.67	146.58	146.58	0.104	0.024	0.057	0.151
iv) with T4	10.49	109.52	109.52	0.099	0.028	0.043	0.156

Table 9a. Comparison of JARPA (Matsuoka *et al.*, 2011)/JARPA II and IDCR-SOWER (Branch, 2011, here those incorporating his comparable areas adjustments) abundance estimates of humpback whales in Areas IV and V.

Area IV

Year	JARPA		IDCR/SOWER	
	estimate	CV	estimate	CV
1978/79	-	-	1,102	0.46
1988/89	-	-	4,167	0.53
1989/90	5,325	0.302	-	-
1991/92	5,408	0.188	-	-
1993/94	2,747	0.153	-	-
1995/96	8,066	0.142	-	-
1997/98	10,657	0.166	-	-
1998/99	-	-	17,938	0.18
1999/00	16,751	0.143	-	-
2001/02	31,134	0.123	-	-
2003/04	27,783	0.115	-	-
2005/06	25,958	0.263	-	-
2007/08	29,067	0.255	-	-

Area V

Year	JARPA		IDCR/SOWER	
	estimate	CV	estimate	CV
1980/81	-	-	1,876	0.60
1985/86	-	-	622	0.50
1990/91	602	0.343	-	-
1991/92	-	-	3,310	0.34
1992/93	4,388	0.623	-	-
1994/95	3,678	0.307	-	-
1996/97	1,474	0.274	-	-
1998/99	3,831	0.430	-	-
2000/01	5,127	0.215	-	-
2002/03	2,873	0.157	-	-
2003/04	-	-	13,246	0.20
2004/05	9,342	0.337	-	-
2006/07	16,438	0.266	-	-
2008/09	13,894	0.338	-	-

Table 9b. Comparison of JARPA+JARPA II and IDCR-SOWER (Branch, 2011) rates of increase estimates in Areas IV and V. The values marked IDCR-SOWER are as estimated by Branch (2011) , whose estimates of CV_{add} were zero for both these Areas; those marked IDCR-SOWER* revise Branch's results by incorporating the base case estimates of CV_{add} obtained for each of these Areas from the analyses of this paper (Table 7).

Area IV

Program	Period (Y/M/D)	estimate	95%CILL	95%CIUL
JARPA	1989/12/31 - 2004/3/1	0.136	0.084	0.187
IDCR-SOWER	1978/12/28 - 1999/2/22	0.148	0.081	0.215

Area V

Program	Period (Y/M/D)	estimate	95%CILL	95%CIUL
JARPA	1991/1/11 - 2005/3/8	0.145	0.076	0.215
IDCR-SOWER	1980/12/17 - 2004/2/28	0.122	0.053	0.191

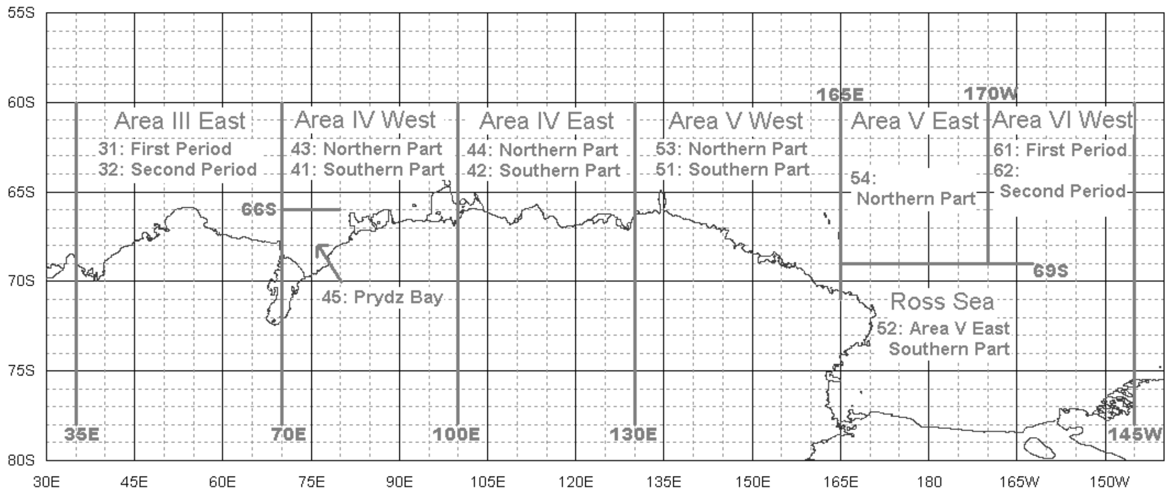


Figure 1. Stratification of the JARPA and JARPA II research area. During JARPA II, Areas IIIE and VIW were stratified into Northern and Southern strata.

