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Distribution and abundance estimates of humpback whales in the Antarctic Areas IV and V (70°E -170°W)

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ABSTRACT

This paper reports current distributions and abundance estimates of humpback (*Megaptera novaeangliae*) whales in the Antarctic Areas IV (70°E-130°E) and V (130°E-170°W) in the waters south of 60 °S. 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. The Density Index (no. whales / 100 n.miles, by lat. 1°x long. 2° square) was analyzed for distribution pattern of this species. Humpback whales were widely distributed in Areas IV and V. It seemed that there was a distribution boundary around 130°E-140°E in relation to the hydrographic features. This boundary was in keeping with previous distribution pattern. Further, it was found that they were concentrated between 90°and 120°E in northern and southern strata where are eastern side of the Kerguren Plateau, and were widely dispersed in other part of Area IV. Habitat expansion of humpback whale was observed in Area IV from the first half (1989/90-1996/97) to the later half of surveys (1997/98 -2003/04). Abundance was estimates using the DISTANCE analysis program. In Area IV, abundance estimates of 5,230 (CV=0.30) in 1989/90, 5,350 (CV=0.19) in 1991/92, 2,740 (CV=0.15) in 1993/94, 8,850 (CV=0.14) in 1995/96, 10,874 (CV=0.17) in 1997/98, 16,211 (CV=0.15) in 1999/2000, 33,010 (CV=0.11) in 2001/02 and 31,750 (CV=0.11) in 2003/04 seasons. In Area V, abundance estimates of 1,354 (CV=0.20) in 1990/91, 3,837 (CV=0.63) in 1992/93, 3,565 (CV=0.31) in 1994/95, 1,543 (CV=0.28) in 1996/97, 8,301 (CV=0.31) in 1998/99, 4,720 (CV=0.22) in 2000/2001, 2,735 (CV=0.16) in 2002/03, 9,765 (CV=0.33) in 2004/05 seasons.

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

INTRODUCTION

In 1904, commercial whaling began in the Antarctic. Initially, the whaling mainly targeted humpback whales that are slow swimmers. Later, the target species were shifted to the blue, fin, sei and Antarctic minke whales one after another with reduction of the target whale stocks. Whaling of humpback, blue fin, sei and Antarctic minke in the Antarctic were banned in 1963, 1964, 1974, 1978 and 1987, respectively.

Abundance of humpback whales off Western Australia were reported in the late of 1990's and early 2000's. Bannister (1994) reported a total population size of some 3,000 whales off Shark Bay, Western Australia, based on the results from comparison of the 1991 sighting rate with those from a 1963 commercial aerial spotter. A preliminary estimate of humpback whales off Western Australia using mark-recapture analyses of photo-identified individuals was 3,878 (SD=1,672) whales in the 1991-92 period (Jenner and Jenner ,1994). These abundanee estimations off Western Australia from 1980's to early 1990's were similar in number. In the late of 1990's, analyses from coastal aerial survey, 8,000-14,000 whales was estimated off Western Australia (Bannister and Hedley, 2001). Abundance estimate from eateh data of humpbaek whales was also reported as 8,000 whales in 1999 (Findlay *et al.*, 2000). Abundanee estimate using IWC/SOWER data for a part of Area IV (80°-130°E) in 1998/99 was estimated as 17,300 (CV=0.17) whales (Matsuoka *et al.*, 2003b). Bannister (1994) reported that the rate of inerease of humpbaek whales off Shark Bay between 1963 and 1991 (over 29 years) was 10.9 % per annum.

On the other hand, there are several reports on abundance estimates of humpbaek whales in the late 1990's off Eastern Australia and Antaretie Area V. Estimate of East Australian humpbaek whales using land-based survey was 3,185 (s.e.=208) whales in the 1996 (Brown *et al.*, 1997). The estimate in the Antarctic Area V in 1991/92 season using IWC/IDCR data was 2,104 whales (CV=0.52) (Brown and Butterworth, 1999). Recent estimate by a land based survey of the migratory population was 6,555 ±389 whales (95%CI) with an rate of inerease of 10.6± 0.5%(95%CI) (Noad *et al.*, 2005).

