Distribution and abundance of sperm whales in the Antarctic Areas IIIE,IV,V and VIW (35°E -145°W)

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ABSTRACT
This paper reports distribution and abundance estimates of sperm whale (*Physeter macrocephalus*) in the Antarctic IWC/management 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. The Density Index (DI; no. whales / 100 n.miles) was analyzed for their distribution pattern based on JARPA sighting data between 1987/88 and 2003/04 seasons. High density values of sperm whales were observed around 70°E-100°E and 160°E-180°. In the research area, solitary schools were 96.5% of sighted schools. Sperm whales (3,069 schools and 3,179 individuals) tended to be concentrated on the Antarctic continental slope, the southern Kerguelen Plateau, around the mouth of the Ross Sea, where the most frequency depth was between 3,000m and 4,000m. Monthly change of the DI observed from December to March, especially Areas IV and V. The longitudinal DI also decrease from December to March between 100°E and 170°W, on the other hand, constancy habitat was found from December to March between 70°E and 100°E where the southern part of the Kerguelen Plateau. This phenomenon may indicate the northward or westward seasonal migration of this species in the Antarctic. Yearly change of the DI was also examined and the DI of this species in Areas IV and V were stable from 1987/88 to 2002/03 seasons. Latest abundance was estimated using the DISTANCE analysis program for each area. Corrected abundance (corrected by g(0)) were estimated 4,422 (CV=0.20) and 9,877 (CV=0.20) in Areas IIIE and IV in 2001/02, and 4,242 (CV=0.26) and 1,090 (CV=0.32) in Areas V and VIW in 2002/03 season, respectively. Total abundance and biomass in the research area was 19,630 (CV=0.13) (538,000 tons). Further monitoring survey will contribute for the sperm whale population management in the Antarctic Ocean.

KEY WORDS: ANTARCTIC, SURVEY-VESSEL, DISTRIBUTION, ABUNDANCE ESTIMATE, SPERM WHALE

INTRODUCTION

Whaling of sperm whale in the Antarctic was banned in 1979/80 season. Distribution pattern of this species between 1965/66 and 1987/88 seasons were reported by Miyashita *et al.* (1995). Recent estimates in the whole Antarctic based on the IWC/IDCR and SOWER of this species were 5,400 (CV=0.38), 10,000 (CV=0.15) and 8,300 (CV=0.16) in first (1978/79-1983/84), second (1985/86-1990/91) and third (1992/93-199/98, not completed) circumpolar series, respectively in the area south of 60°S (Branch and Butterworth, 2001). Abundance estimates of sperm whales using JARPA 1989/90-1995/96 seasons were preliminary estimated to be 3,000-4,300 in Area IV and 2,200-3,100 in Area V (Matsuoka *et al.*, 1998).

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) was designed as large-scale and long-term monitoring line transect surveys. It has been carried out in a consistent way every other year in Areas IV and V since 1987/88 season during the austral summer seasons. After two seasons 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. In addition, 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. Details of the survey procedure ae reported in the JARPA review meeting (Nishiwaki *et al.*, 2005). This paper reports distribution and abundance estimates of sperm whale in each Area between 1989/90 and 2002/03 seasons.

SURVEYS AND DATA COLLECTION

Sighting surveys

Unique sighting procedures to collect unbiased sighting data have been introduced in the JARPA including 1) distance and angle were corrected by using the results of the distance and angle estimation experiments, 2) sighting rate was obtained on each day, 3) effective search half width was obtained by fitting a hazard rate or half normal models, 4) smearing parameter was obtained by the Buckland and Anganuzzi method II, 5) sighting data were pooled by each season and each stratum as much as possible for estimations 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°S to the ice-edge in the Areas IIIE (35°E-70°E), IV (70°E-130°E), V (130°E-170°W) and VIW (170°W-145°W) were covered (Fig. 1). 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°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°S and the Ross Sea defined as south of 69°S. There are no stratifications for Areas IIIE and VIW. Distribution of the searching efforts in JARPA1987/88-2003/04 seasons, including middle latitude transit sighting survey, is shown in Fig. 2.

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°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 1987/88 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

The Density Index (DI)

The Density Index (number of primary sightings of whales (individuals) / 100 n.miles, by lat. 1°x long. 2° square) of sperm whale distribution in the research sub-area was calculated by month.

Bottom topography

The depth of the sea where each sperm whale sighted was calculated using the Marine Explore (ME) by the Environment Simulation Laboratory Co., Ltd (http://www.esl.co.jp).

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 = numbers 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 sperm whales dictates the need to include as many data as possible.

Truncation distance

The perpendicular distance distribution was truncated at 3.0 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. Smearing parameters are normally estimated separately for each stratum from the data (Table 2).

