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Distribution and abundance estimates of blue whales in the Antarctic Areas IIIE,IV, V and VIW (35°E -145°W) based on JARPA data

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ABSTRACT
This paper reports current distributions and abundance estimates of blue (*Balaenoptera musculus intermedia*) whales in the Antarctic Areas IIIE (35°E-70°E), IV(70°E-130°E), V (130°E-170°W) and VIW (170°W -145°W) in the waters south of 60 °S. These estimates were based on JARPA sighting data between 1989/90 and 2004/05 seasons (for 16 years) using the DISTANCE analysis program. Current abundance of blue whale (south of 60°S, 35°E-145°W) was 1,300 (CI: 690-2,440) in 2003/04 + 2004/05 seasons. This estimate (2003/04+2004/05) in the half of Antarctic IWC management Areas is reasonable compared to recent result. Anyway, they are so far from the pristine level.

KEY WORDS: ANTARCTIC, SURVEY VESSEL, DISTRIBUTION, ABUNDANCE ESTIMATE, BLUE WHALE

INTRODUCTION

In 1904, commercial whaling began in the Antarctic. Initially, the whaling mainly targeted humpback whale that are slow swimmers. Later, the target species were shifted to the blue, fin, sei and Antarctic minke whales one after anothers with reduction of the target whale stocks. Whaling of humpback, blue and fin in the Antarctic were banned in 1963, 1964, 1974, respectively. Initially, there were as many as 200,000 blue whales in the whole Antarctic by logistic model, and now were estimated as 1,700 (860-2,900) in 1996 using the IWC catch data, IWC/IDCR/SOWER abundance and JARPA sighting rate data (Branch et al., 2004).

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) was designed as large-scale and long-term monitoring exercise using line-transect surveys. It has been carried out in a broadly consistent way every other year in Areas IV and V since 1987/88 season during the austral summer seasons. After a season of feasibility research (1987/88 in Area IV and 1988/89 in Area V), a full-scale research has been conducted since 1989/90 season. Additional surveys were conducted once a year on alternately in the eastern part of Area III (IIIE) and the western part of Area VI (VIW) to investigate the stock of Antarctic minke whales from 1995/96 season. The sighting procedures followed the method used in the IWC/IDCR (International Decade for Cetacean Research) and SOWER (Southern Ocean Whale and Ecosystem Research) cruises as much as possible. This paper reports distribution and abundance estimates of blue whale in each Area between 1989/90 and 2004/05 seasons.

SURVEYS AND DATA COLLECTION

The procedures to collect and analyses sighting data that have been used in JARPA are very similar to those used for IWC/IDCR-SOWER cruises and include: 1) distance and angle are corrected by using the results of the distance and angle estimation experiments, 2) sighting rate is obtained on each day, 3) effective search half width is obtained by fitting a hazard rate or half normal models, 4) smearing parameters are obtained by the Buckland and Anganuzzi method II, 5) g (0) is assumed to be 1, and 6) sighting data are pooled by each season and each stratum as much as needed for reliable estimation of the effective search half-width (ws) and the mean school size (E(s)). Details of the sighting procedures were given in the Review of the sighting survey in the JARPA (Nishiwaki *et al*., 2005).

Research area covered

The area from south of 60^{o}S to the ice-edge in the Areas IIIE (35^{o}E-70^{o}E), IV (70^{o}E-130^{o}E), V (130^{o}E-170^{o}W) and VIW (170^{o}W -145^{o}W) were covered (Fig. 1a). Each Area of IV and V was divided into two sectors (western sector and eastern sector). Each sector also divided into two strata (northern and southern strata), the 60^{o}S latitude line to the line of 45 n.miles from the ice-edge (northern stratum), and ice-edge to 45 n.miles from the ice-edge line (southern stratum) except the Prydz Bay and the Ross Sea regions. The Prydz Bay defined as south of 66^{o}S and the Ross Sea defined as south of 69^{o}S. An exception, in the 1999/2000 and 2001/02 seasons, northern boundary of the research area was set as 58^{o}S in the Area III east from view point of the strategy for Antarctic minke distribution. There are no stratifications for Areas IIIE and VIW. Distribution of the searching efforts in JARPA1987/88-2004/05 seasons, including the first two years feasibility research and middle latitude transit sighting survey, is shown in Fig. 1b.