The Japanese Whale Researeh Program under Speeial Permit in the Antarctie (JARPA) was designed as large-seale and long-term monitoring line transeet surveys. It has been earried out in a eonsistent way every other year in Areas IV and V sinee 1987/88 season during the austral summer seasons. After a season of feasibility researeh (1987/88 in Area IV and 1988/89 in Area V), a full-seale research has been conducted since 1989/90 season. Additional surveys were eonducted onee 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 proeedures followed the method used in the IWC/IDCR (International Deeade for Cetacean Research) and SOWER (Southern Ocean Whale and Eeosystem Researeh) cruises as much as possible. In the researeh areas, the Antarctie minke whale was the dominantly sighted species through the surveys from 1987/88 to 2004/05 seasons. However, in Area IV, the humpbaek whale was the sub-dominantly sighted species in 1995/96, the dominant sighted speeies in 1997/98, and again the sub-dominantly sighted species in 1999/2000 and 2001/02 seasons (Ishikawa *et al.*, 2000 and 2002). This paper reports distribution and abundanee estimates of humpback whales in each Area between 1989/90 and 2004/05 seasons.

SURVEYS AND DATA COLLECTION

Sighting surveys

Unique sighting procedures to eollect unbiased sighting data have been introdueed in the JARPA including 1) distanee and angle were correeted by using the results of the distance and angle estimation experiments, 2) sighting rate was obtained on eaeh 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) *g (0)* was assumed to be 1, and 6) sighting data were pooled by each season and eaeh stratum as mueh 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).

Researeh 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 eovered (Fig. 1a). Eaeh Area of IV and V was divided into two seetors (western seetor and eastern seetor). 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. An exception, in the 1999/2000 and 2001/02 seasons, northern boundary of the research area was set as 58 °S in the Arca 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 middle latitude transit sighting survey, is shown in Fig. 1b.

Design of the track line

The saw tooth type track line was applied to provide for a wider area of coverage. The starting point of the saw tooth track line was randomly selected from 1 n.mile intervals on the longitudinal lines. The track line 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.

Survey mode

Two or three sighting/sampling vessels (SSVs) conducted sighting and sampling survey on the predetermined parallel track lines 7n.miles apart at a standard speed of 11.5 knots under the closing mode. The sighting survey by the dedicated sighting vessel (SV) was conducted on the predetermined track line a standard speed of 11.5 knots under the closing mode and the passing mode.

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 by each track line. 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 by each track line as follows;

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

Then combined P and its CV were calculated for each stratum. 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 humpback, fin and 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) separately for each Area and survey year (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).

RESULTS

Distributions

The research area was covered uniformly during 1987/88 to 2004/05 seasons (Fig.1b). Fig. 1c shows the map of the Density Index (number of primary sightings of whales / 100 n.mile) of humpback whales during JARPA -1987/88-2004/05 seasons by Lat.1°× Long.2°square, including transit surveys. Humpback whales were widely distributed in Areas IV and V. It seems that there was a boundary around 130°E-140°E where the minimum distance between Antarctic Continent and Southern Boundary of the Antarctic Circumpolar Current (SBACC)(Fig2a). This distribution boundary was in keeping with previous boundary. Further, they were concentrated between 90°and 120°E in northern and southern strata where are eastern side of the Kerguren Plateau, and were widely dispersed in other part of Area IV (Fig. 2a). In Area IV, it must be noted that there was a meander of the southern boundary of the Antarctic Circumpolar Current in these longitudinal area and high density areas of this species were observed along this front in 1997/98 season (Matsuoka *et al.*, 2003a).

To compare to distribution pattern between the first half of surveys (1989/90-1996/97) and late of surveys (1997/98-2003/04), concentration area of humpback whales was expanded to the southern and to the eastern strata year by year between 90° E and 120° E (Figs. 2b and 2c). Average of the latitude was 60°30'S in the first half of JARPA, and was 62 ° 30'S in the later half of the JARPA (Fig. 2e).