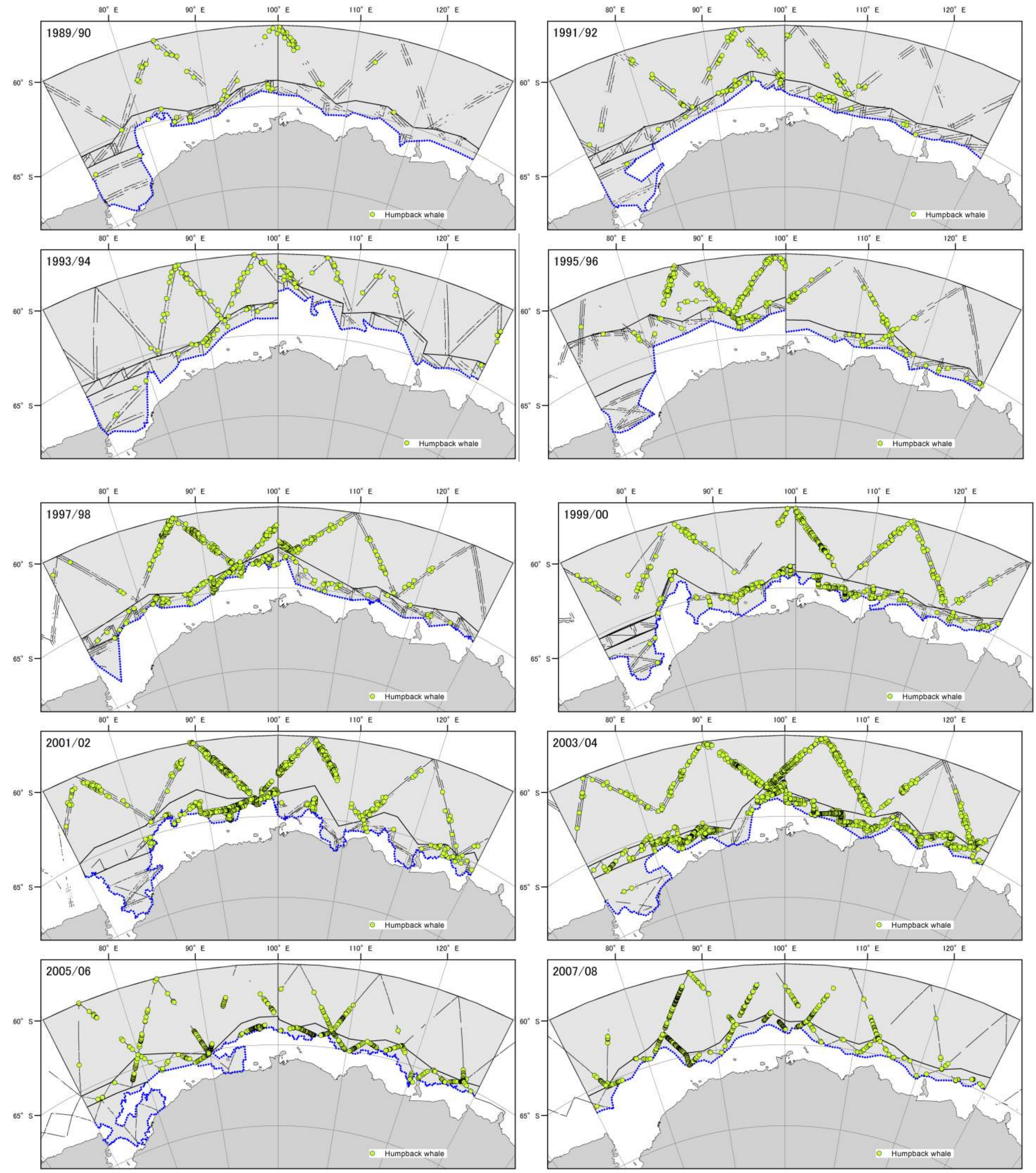


Figure 2a. Primary search effort (thin lines) and associated primary sightings (circle) of humpback whales in Area IV (70°E-130°E) with the ice edge line (dotted) during the 1989/90 to 2007/08 JARPA surveys..