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 for each stratum.

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. If the regression coefficient was not significant at 15% level, mean of observed school size was substituted to formula (1).

Probability of an animal being seen on the trackline, g(0), and corrected abundance

Abundance estimates based on the line transect model could be substantially underestimated for the long-diving species such as sperm whale if the probability of an animal being seen on the track line, g(0), is not considered. In this paper, we used the g(0) value of 0.32 (CV=0.11) for sperm whales (Kasamatsu and Joyce, 1995) to obtain the corrected abundance.

RESULTS AND DISCUSSIONS

Distribution of sperm whale

Fig.2. shows distribution of the search effort (n.miles). The research area was covered uniformly during 1987/88 to 2003/04 seasons. Total 267,336 n.miles were searched and a total of 3,069 schools was sighted (3,179 individuals) in the research area. Solitary schools were 96.5% of this species. Fig. 3 shows the all sighting position of the primary sightings of sperm whales from 1987/88 to 2003/04 seasons, including transit surveys with bottom topography. The distribution of sperm whales in the research area were widely distributed every year. They were rarely found within the Prydz Bay and the Ross Sea. There was no

sightings in the south of 72°S in the Ross Sea.

Figs. 4 show the map of the Density Index (number of primary sightings of whales / 100 n.mile) of sperm whales during JARPA -1987/88-2003/04 seasons by Lat.1°× Long.2°square, including transit surveys. High density values of sperm whales were observed between 70°E and 100°E. They tended to be concentrated on the Antarctic continental slope, the southern Kerguelen Plateau, around the mouth of the Ross Sea, where the most frequency depth was between 3,000m and 4,000m (Fig.5). Table 3 shows summary of the primary sightings of sperm whales in the JARPA during 1987/88 to 2003/04 seasons by each month (south of 60°S).

Monthly change of the DI and seasonal migration

Fig. 6 show the monthly map of the DI of this species between 1987/88 and 2003/04 seasons. Areas IV and V were surveyed uniformly from December to March, however, Areas IIIE and VIW were surveyed mainly December (Fig. 7). Monthly DI decrease from December to March in Areas IV and V. Monthly change of the DI were 1.71, 1.30, 1.08, and 0.19 from December to March, respectively (Table 3 and Fig. 8). Fig. 9. show the longitudinal monthly change of the DI of this species (south of 60°S). The longitudinal DI also decrease from December to March between 100°E and 170°W, on the other hand, stational habitat was found from December to March between 70°E and 100°E where the southern part of the Kerguelen Plateau. This phenomenon may indicate the northward or westward seasonal migration of this species.

Yearly change of the DI

Fig. 10 show the yearly change of the DI using efforts and number of primary sightings of sperm whales in the research sub-area (north of 35°N) between 1987/88 and 2002/03 seasons using data only January and February, because of the monthly change of DI. The DI of sperm whales in Areas IV and V were stable from 1987/88 to 2002/03.

Abundance and biomass estimates

Table 4 shows latest abundance estimates of sperm whale based on the 2001/02 and 2002/03 seasons using the DISTANCE analysis program for each area. Figs. 11 show the perpendicular distances in nautical miles used in the present analyses. Uncorrected abundance (i.e. assuming g(0)=1) were estimated 1,415 (CV=0.20) and 3,161 (CV=0.16) in Areas IIIE and IV in 2001/02, and 1,357 (CV=0.23) and 349 (CV=0.30) in Areas V and VIW in 2002/03 season, respectively.

Table 5 shows collected abundance using g(0)=0.32 (CV=0.11) by Kasamatsu and Joyce (1995) were estimated 4,422 (CV=0.20) and 9,877 (CV=0.20) in Areas IIIE and IV in 2001/02, and 4,242 (CV=0.26) and 1,090 (CV=0.32) in Areas V and VIW in 2002/03 season, respectively. Total abundance and biomass in the whole research area was 19,630 (CV=0.13) and 538,000 tons, respectively. Further attention should be given to the monthly change of the DI (Fig. 8), although Areas IV and V surveyed mainly in January and February, the DI of this species suggested that current estimations of these Areas were under-estimated.

Compare to the recent estimates (g(0)=1) of the whole Antarctic based on the IWC/IDCR and SOWER of this species was 8,300 (CV=0.16) in the third (1992/93-199/98, not completed) circumpolar series in the area south of 60°S (Branch and Butterworth, 2001), present estimates of the half of the Antarctic as 6,282 (CV=0.11) are yielded similar results.