Design of the trackline

The sawtooth type trackline was applied to provide for a wider area of coverage. The starting point of the sawtooth trackline was randomly selected from 1 n.mile intervals on the longitudinal lines. The trackline legs were systematically set on the ice-edge and on the locus of the 45n.miles from the ice-edge in southern stratum, and the 45 n.miles from the 60^{o}S latitude line in northern stratum.

Research vessels

Kyo-Maru No.1, *Toshi-Maru No.25*, *Toshi-Maru No.18* operated for the surveys from 1989/90 to 1997/1998. *Kyosin-Maru No.2* has been engaged since 1995/96 survey. *Yusin-Maru* operated for the 1998/1999 survey as the replacement of *Toshi-Maru No.18*. *Yusin-Maru No.2* operated from the 2001/2002 survey as the replacement of *Toshi-Maru No.25*.

METHODS

Abundance estimation

Methodology of abundance estimation used in this study was described by Burt and Stahl (2000) which is the standard methodology adopted by IWC. The program DISTANCE (Buckland *et al*., 1993) was used for abundance estimation. Following formula was used for abundance estimation.

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

where,

P = abundance in numbers
A = area of stratum
E(s) = estimated mean school size
N = numb ers of schools primary sighted
W = effective search half-width for schools
L = search effort

The CV of P is calculated as follows;

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

Assuming abundance is log-normally distributed, 95% confidential interval of the abundance estimate was calculated as (*P*/*C*, *CP*);

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

where,
$Z_{0.025}$ represents 2.5-percentage point of standard normal distribution. Details of the analyses methods were described by Buckland *et al*.. (1993) or Branch and Butterworth (2001).

Correction of the estimated angle and distance
To correct biases of distance and angle estimation, an experiment was conducted on each vessel in each year. Bias was estimated for each platform (Table 1). Linear regression models with standard error proportional to true (radar) distance were conducted to detect significant bias of estimated distance at 5% level. In order to correct significant biases, the estimated distance was divided by the estimated slope through the origin. Linear regression models with constant variance were conducted to detect significant bias of estimated angle at 5% level. In order to correct significant biases, the estimated slope through the origin divided estimated angle (Burt and Stahl, 2000).

Survey modes
The Sighting and Sampling Vessel (SSV) and the dedicated Sighting Vessel (SV) modes are grouped in these analyses, although separate estimates are obtained from SSV and SV modes for Antarctic minke whale analyses. A restrictive approach is followed here than for minke whales since the small number of sightings available for blue whales dictates the need to include as many data as possible.

Truncation distance
The perpendicular distance distribution was truncated at 2.7 n.miles in principle. The truncated number of detection was substitute to formula (1).

Smearing parameters
The truncated sightings data are smeared before their use in the estimation of the effective search half-width (*ws*) and the mean school size E(s). Radial distance and angle data are conventionally smeared using Method II of Buckland and Anganuzzi (1988) and then grouped into intervals of 0.3 n.miles for estimating *ws* values. For minke whales, smearing parameters are normally estimated separately for each stratum from the data. However, due to the lower numbers of sightings for the species in this paper, some

pooling is necessary to apply the Buckland and Anganuzzi method. Smearing parameters are thus obtained from pooled sightings (irrespective of whether school size was confirmed or not) as 11.437 (angle) and 0.216 (distance), because number of sightings was small.

Effective search half-width

Hazard rate model with no adjustment terms or half normal models that automatically selected by the AIC. was used as a detection function model. It was assumed that *g(0)* is 1 (i.e. Probability of detection on the track is 1.). Effective search half-width was estimated 1.521 (CV=0.069) (Fig.3).

Mean school size

Regression of log of school size on *g*(*x*) described by Buckland *et al.* (1993) was used to estimate mean school size as 1.644 (CV=0.042). If the regression coefficient was not significant at 15% level, mean of observed school size was substituted to formula (1).