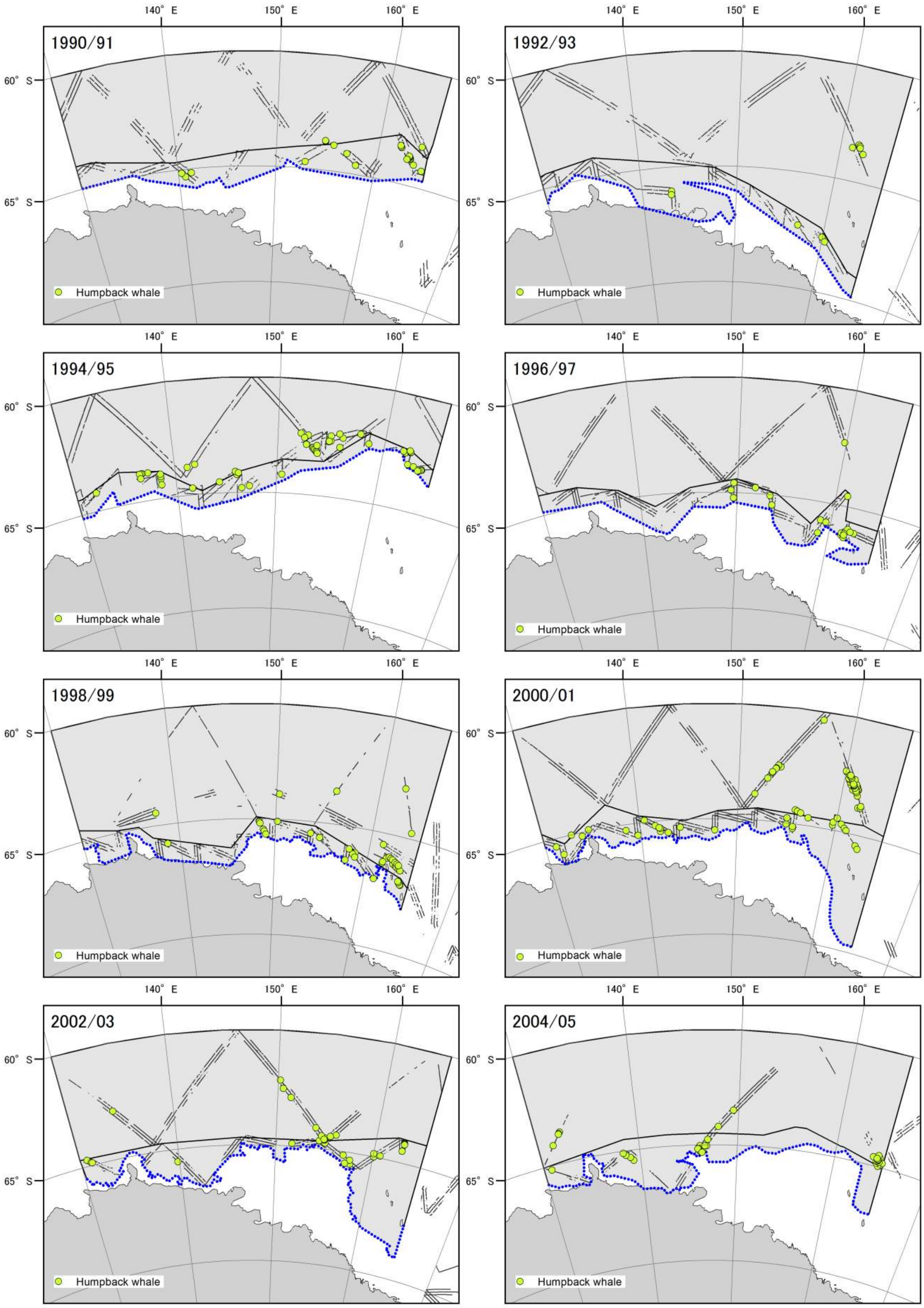


Figure 2b. Primary search effort (thin lines) and associated primary sightings (circle) of humpback whales in Area VW (130°E-165°E) with the ice edge line (dotted) during the 1990/91 to 2008/09 JARPA surveys..

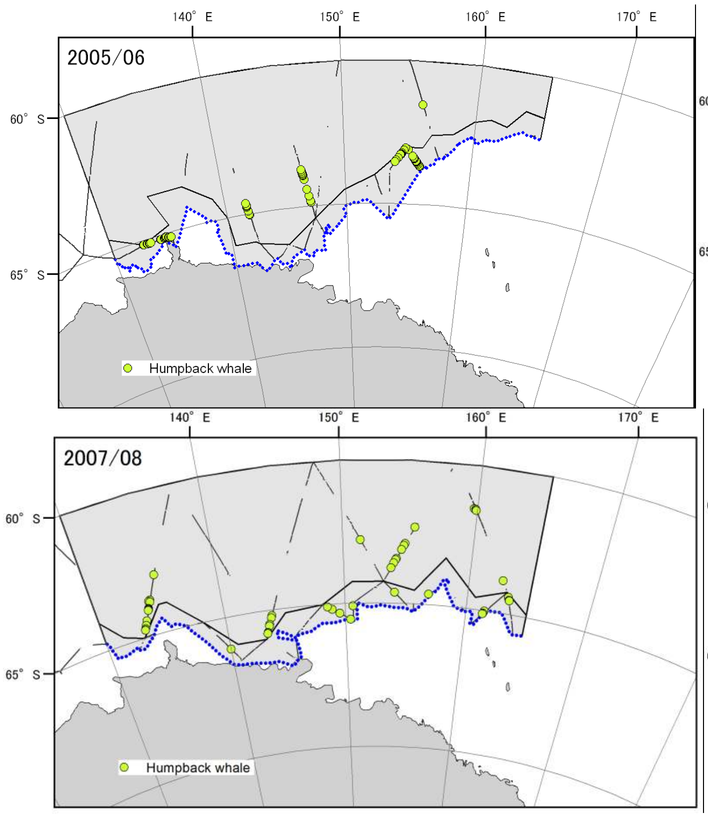


Figure 2b. (Cont.).