In Area V, they were distributed clearly along the Pacific Antarctic ridge where the southern boundary of the Antarctic Circumpolar Current was observed (Fig. 2a). The primary sighting positions of humpback whales with the searching efforts between 1989/90 and 2004/05 seasons, which were used in present analyses for current abundance estimation, are shown in Fig. 3.

Monthly change in the density index (DI: whales / 100 n.miles)

Fig. 4. shows monthly change in the density index (DI: whales / 100 n.miles) using JARPA efforts and number of primary sightings of humpback whales in the research area (south of 60°S) between 1989/90 and 2004/05 seasons. The DI of humpback whales increase from December to February and decrease in March.

Abundance estimates

Tables 3a and 3b show the size of areas (A), total number of the primary sightings (n), 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. The P was calculated by each track line and then combined for each stratum. Fig.5 shows the perpendicular distance in nautical miles used in the present analyses. Fig.6 shows abundance estimates of humpback whale in Areas IV and V (south of 60°S) surveyed during January to February, between 1989/90 and 2004/2005 seasons (over 16 years). Vertical lines show the 95% confidential intervals.

In Area IV, abundance estimates of 5,230 (CV=0.30) in 1989/90, 5,350 (CV=0.19) in 1991/92, 2,740 (CV=0.15) in 1993/94, 8,850 (CV=0.14) in 1995/96, 10,874 (CV=0.17) in 1997/98, 16,211 (CV=0.15) in 1999/2000, 33,010 (CV=0.11) in 2001/02 and 31,750 (CV=0.11) in 2003/04 seasons.

In Area V, abundance estimates of 1,354 (CV=0.20) in 1990/91, 3,837 (CV=0.63) in 1992/93, 3,565 (CV=0.31) in 1994/95, 1,543 (CV=0.28) in 1996/97, 8,301 (CV=0.31) in 1998/99, 4,720 (CV=0.22) in 2000/2001, 2,735 (CV=0.16) in 2002/03, 9,765 (CV=0.33) in 2004/05 seasons (Tables 3a-3b).

DISCUSSIONS

Animals north of 60°S

Needless to say, humpback whales were also distributed in north of 60°S. According to the previous catch records and sighting information of the JSV data (Japanese whale seouting vessels), humpback whales were widely distributed from 40°S to the south of 60°S during January to February (Fig 7; Miyashita *et al.*,1995). Present abundance estimates are not included these animals.

Habitat expansion of humpback whales in Area IV

Present abundance estimates in Area IV inereased year by year espeeially after 1997/98 season (Fig. 8). After 1997/98 season, humpback whales tended to be distributed more in the southern and eastern strata year by year (Ishikawa *et al.*, 2000 and 2002), (Figs. 2b and 2c). These distribution changes suggested that humpback whale populations are recovering and expanding their distributions to the south and east in the feeding grounds year by year. Further, according to oceanographie researeh, the southern boundary of the Antarctic Circumpolar Current (SB-ACC) in the research area was moved to south year by year from 1997/98 to 2001/02 (Watanabe *et al.*, 2005). It is known that distribution of humpback whales related to the SB-ACC (Matsuoka *et al*, 2003a), it is reasonable to support a view that habitat change from north of 60°S to the south related to the shift of SB-ACC moved to the southern region. It is also reasonable to support a view that present estimation of increasing might include two phenomena of their "real rate of population inerease" and "effect of habitat expansions". Further environmental analyses such as satellite information and oceanographic data are required to interpret "habitat expansion" more precisely in the feeding grounds.

Effect of the Survey mode on abundance estimate

We preliminary examined if the effect of the survey modes (between SSV and SV, between closing mode and passing mode) was significant or not, using GLM. From results of the GLM, the effects of the survey modes were not significant between "SSV and SV" and between "closing mode and passing mode". Details of the analyses will be reported to this SC meeting. Therefore, in the case of humpback whales, survey mode effects were not observed and we pooled sighting data in closing and passing mode and combined SSV abundance and SV abundance without correction in this study.