RESULT AND DISCUSSION

Distribution

Fig.1b. shows distribution of the search effort. Blue whales were encountered through the surveys and they were widely distributed in the research area. (Fig. 2).

Abundance estimate

Tables 2a-d show total number of the primary sightings (n), areas (A), effort (L), n/L, effective search half width (esw), estimated mean school size (E(s)), estimated whale density (D: whales / 100 n.miles^2), abundance estimation (P) with CVs by each stratum. Fig 3 shows the perpendicular distance in nautical miles used in the present analyses.

Abundance of this species (south of 60°S, 35°E-145°W) was 1,300 (CI: 690-2,440) in 2003/04 + 2004/05 seasons. The CIs are not included the process error caused by year to year combined estimates. There is no stock information of blue whales in the JARPA research area. Initially, there were as many as 200,000 blue whales in the whole Antarctic by logistic model, and now were estimated as 1,700 (860-2,900) in 1996 using the IWC catch data, IWC/IDCR=SOWER abundance and JARPA sighting rate data (Branch *et al*., 2004). Present estimate (2003/04+2004/05) of this species 1,300 in the half of Antarctic IWC management Areas is reasonable compared to recent result. They are so far from the pristine level. The number of survey years is still short to detect precise yearly trend.

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REFERENCES

Branch, T. A., and Butterworth, D., S., 2001. Estimates of abundance south of 60^{o}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. *MARINE MAMMAL SCIENCE* 20 (4): 726-754.

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. *Distance sampling: Estimating Abundance of Biological Populations.* Chapman & Hall, London, UK. 446 pp.

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

Burt, M., L. and Stahl, D, 2000. Minke whale abundance estimation from the 1997-98 IWC-SOWER Antarctic cruise in Area II. Paper SC/52/IA13 submitted to the IWC Scientific Committee, 2000 (unpublished). 17pp.

Nishiwaki, S., Ishikawa, H. and Fujise, Y. , 2005. Review of the survey procedure in the JARPA. Paper JA/ J05/ JR 2.

Table 1. Estimated observer bias in distance and angle estimation (JARPA) during 1989/90 to 2004/05 seasons.

1989/90

Vessel	platform	distance	angle
K01	barrel	n.s.	0.930
	upper bridge	n.s.	0.872
T18	barrel	n.s.	1.047
	upper bridge	n.s.	n.s.
T25	barrel	1.099	n.s.
	upper bridge	1.075	n.s.

1990/91

Vessel	platform	distance	angle
K01	barrel	n.s.	1.051
	upper bridge	0.953	1.064
T18	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
T25	barrel	0.882	n.s.
	upper bridge	0.961	n.s.

1991/92

Vessel	platform	distance	angle
K01	barrel	0.930	n.s.
	upper bridge	n.s.	0.950
T18	barrel	n.s.	n.s.
	upper bridge	0.960	n.s.
T25	barrel	n.s.	n.s.
	upper bridge	1.070	n.s.

1992/93

Vessel	platform	distance	angle
K01	barrel	n.s.	0.942
	upper bridge	1.083	0.941
T18	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
T25	barrel	n.s.	1.056
	upper bridge	n.s.	1.082

1993/94

Vessel	platform	distance	angle
K01	barrel	0.863	n.s.
	upper bridge	n.s.	n.s.
T18	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
T25	barrel	n.s.	n.s.
	upper bridge	n.s.	1.057

1994/95

Vessel	platform	distance	angle
K01	barrel	n.s.	n.s.
	upper bridge	n.s.	0.933
T18	barrel	n.s.	n.s.
	upper bridge	0.934	n.s.
T25	barrel	0.940	n.s.
	upper bridge	0.902	n.s.

1995/96

Vessel	platform	distance	angle
K01	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
T18	barrel	n.s.	n.s.
	upper bridge	1.110	0.956
T25	barrel	0.889	n.s.
	upper bridge	0.905	1.040
KS2	barrel	n.s.	0.905
	upper bridge	n.s.	0.898

1996/97

Vessel	platform	distance	angle
K01	barrel	0.822	n.s.
	upper bridge	0.844	n.s.
T18	barrel	0.711	n.s.
	upper bridge	n.s.	n.s.
T25	barrel	0.799	n.s.
	upper bridge	0.773	1.036
KS2	barrel	0.789	0.951
	upper bridge	0.662	1.050

1997/98

Vessel	platform	distance	angle
K01	barrel	0.842	n.s.
	upper bridge	0.746	n.s.
T18	barrel	0.902	n.s.
	upper bridge	0.788	n.s.
T25	barrel	0.729	n.s.
	upper bridge	0.914	n.s.
KS2	barrel	0.876	n.s.
	upper bridge	0.788	n.s.