High productivity in the meander of the southern boundary of ACC

From the viewpoint of large scale whale distribution of sperm whales in Area IV was concentrated between 70° E and 100° E (south of 60° S) rather than other parts of the research area. This area was characterized by a large meander (rise to 61° S and slow-moving down to 63° S) of the southern boundary of the ACC which seemed to be formed by large scale up-welling with nutritious bottom waters resulting from the bottom shape of the southern Kerguelen Plateau (Watanabe *et al.*, 2005). The BROKE, Australian Antarctic survey, indicated the possibility of the occurrence of large-scale upwelling between 80°E and 100° E (Bindoff *et. al*, 2000). In the JARPA 1999/2000 cruise, a high density of Euphausiids was reported between 100 °E and 120° E (Murase *et al.*, 2002). Large male sperm whales used this longitudinal section between 70° E and 100° E as their key feeding area during December to March. Oceanographic survey and further analyses are recommended to elucidate the relationship between the distributional patterns of whales and their circumstance.

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REFERENCES

Bindoff, Nathaniel, L., Rosenberg, Mark, A. and Warner, Mark J. 2000. On the circuration and water masses over the Antarctic continental slope and rise between 80 and 150 E. *Deep-Sea Research part II*: Topical Studies in Oceanography, Vol. 47 (12-13) pp. 2299-2326.

Branch, T. A., and Butterworth, D., S., 2001. 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.

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.

Kasamatsu, F. 1993. Studies on distribution, migration and abundance of cetacean populations occuring in the Antarctic waters. PhD thesis, University of Tokyo (in Japanese).

Kasamatsu, F. and Joyce, G.G. 1995. Current status of Odontocetes in the Antarctic. Antarctic Science 7 (4): 365-379.

Lockyer, C. 1981. Estimates of growth and energy budget for the sperm whale *Pyster Catodon. In Mammals in the Sea*, Vol.3. Rome: FAO, 489-504.

Matsuoka, K., Nishiwaki, S., Hakamada, T. and Kasamatsu, F., 1998. Abundance and distribution of sperm and beaked whales in the Antarctic Areas IV and V. Paper SC/50/CAWS9 submitted to the IWC Scientific Committee, 1998 (unpublished).

Matsuoka, K., Watanabe, T., Ichi, T., Shimada, H. and Nishiwaki, S., 2003a. Large whale distributions (south of 60°S, 35°E-130°E) in relation to the southern boundary of the ACC. *Antarctic Biology in a Global Context,* pp26-30. Edited by A. H. L. Huiske, W.W.C. Gieskes, J. Rozema, R.M.L. Schrno, S.M. van der Vies & W.J. Wolff. Backhuys Publishers, Leiden, The Netherlands.

Miyashita, T., Kato, H. and Kasuya, T., 1995. Worldwide Map of Cetacean Distribution based on Japanese Sighting Data (Volume 1).pp43-56.

Murase, H., Matsuoka, K., Ichii, T. and Nishiwaki, S. 2002. Relationship between the distribution of euphausiids and baleen whales in the Antarctic (35°E-145°W). *Polar Biol* 25:135-145.

Nishiwaki, S., Ishikawa, H., Narita, H., Otani, S., Kiwada, H., Kariya, T., Yoshimura, I., Takamatsu, T., Teraoka, T., Shiozaki, M., Abe, N., Okamura, S., Yasui, K. and Mori, M., 2001a. Cruise report of the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) Area V and Western Part of Area VI in 2000/2001. Paper SC/53/O11 presented to the IWC Scientific Committee, (unpublished). 21pp.

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

Watanabe, T., Yabuki, T., Suga, T., Hanawa, K., Matsuoka, K. and Kiwada, H, 2005. Results of oceanographic analyses conducted under JARPA and possible evidence of environmental changes. Paper JA/J05/JR15.

Table 1. Estimated observer bias in distance and angle estimation during 2001/02 to 2002/03 seasons.

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.

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

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

Table 2. Smearing parameters used in this analysis.

2001/02	angle	distance
IIIE	13.469	0.252
IV-NE	8.478	0.224
IV-NW	13.333	0.307
IV-SE	10.588	0.244
IV-SW	10.545	0.206

2002/03	angle	distance
VIW	11.163	0.429
V-NE	10.000	0.217
V-NW	12.000	0.500
V-SE	7.241	0.171
V-SW	12.000	0.500

Table 3. Summary of the primary sightings of sperm whales in the JARPA during 1989/90 to 2003/04 seasons by each month (south of 60S). L: searching distance (n.miles), MSS: mean school size. DIW: Density Index of whales (number of whales / 100 n.miles).