Recounting of humpback whales in the research area

There is no matching data using photo-id and biopsy samples between northern and southern strata in the same year. In JARPA cruises, the photo-id (n=209) and biopsy sampling (n=342) were conducted for humpback whales at the same time during sighting survey as same manner of the IWC/SOWER cruise. However, there are no photo-id matching and DNA matching during the same cruise between northern strata and southern strata. Therefore, in the case of humpback whales, it is reasonable to say that the bias was very low in likelihood of recounting of humpbaeks as they follow the retreating ice edge. Present abundance estimates was calculating using only peak migration season data between January and February, effect of recounting animals in the feeding area was very low (Fig.4).

Larger abundance estimates of humpback whales in feeding ground than in breeding grounds

Present estimates in the feeding grounds were generally high compare to recent estimations in the breeding grounds (see the Introduction). Recent studies in the Western Antarctic Peninsula humpback wintering study (McKay *et al.*, 2004) and the North Atlantic humpback whale study (Smith*et al.*, 1999) suggested that some portion of individuals could not return to their breeding ground. Because the entire portion does not always return to the breeding ground every year, abundance estimates in breeding area could be lower than those in feeding ground. In addition, as another reason of this difference, because all breeding areas were not surveyed at this moment, abundance estimates in breeding area could be lower than those in feeding ground.

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

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

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 2. Smearing parameters used in this analysis. *,**These parameters were estimated from entire data set, because number of sightings was small.

Humpback

	Area IV			Area V	
	angle	distance		angle	distance
1989/90	4.9775	0.308	1990/91	3.963	0.257
1991/92	6.589	0.266	1992/93	4.616	0.396
1993/94	5.821	0.356	1994/95	6.411	0.206
1995/96	5.742	0.273	1996/97	7.732	0.214
1997/98	5.612	0.231	1998/99	8.710*	0.281**
1999/2000	6.769	0.233	2000/01	6.559	0.307
2001/02	5.289	0.233	2002/03	4.106	0.174
2003/04	7.180	0.188	2004/05	6.486	0.250