1998/99

Vessel	platform	distance	angle
K01	barrel	0.902	n.s.
	upper bridge	0.956	1.057
T25	barrel	n.s.	1.053
	upper bridge	n.s.	1.065
YS1	barrel	0.923	n.s.
	upper bridge	0.968	n.s.
KS2	barrel	0.928	0.950
	upper bridge	n.s.	n.s.

1999/2000

Vessel	platform	distance	angle
K01	barrel	n.s.	n.s.
	upper bridge	1.050	n.s.
T25	barrel	n.s.	1.081
	upper bridge	n.s.	n.s.
YS1	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
KS2	barrel	n.s.	0.930
	upper bridge	n.s.	n.s.

2000/2001

Vessel	platform	distance	angle
K01	barrel	n.s.	1.051
	upper bridge	n.s.	n.s.
T25	barrel	n.s.	n.s.
	upper bridge	1.062	n.s.
YS1	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
KS2	barrel	n.s.	n.s.
	upper bridge	n.s.	0.861

2001/2002

Vessel	platform	distance	angle
K01	barrel	0.957	0.921
	upper bridge	0.957	n.s.
T25	barrel	0.951	n.s.
	upper bridge	0.960	n.s.
YS1	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
KS2	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.

2002/2003

Vessel	platform	distance	angle
K01	barrel	1.073	n.s.
	upper bridge	n.s.	n.s.
YS1	barrel	1.051	1.037
	upper bridge	1.058	0.938
YS2	barrel	1.050	n.s.
	upper bridge	n.s.	n.s.
KS2	barrel	n.s.	n.s.
	upper bridge	n.s.	1.088

*n.s. indicates no significant at 5% level.

2003/2004

Vessel	platform	distance	angle
K01	barrel	0.957	0.921
	upper bridge	0.957	n.s.
YS1	barrel	0.951	n.s.
	upper bridge	0.960	n.s.
YS2	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.
KS2	barrel	n.s.	n.s.
	upper bridge	n.s.	n.s.

2004/2005

Vessel	platform	distance	angle
K01	barrel	1.113	1.096
	upper bridge	1.044	n.s.
YS1	barrel	1.029	0.939
	upper bridge	1.024	0.919
YS2	barrel	1.102	1.061
	upper bridge	n.s.	n.s.
KS2	barrel	1.084	0.966
	upper bridge	1.064	n.s.

*n.s. indicates no significant at 5% level.

Table. 2a. Abundance estimates of blue whale in Area IV between 1989/90 and 2003/04 seasons. Truncate is 2.4 n.miles. The g (0) is assumed to be 1. n: number of primary schools, L: searching distance, esw: the effective search half width, E(s): mean school size, D: estimated density (individuals / 100 n.miles ^{2}), P: estimated population abundance (individuals).

Season	Stratum	area (n.mile ^{2})	n	L (n.mile)	n / L * 10^2	CV	esw (n.mile)	CV	E (S)	CV	**D (ind.) * 10^2**	**P (ind.)**	**CV**
1989/90	IV	548,721	4.0	8664.4	0.046	0.479	1.521	0.069	1.644	0.042	**0.012**	**64**	**0.481**
1991/92	IV	534,400	2.0	9783.3	0.020	1.075	1.521	0.069	1.644	0.042	**0.003**	**17**	**1.078**
1993/94	IV	503,561	4.0	13049.4	0.031	0.657	1.521	0.069	1.644	0.042	**0.013**	**63**	**0.619**
1995/96	IV	536,721	1.0	12723.1	0.008	0.931	1.521	0.069	1.644	0.042	**0.001**	**6**	**0.934**
1997/98	IV	524,233	5.0	14108.3	0.035	0.533	1.521	0.069	1.644	0.042	**0.029**	**151**	**0.602**
1999/2000	IV	560,837	13.0	12661.8	0.103	0.366	1.521	0.069	1.644	0.042	**0.038**	**215**	**0.395**
2001/02	IV	581,308	10.0	12555.9	0.080	0.391	1.521	0.069	1.644	0.042	**0.050**	**292**	**0.434**
2003/04	IV	659,759	6.0	13392.0	0.045	0.438	1.521	0.069	1.644	0.042	**0.014**	**91**	**0.717**