Month	III-E				IV				V				VI-W				total				
	Sch.	Ind.	MSS	DIW	Sch.	Ind.	MSS	DIW	Sch.	Ind.	MSS	DIW	Sch.	Ind.	MSS	DIW	L	Sch.	Ind.	MSS	DIW
Nov	23	25	1.09	2.27	0	0	-	-	0	0	-	-	0	0	-	-	1,356	23	25	1.09	1.84
Dec	419	429	1.02	1.86	374	392	1.05	2.37	205	216	1.05	2.23	92	95	1.03	0.56	66,300	1,090	1,132	1.04	1.71
Jan	0	0	-	-	765	783	1.02	1.55	356	376	1.06	0.98	2	3	1.50	0.57	89,724	1,123	1,162	1.03	1.30
Feb	0	0	-	-	566	583	1.03	1.43	199	206	1.04	0.66	0	0	-	-	72,994	765	789	1.03	1.08
Mar	2	2	1.00	0.03	26	28	1.08	0.23	39	40	1.03	0.24	1	1	1.00	0.06	36,962	68	71	1.04	0.19
total	444	456	1.03	1.49	1,731	1,786	1.03	1.49	799	838	1.05	0.87	95	99	1.04	0.49	267,336	3,069	3,179	1.04	1.19

Table 4. Abundance estimates of sperm whale in the research area (south of 60°S) using 2001/02 and 2002/03 seasons. 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	period	n	L	n/L*100	CV	esw	CV	E(s)	CV	D*100	P	CV
2001/02	Area III E	354,965	11/29-12/8	59.1	4822.9	1.225	0.180	1.570	0.162	1.022	0.021	0.399	1,415	0.200
	Area IV NW	200,738	12/26-1/10	55.0	3043.6	1.807	0.279	1.345	0.181	1.000	0.000	0.671	1,348	0.294
	Area IV NE	223,108	1/11-26	39.7	3271.6	1.214	0.273	1.603	0.148	1.000	0.000	0.379	845	0.285
	Area IV SW	61,517	2/12-22	73.6	2321.8	3.172	0.252	1.394	0.228	1.027	0.019	1.169	719	0.278
	Area IV SE	66,790	1/27-2/11	31.5	2885.2	1.091	0.363	1.466	0.312	1.000	0.000	0.372	248	0.401
2002/03	Area VI W	309,998	12/2-1/1	20.9	5950.2	0.352	0.272	1.564	0.219	1.000	0.000	0.112	349	0.304
	Area V NW	257,084	2/11-21	1.9	2777.2	0.068	0.673	3.000	0.000	1.000	0.000	0.011	29	0.673
	Area V NE	338,026	1/4-26	39.7	5077.1	0.781	0.259	1.379	0.378	1.000	0.000	0.283	958	0.324
	Area V SW	65,671	2/26-3/8	8.0	2209.8	0.362	0.414	1.701	0.243	1.000	0.000	0.106	70	0.440
	Area V SE	58,424	1/27-2/9	53.9	2111.9	2.552	0.190	2.483	0.132	1.000	0.000	0.514	300	0.202

Table. 5. Abundance estimates of humpback whale in Area IV (south of 60°S) between 1989/90 and 2003/04. P: estimated population abundance (individuals). Estimate g(0) is 0.32 (CV=0.11) for sperm whale (Kasamatsu and Joyce, 1995). The mean body weight of sperm whales is 27.4 tones, Lockyer (1981).

Area	Season	P	CV	Corrected abundance	CV	biomass (ton)
Area IIIE	2001/02	1,415	0.20	4,422	0.23	121,153
Area IV	2001/02	3,161	0.16	9,877	0.20	270,623
Area V	2002/03	1,357	0.23	4,242	0.26	116,217
Area VIW	2002/03	349	0.30	1,090	0.32	29,860
Total		6,282	0.11	19,630	0.13	537,854

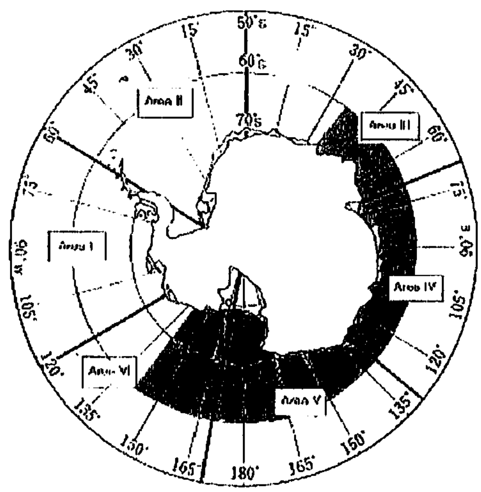

Fig.1. The IWC Antarctic Areas for the management of baleen whales (except Bryde's whale) and research Area of the JARPA surveys between 35°E and 145°W (colored). Areas III east (IIIE: 35°E-70°E), IV(70°E-130°E), V (130°E-170°W) and VI west (VIW: 170°W-145°W).