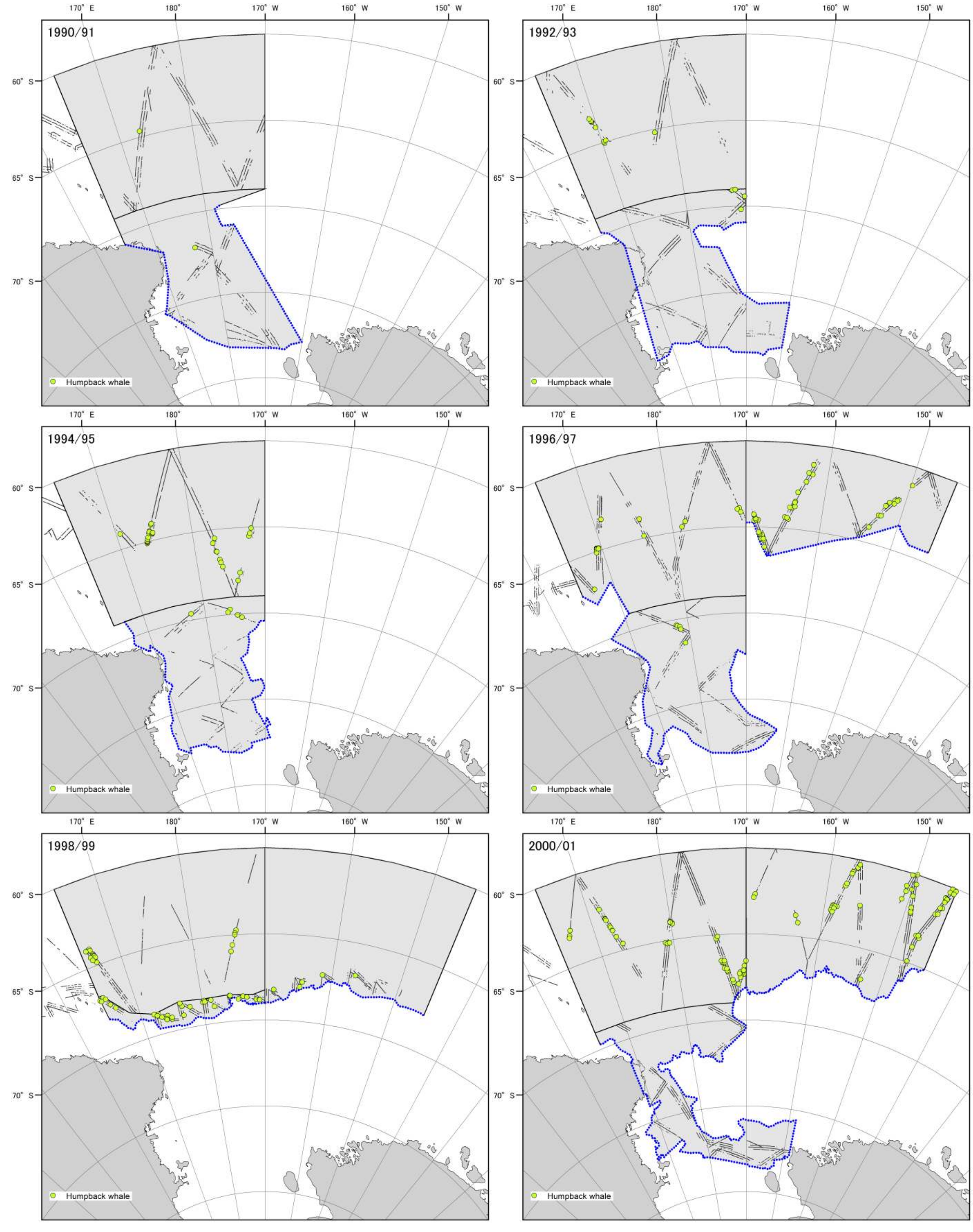


Figure 2c. Primary search effort (thin lines) and associated primary sightings (circle) of humpback whales in Areas VE and VIW (165^{o}E-145^{o}W) with the ice edge line (dotted) during the 1990/91 to 2008/09 JARPA surveys..

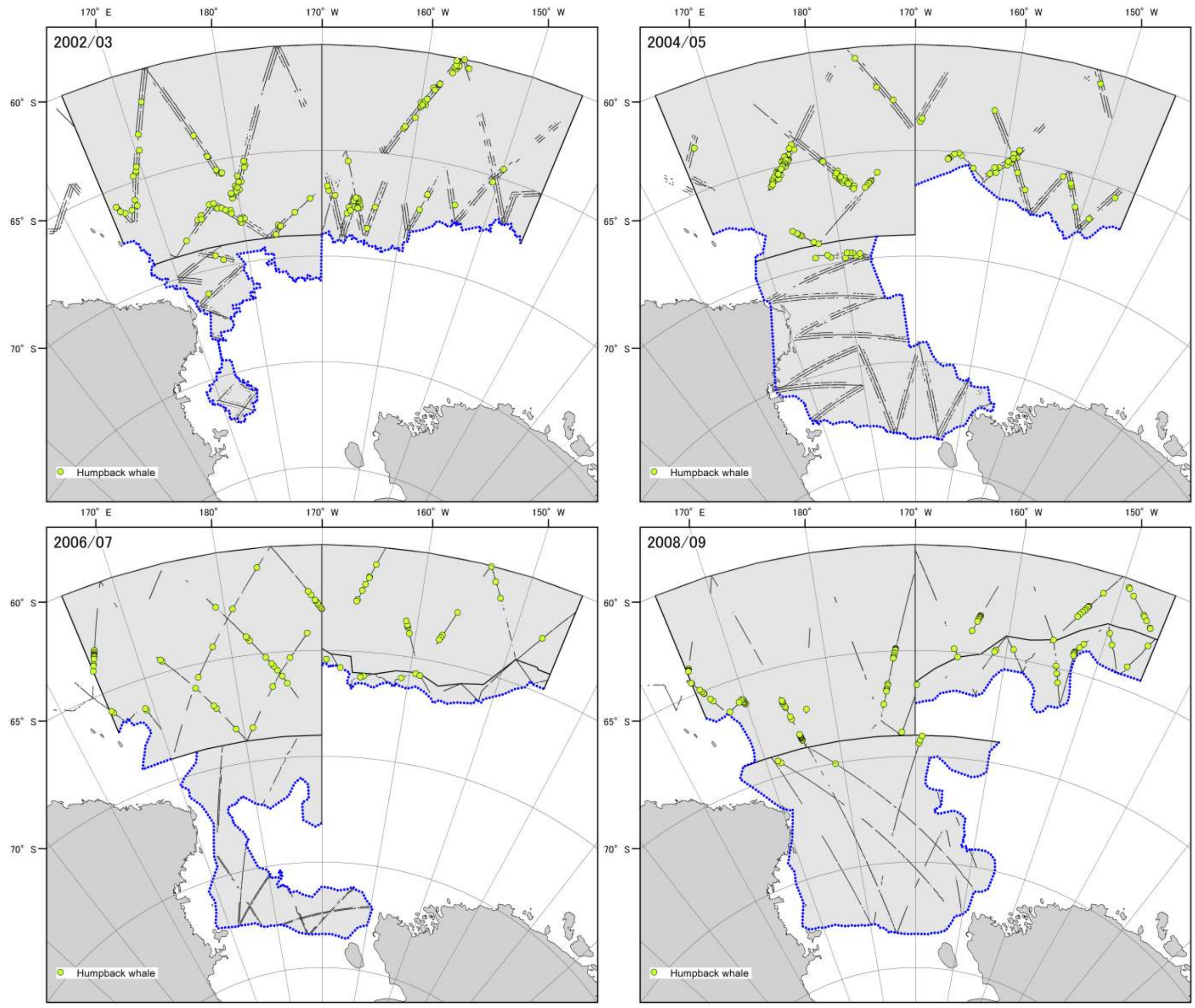


Figure 2c. (Cont.).