Table. 2b. Abundance estimates of blue whale in Area V between 1990/91 and 2004/05 seasons.

Season	Stratum	area (n.mile ^{2})	n	L (n.mile)	n / L * 10^2	CV	esw (n.mile)	CV	E (S)	CV	**D (ind.) * 10^2**	**P (ind.)**	**CV**
1990/91	V	851,204	3.0	8,530.7	0.035	1.01	1.521	0.07	1.644	0.04	**0.024**	**203**	**1.01**
1992/93	V	847,525	4.0	8,124.5	0.049	0.56	1.521	0.07	1.644	0.04	**0.027**	**228**	**0.67**
1994/95	V	714,033	9.0	9,545.5	0.094	0.37	1.521	0.07	1.644	0.04	**0.038**	**273**	**0.63**
1996/97	V	917,841	1.0	11,140.9	0.009	0.74	1.521	0.07	1.644	0.04	**0.001**	**7**	**0.75**
1998/99	V	730,433	4.0	6,952.0	0.058	1.27	1.521	0.07	1.644	0.04	**0.030**	**219**	**2.07**
2000/01	V	754,401	7.7	14,166.1	0.054	0.55	1.521	0.07	1.644	0.04	**0.039**	**291**	**0.49**
2002/03	V	719,205	3.9	12,176.0	0.032	0.52	1.521	0.07	1.644	0.04	**0.020**	**140**	**0.53**
2004/05	V	913,798	8.0	13,367.2	0.060	0.42	1.521	0.07	1.644	0.04	**0.056**	**514**	**0.73**

Table. 2c. Abundance estimates of blue whale in Area IIIE between 1995/96 and 2003/04 seasons.

Season	Stratum	area (n.mile ^{2})	n	L (n.mile)	n / L * 10^2	CV	esw (n.mile)	CV	E (S)	CV	**D (ind.) * 10^2**	**P (ind.)**	**CV**
1995/96	FIIIE	378,299	8.0	5646.8	0.142	0.43	1.521	0.07	1.644	0.04	**0.077**	**290**	**0.43**
1997/98	FIIIE	277,996	10.9	6704.0	0.163	0.48	1.521	0.07	1.644	0.04	**0.088**	**245**	**0.48**
1999/2000	FIIIE	226,025	10.5	3679.7	0.285	0.58	1.521	0.07	1.644	0.04	**0.154**	**349**	**0.58**
2001/02	FIIIE	354,965	2.0	4822.9	0.041	0.62	1.521	0.07	1.644	0.04	**0.022**	**80**	**0.62**
2003/04	FIIIE	324,032	16.0	5241.3	0.305	0.33	1.521	0.07	1.644	0.04	**0.165**	**535**	**0.34**

Table. 2d. Abundance estimates of blue whale in Area VIW between 1996/97 and 2004/05 seasons.

Season	Stratum	area (n.mile ^{2})	n	L (n.mile)	n / L * 10^2	CV	esw (n.mile)	CV	E (S)	CV	**D (ind.) * 10^2**	**P (ind.)**	**CV**
1996/97	FVIW	137,886	5.0	6464.2	0.077	0.44	1.521	0.07	1.644	0.04	**0.042**	**58**	**0.45**
1998/99	SVIW	316,727	0.0	1114.5	0.000	-	-	-	-	-	**-**	**-**	**-**
2000/01	FVIW	290,908	0.0	4383.6	0.000	-	-	-	-	-	**-**	**-**	**-**
2002/03	FVIW	309,998	1.0	5950.2	0.017	0.93	1.521	0.07	1.644	0.04	**0.009**	**28**	**0.93**
2004/05	FVIW	292,218	4.0	3,954.7	0.101	0.37	1.521	0.07	1.644	0.04	**0.055**	**160**	**0.38**