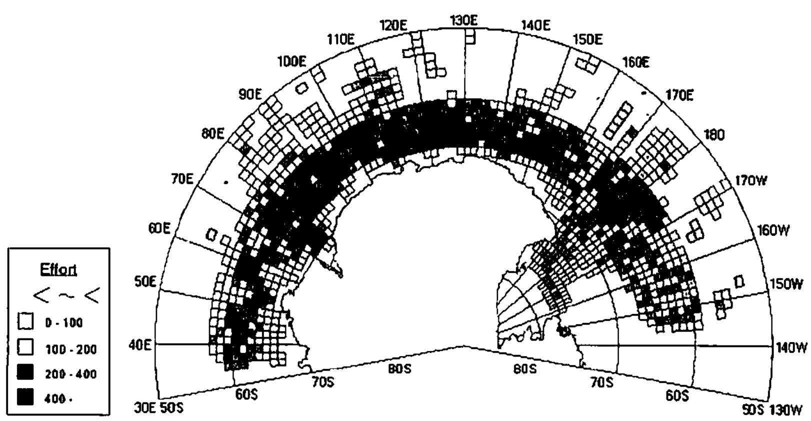

Fig.2. Map of the the searching efforts by by Lat.1°× Long.2°square in the JARPA1987/88-2003/04 seasons, including middle latitude transit sighting survey. Research area was covered uniformly.

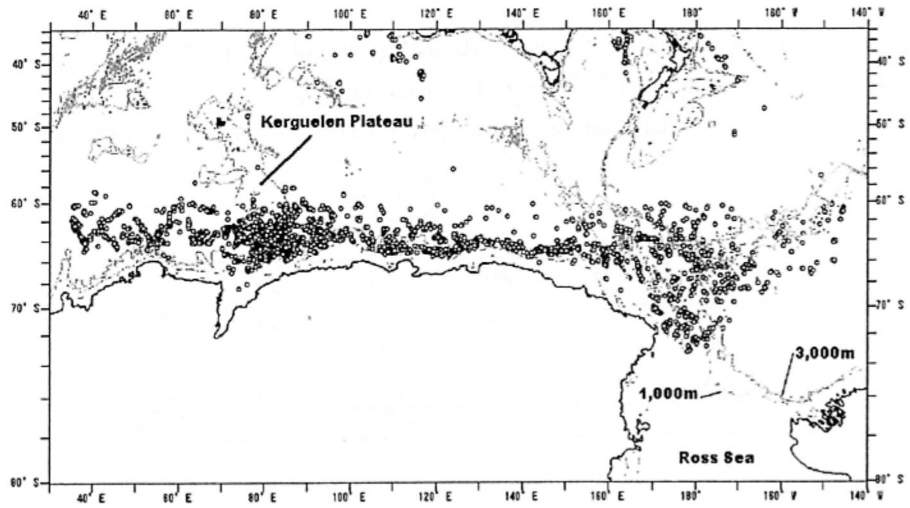

Fig.3. Sighting positions of sperm whales (black circle) in the research area during the JARPA from 1987/89 to 2003/04 season with bottom topography. Dotted line show the depth of water 1,000 m. Solid line show the depth of water 3,000 m.

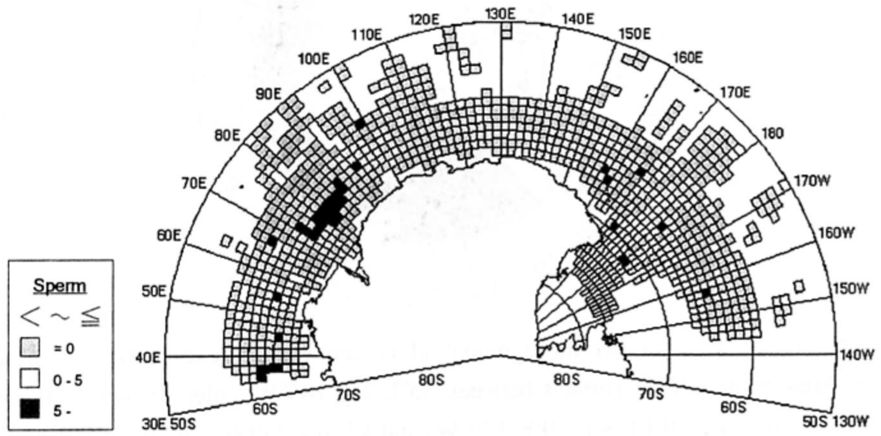

Fig.4. Map of the Density Index (number of primary sightings of whales / 100 n.mile) of sperm whales during JARPA -1987/88-2003/04 seasons by Lat.1°× Long.2°square from November to March.