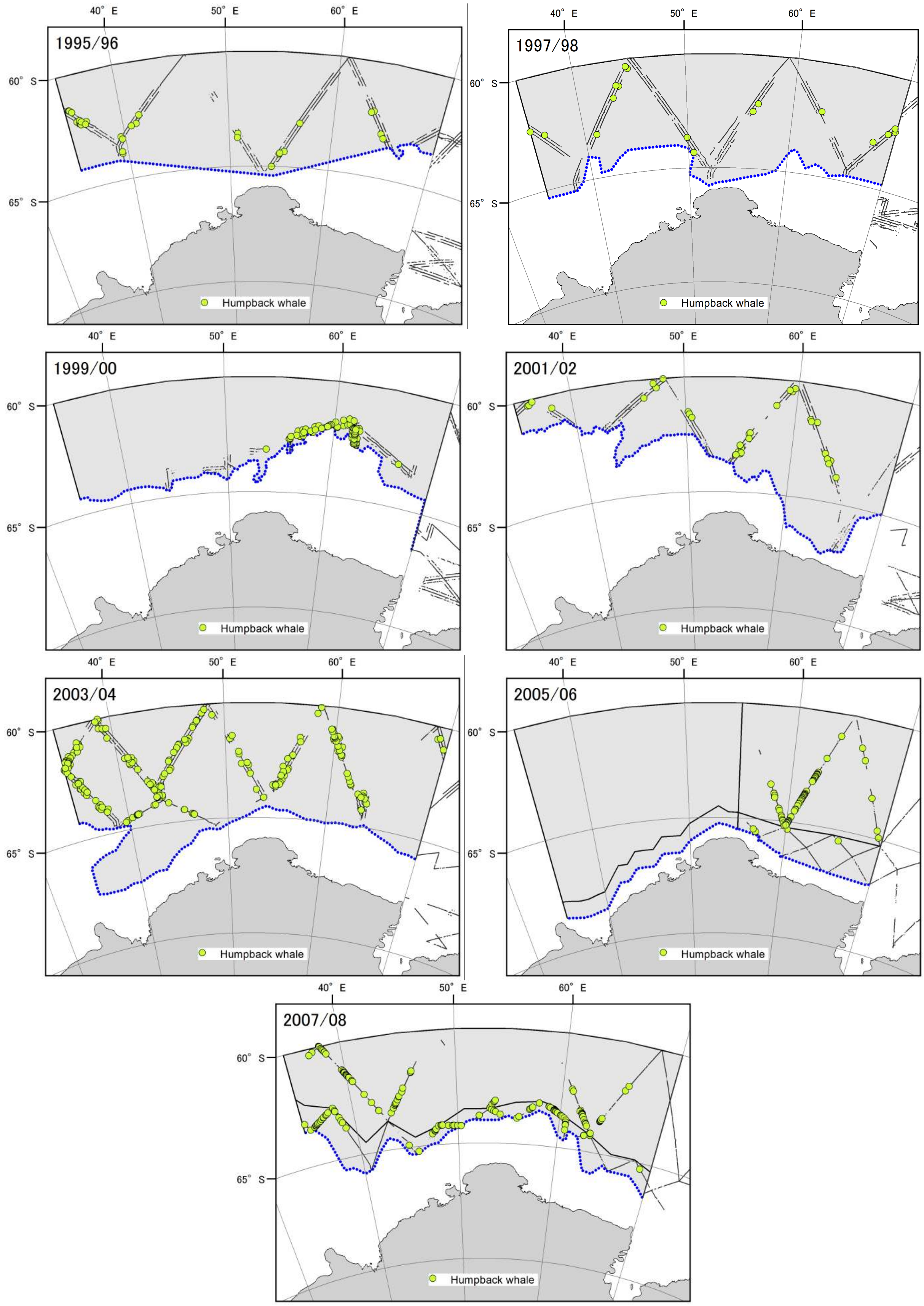


Figure 2d. Primary search effort (thin lines) and associated primary sightings (circle) of humpback whales in Area IIIE (35^{o}E-70^{o}E) with the ice edge line (dotted) during the 1995/96 to 2007/08 JARPA surveys..