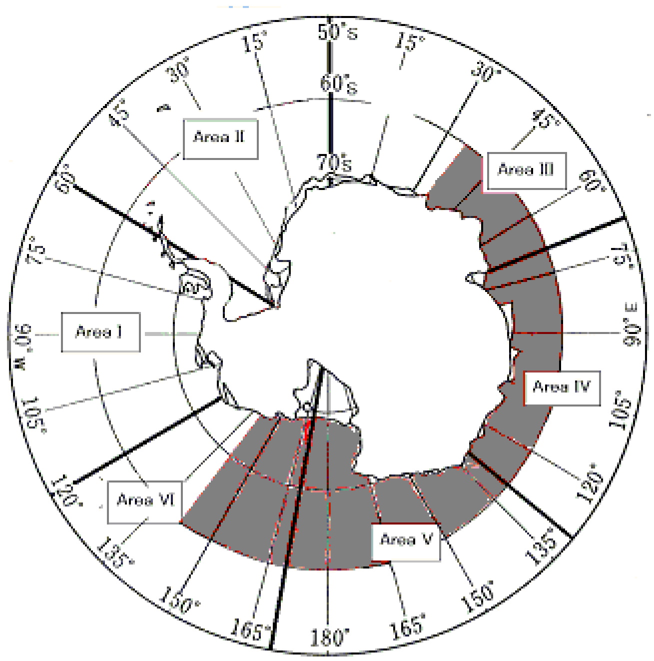

Fig.1a. The IWC Antarctic Areas for the management of baleen whales (except Bryde's whale) and research Area of the JARPA surveys between 35°E and 145°W (colored). Areas III east (IIIE: 35 °E-70°E), IV(70° E-130° E), V (130°E-170°W) and VI west (VIW: 170°W -145°W).