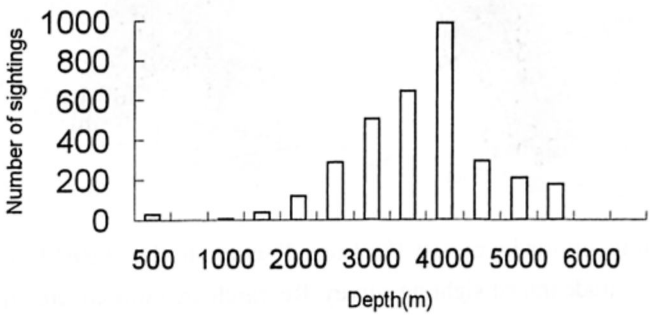

Fig. 5. Relationship between the sea water depth and number of sightings of sperm whale from 1987/89 to 2003/04 season (south of 60°S).

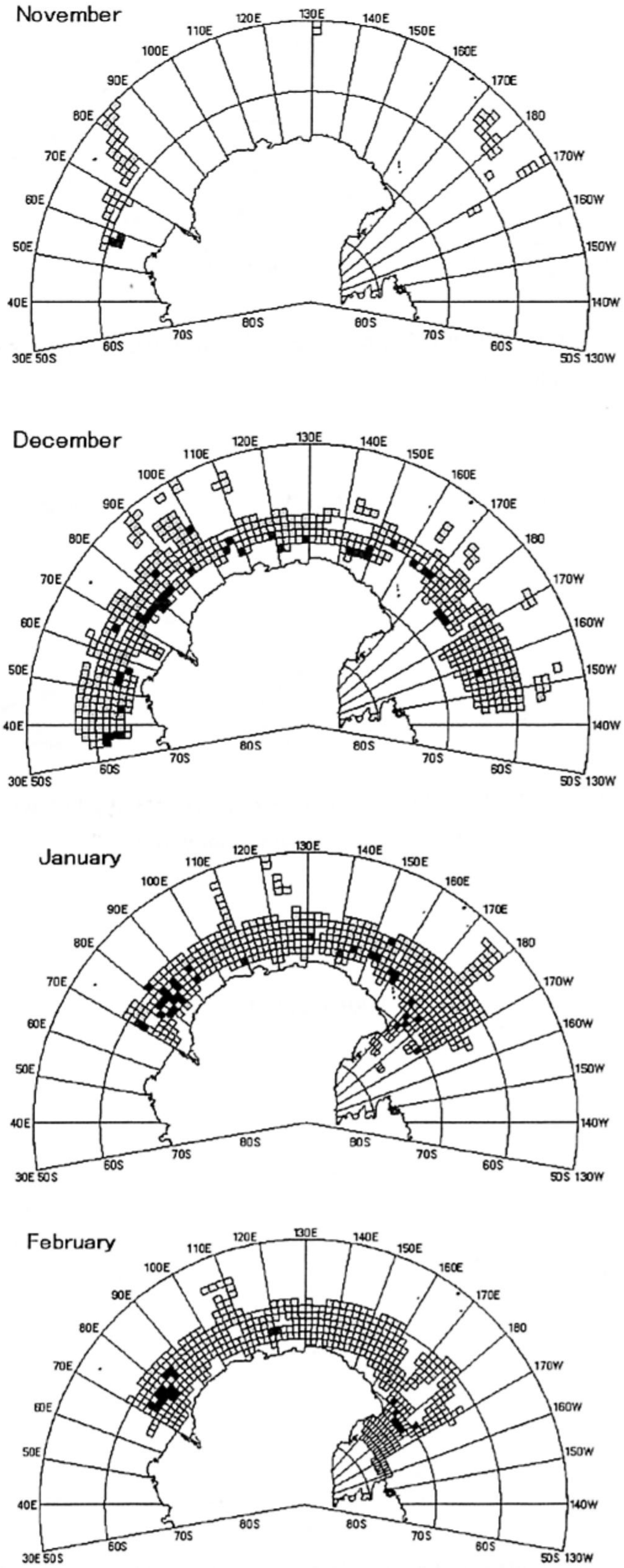

Fig.6. Monthly map of the Density Index (number of primary sightings of whales / 100 n.mile) of sperm whales during JARPA -1987/88-2003/04 seasons by Lat.1°× Long.2°square.