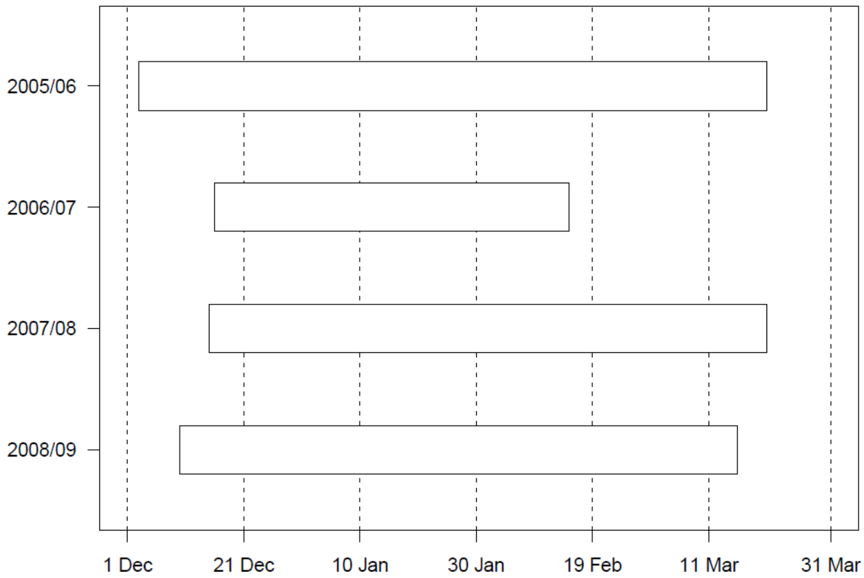
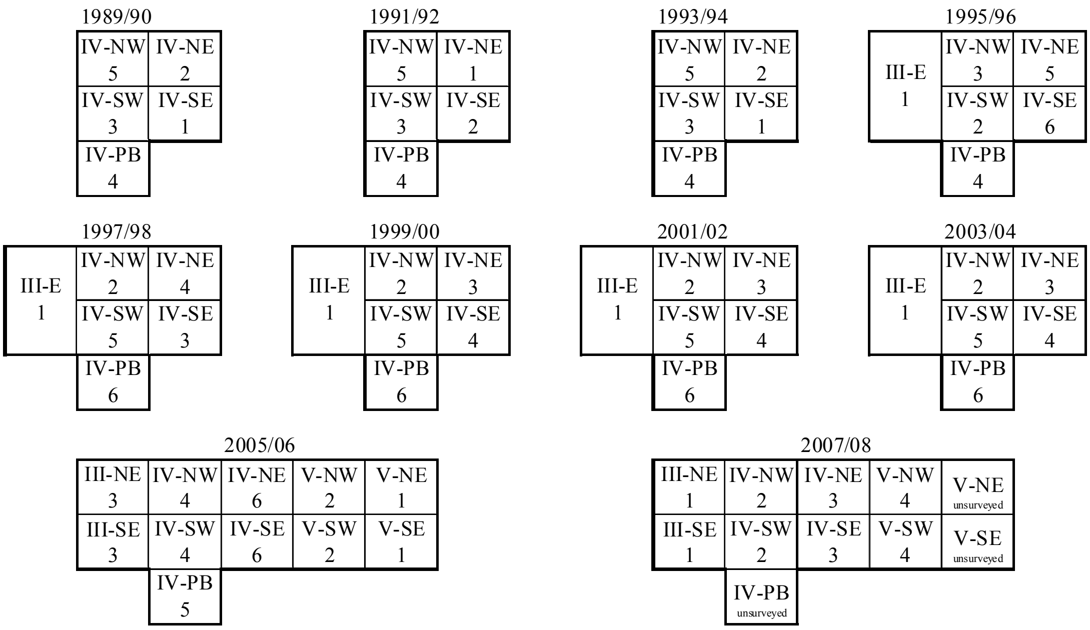


Figure 3. Start and end dates of JARPA II surveys (2005/06-2008/09) for abundance estimation of humpback whales in the survey area.

a) Areas IIIE, IV and part of V combined (35°E-175°E).



b) Areas V and VIW combined (130°E-145°W)

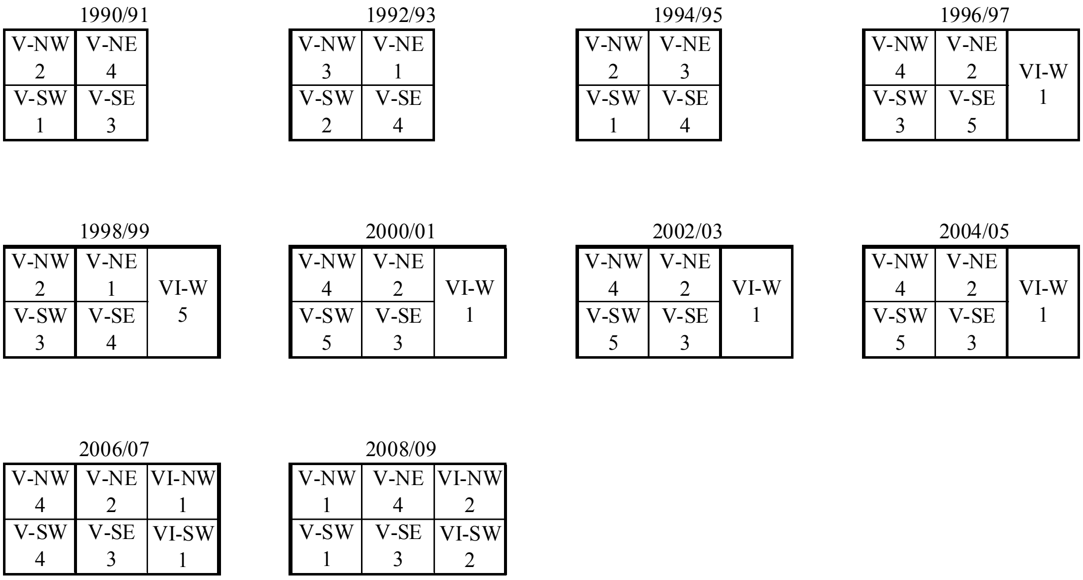


Figure 4. Survey order by strata for the JARPA cruises from 1989/90 to 2008/09. Key: III=Area III, IV=Area IV, V=Area V, VI=Area VI, E=East, W=West, NW=North-West, NE=North-East, SW=South-West, SE=South-East, PB= Prydz Bay. A common number in a season indicates that two strata were surveyed in the same period. V-NE, V-SE and IV-PB strata could not be surveyed at all in 2007/08 season.