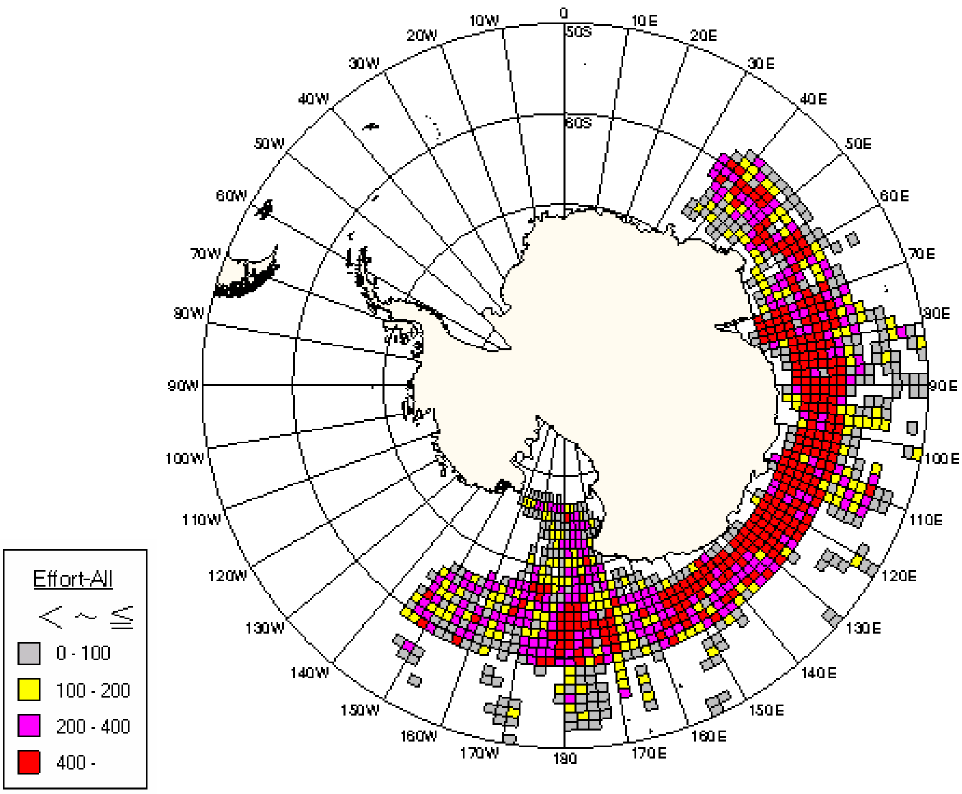

Fig.1b. Map of the the searching efforts by by Lat.1°× Long.2°square in the JARPA1987/88-2003/04 seasons, including middle latitude transit sighting survey. Research area was covered uniformly.

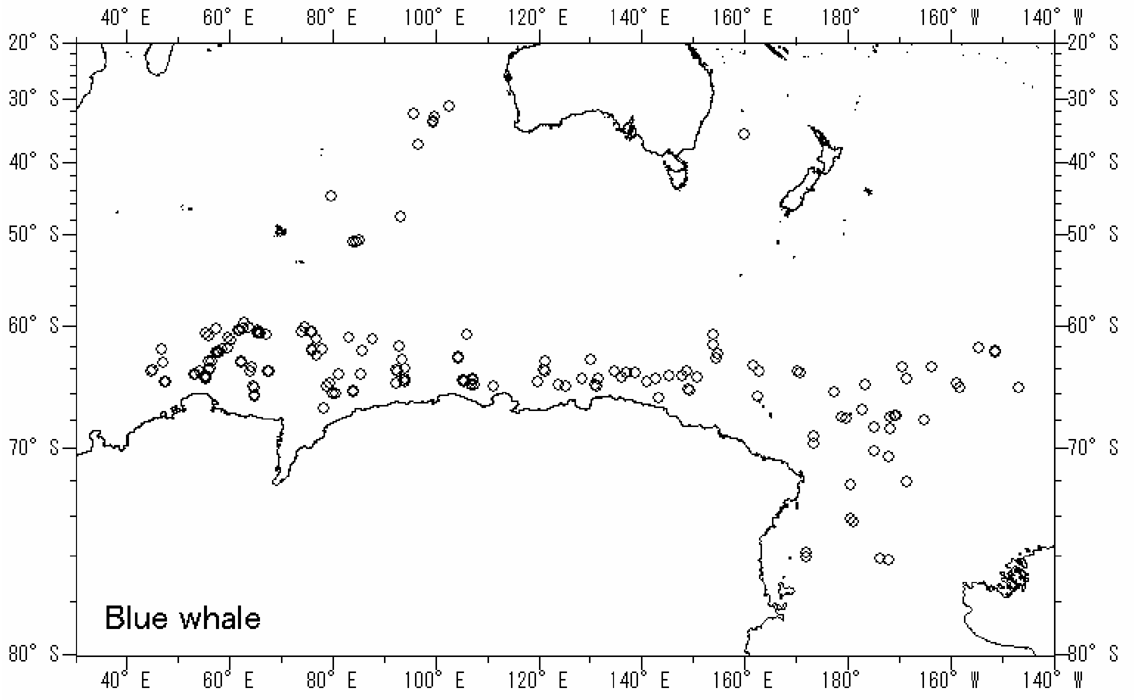

Fig.2. Sighting position of the blue whales in JARPA surveys between 1989/90 and 2004/05 seasons including transit surveys.

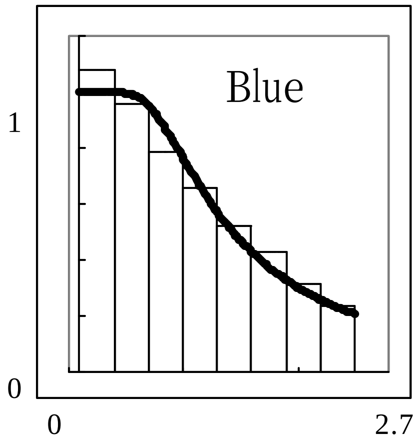

Fig. 3. Detection probability function of Blue whale in Area IIIE, IV, V and VIW surveyed from 1989/90 to 2004/2005 seasons.