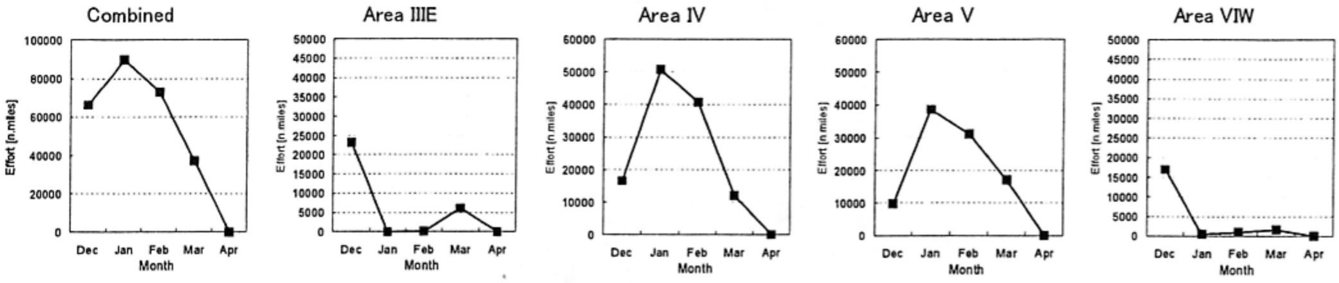

Fig.7. Monthly change of the searching effort by each sub-area in the JARPA surveys between 1989/90 and 2003/04 seasons (south of 60S).

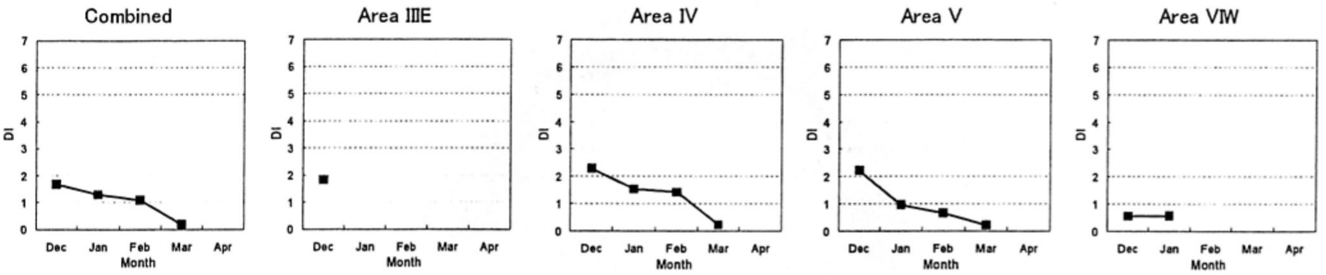

Fig.8. Monthly change of the Density Index (number of primary sightings of whales / 100 n.mile) of sperm whales during JARPA -1987/88-2003/04 seasons. (south of 60S).

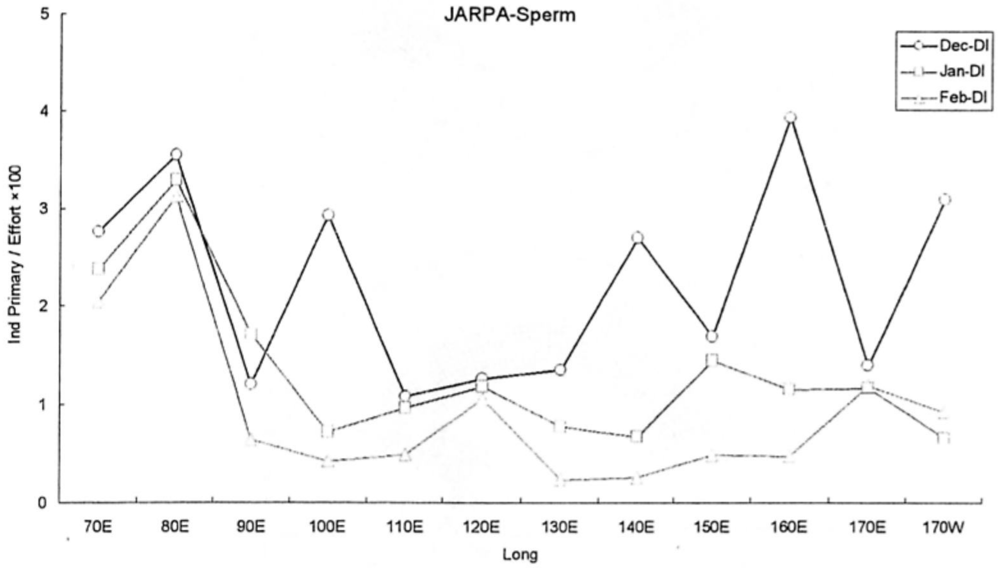

Fig.9. Monthly change of the Density Index (number of primary sightings of whales / 100 n.mile) of sperm whales by longitude during JARPA -1987/88-2003/04 seasons. (south of 60S).