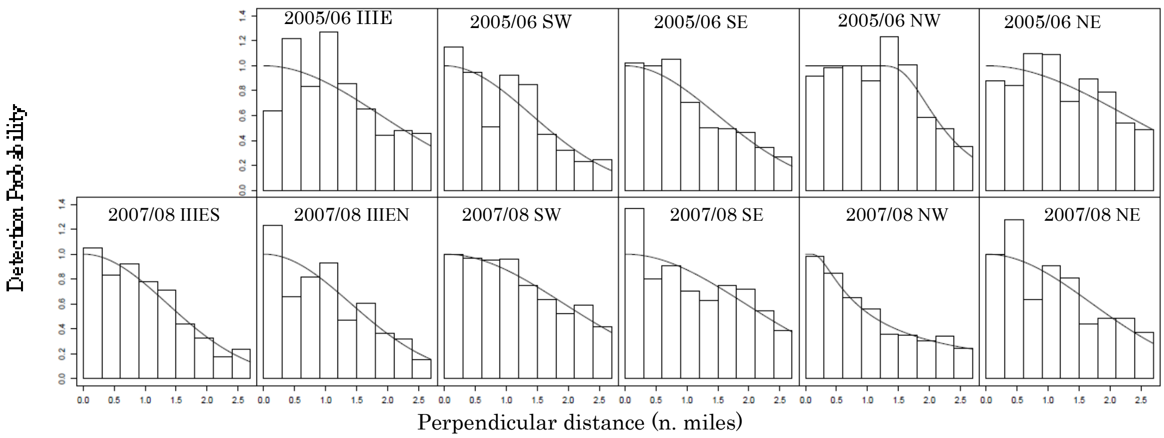


Figure 5a. Estimated detection probability functions (AIC-based selection between hazard rate and half-normal forms) for humpback whales in Areas IIIE and IV during the 2005/06 and 2007/08 JARPA II surveys. These results are for data combined across the SVC and SVP survey modes.

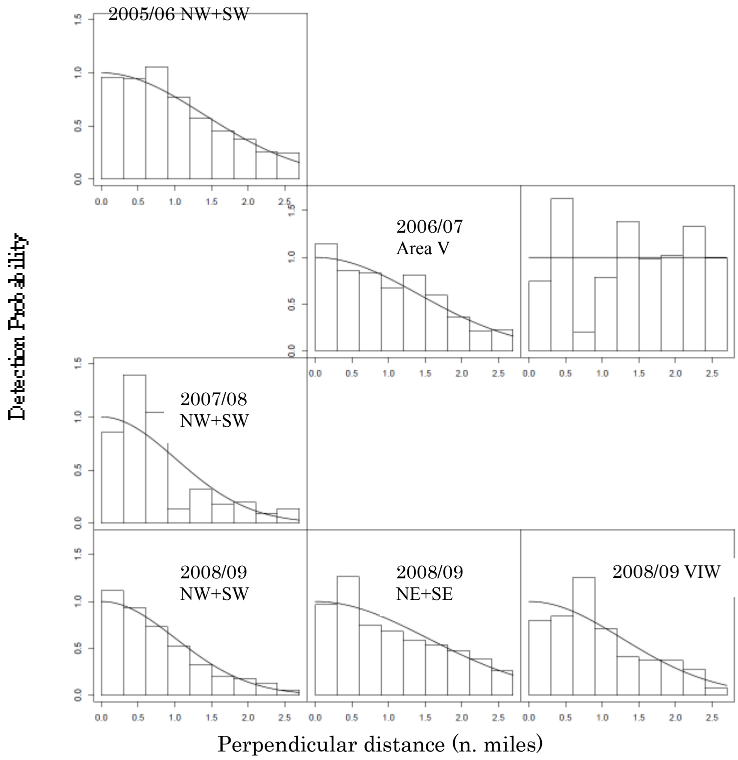
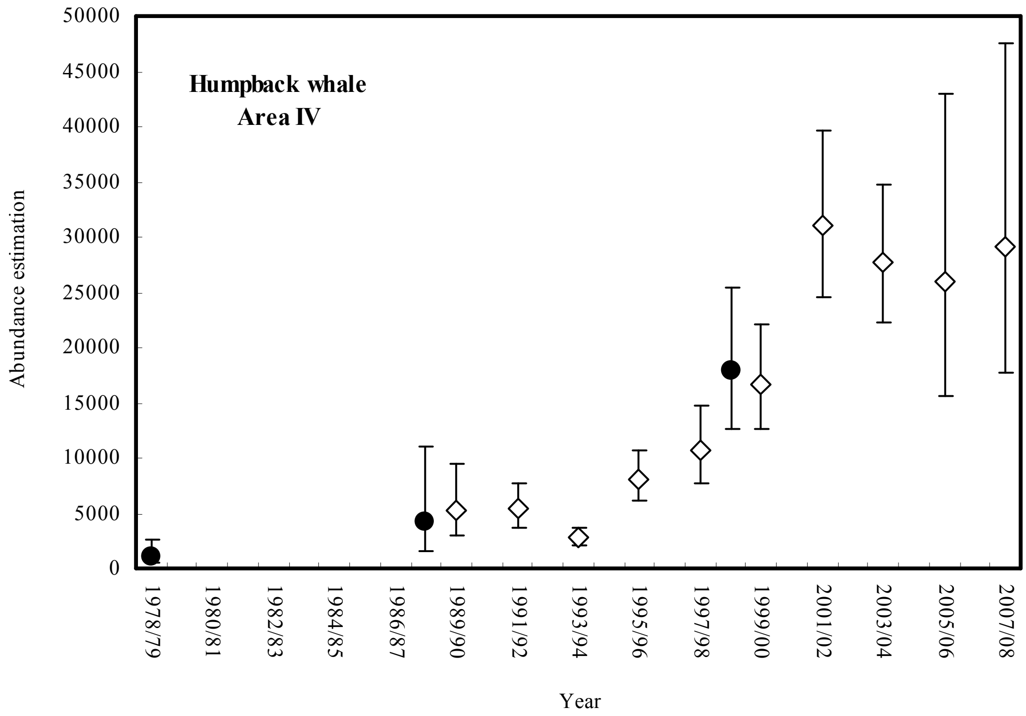