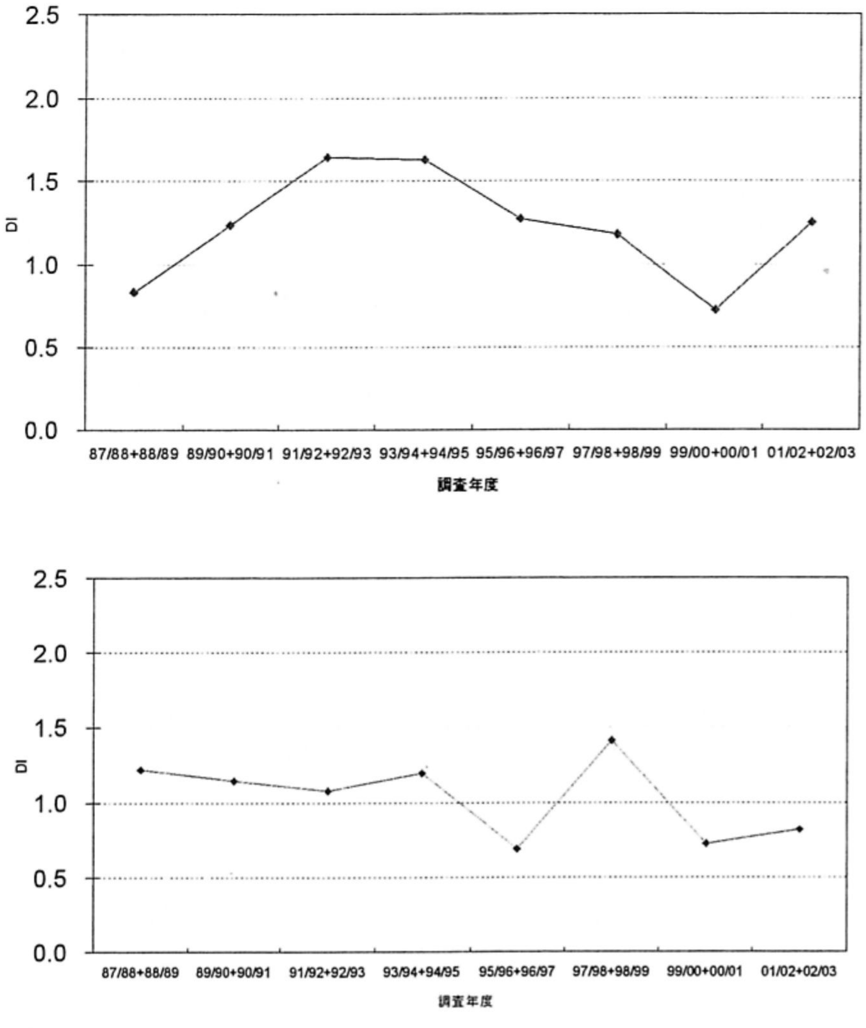

Fig. 10. Yearly change of the Density Index (DI) of sperm whales (number of primary sightings of whales / 100 n.mile) in the JARPAfrom 1987/88-2002/03 season (south of 60S). Upper; Areas IV and V. Lower: Northern strata of Areas IV and V.

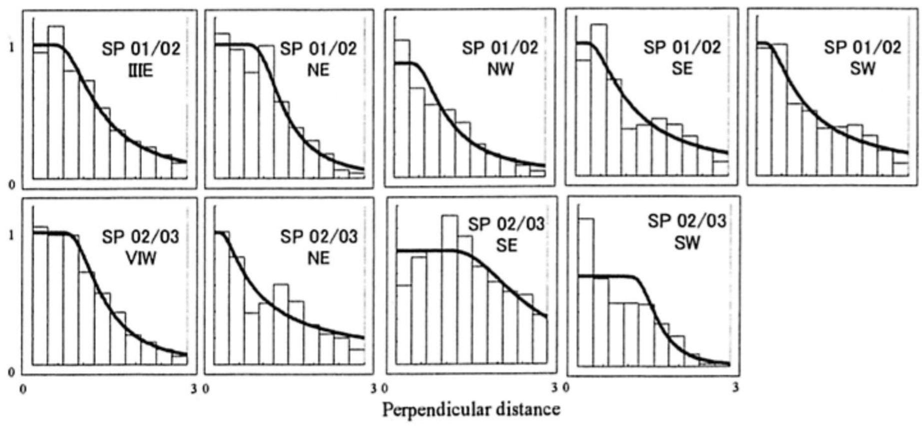

Fig. 11. Detection probability function of sperm whale in Area IIIE, IV, V and VIW surveyed in 2001/02 and 2002/2003 seasons.