Figure 5b. Estimated detection probability functions (AIC-based selection between hazard rate and half-normal forms) for humpback whales in Areas V and VIW during 2005/06 - 2008/09 JARPA II surveys. These results are for data combined across the SVC and SVP survey modes.



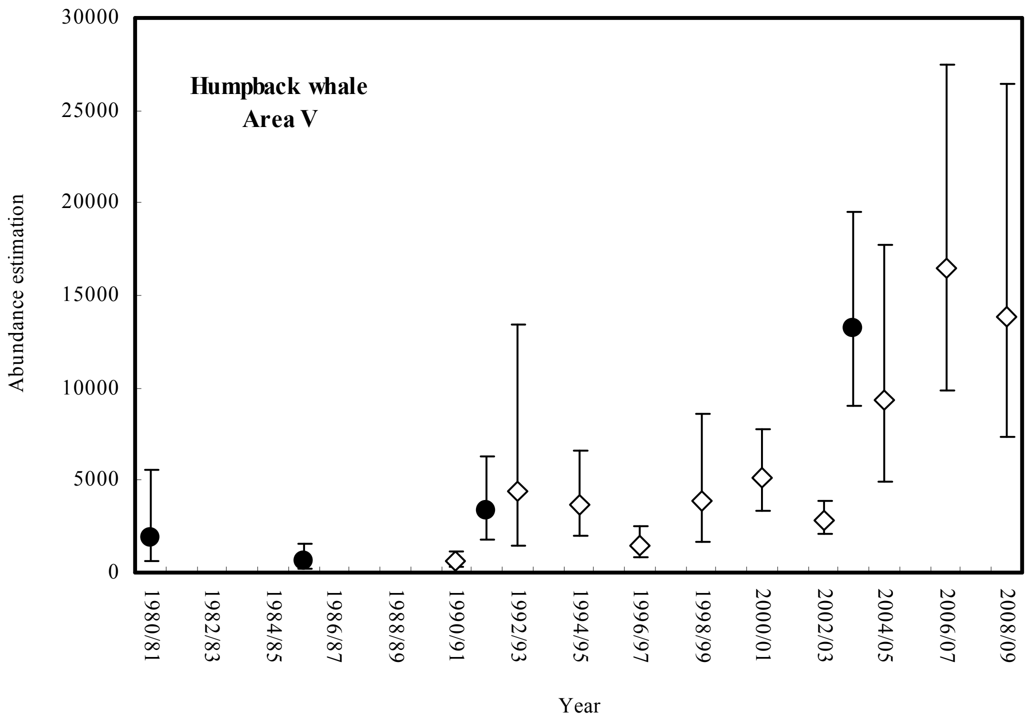


Figure 6. Abundance estimates for humpback whales in Areas IV and V (south of 60^{o}S), which were surveyed primarily during January to February, from the JARPA and JARPA II surveys from 1989/90 to 2008/09. Estimates from the IDCR-SOWER surveys (Branch, 2011) are shown by the filled circles. Vertical lines show 95％ confidence intervals.

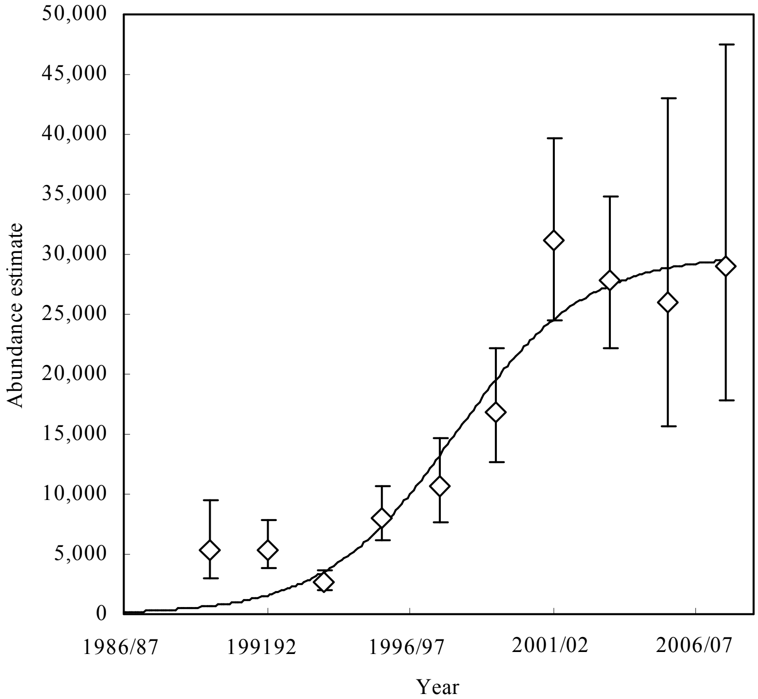


Figure 7. Abundance estimates in Area IV and predicted abundance estimate by regression model (6). Vertical lines show 95% confidence intervals of abundance estimates.