Table. 3a. Abundance estimates of humpback whale in Area IV (south of 60°S) between 1989/90 and 2003/04. 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	NW	218,378	21.2	1,987.6	1.067	0.297	0.996	0.226	2.000	0.093	1.071	2,339	0.33
	NE	213,661	20.0	1,964.4	1.018	0.448	0.727	0.426	1.750	0.082	1.225	2,618	0.52
	SW	41,683	10.4	2,518.3	0.411	0.391	0.937	0.201	1.804	0.056	0.396	165	0.41
	SE	40,371	1.0	1,362.2	0.073	0.732	0.937	0.201	1.804	0.056	0.071	29	0.76
	PB	34,628	2.0	831.9	0.240	0.482	1.139	0.129	1.526	0.059	0.231	80	0.53
	Total	548,721	54.6	8,664.4	0.630	0.215					0.953	5,230	0.301
1991/92	NW	219,773	41.7	2,482.7	1.680	0.231	1.052	0.202	1.929	0.062	1.540	3,384	0.26
	NE	217,764	16.0	2,173.9	0.736	0.300	1.005	0.143	1.803	0.049	0.661	1,438	0.32
	SW	34,259	19.7	2,237.5	0.880	0.350	1.379	0.172	1.680	0.082	0.536	184	0.37
	SE	34,871	17.0	2,281.7	0.745	0.378	0.746	0.327	1.870	0.051	0.905	316	0.42
	PB	27,733	1.0	607.5	0.165	0.730	1.379	0.172	1.680	0.082	0.100	28	0.75
	Total	534,400	95.4	9,783.3	0.975	0.150					1.001	5,350	0.190
1993/94	NW	232,782	43.7	4,160.7	1.050	0.191	1.220	0.122	1.614	0.068	0.695	1,618	0.21
	NE	171,281	30.5	3,175.1	0.960	0.290	1.874	0.171	1.774	0.079	0.454	778	0.31
	SW	33,394	24.8	2,377.7	1.043	0.336	1.381	0.157	1.571	0.070	1.075	198	0.35
	SE	30,908	7.0	2,258.9	0.310	0.315	1.381	0.157	1.571	0.070	1.075	72	0.33
	PB	35,196	4.0	1,077.0	0.371	0.688	1.381	0.157	1.571	0.070	1.075	74	0.70
	Total	503,561	110.0	13,049.4	0.843	0.138					0.544	2,740	0.154
1995/96	NW	217,044	122.2	3,530.5	3.461	0.171	1.126	0.070	1.543	0.037	2.372	5,149	0.18
	NE	228,383	45.8	2,979.7	1.537	0.280	1.076	0.119	1.826	0.079	1.304	2,979	0.29
	SW	33,433	54.5	2,851.2	1.911	0.318	1.468	0.118	1.909	0.050	1.243	416	0.32
	SE	29,932	27.6	2,039.9	1.353	0.246	1.248	0.154	1.893	0.087	1.026	307	0.27
	PB	27,929	0.0	1,321.8	-	-	-	-	-	-	-	0	-
	Total	536,721	250.1	12,723.1	1.966	0.123					1.649	8,850	0.142
1997/98	NW	224,230	191.6	3,367.2	5.690	0.200	1.829	0.071	1.870	0.035	2.908	6,522	0.20
	NE	224,567	107.2	3,622.7	2.959	0.367	1.681	0.085	1.658	0.040	1.459	3,277	0.37
	SW	31,505	171.3	3,432.5	4.991	0.157	1.533	0.064	1.767	0.030	2.876	906	0.16
	SE	41,450	25.2	3,195.9	0.789	0.218	1.549	0.168	1.555	0.090	0.396	164	0.24
	PB	2,481	2.0	490.0	0.408	0.758	1.533	0.064	1.767	0.030	0.235	6	0.76
	Total	524,233	497.3	14,108.3	3.525	0.123					2.074	10,874	0.166
1999/2000	NW	236,307	54.7	2,825.3	1.936	0.193	1.347	0.113	1.532	0.066	1.101	2,601	0.20
	NE	229,576	160.7	3,550.8	4.525	0.208	0.828	0.170	1.538	0.032	4.203	9,648	0.23
	SW	34,825	106.3	2,336.7	4.549	0.245	0.579	0.222	1.710	0.039	6.718	2,339	0.27
	SE	33,129	165.1	2,704.3	6.105	0.191	1.447	0.068	2.183	0.054	4.607	1,526	0.20
	PB	27,000	3.0	1,244.7	0.241	0.610	0.579	0.222	1.710	0.039	0.356	96	0.65
	Total	560,837	489.8	12,661.8	3.868	0.110					2.890	16,211	0.146
2001/02	NW	200,738	252.2	3,043.6	8.286	0.191	1.259	0.071	1.941	0.035	6.389	12,825	0.20
	NE	223,108	238.2	3,271.6	7.281	0.206	1.266	0.061	1.754	0.032	4.966	11,079	0.21
	SW	61,517	386.8	2,321.8	16.658	0.176	1.201	0.053	1.870	0.027	12.969	7,978	0.18
	SE	66,790	63.5	2,685.2	2.201	0.257	1.090	0.097	1.672	0.057	1.688	1,127	0.26
	PB	28,155	0.0	1,033.7	-	-	-	-	-	-	-	0	-
	Total	581,308	940.7	12,555.9	7.492	0.104					5.679	33,010	0.112
2003/04	NW	279,634	241.2	3,236.6	7.452	0.249	1.334	0.051	1.680	0.026	4.692	12,827	0.25
	NE	247,970	278.9	3,738.5	7.460	0.137	1.495	0.050	1.666	0.025	4.157	10,385	0.14
	SW	46,122	389.3	2,275.2	17.111	0.112	1.417	0.063	1.886	0.021	11.387	5,252	0.12
	SE	51,093	448.2	3,633.2	12.336	0.139	1.489	0.039	1.643	0.019	6.806	3,195	0.14
	PB	34,940	2.0	508.5	0.393	1.294	1.417	0.063	1.886	0.021	0.262	91	1.30
	Total	659,759	1359.6	13,392.0	10.152	0.077					4.812	31,750	0.114

Table. 3b. Abundance estimates of humpback whale in Area V (south of 60°S) between 1990/91 and 2004/05 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 (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	NW	232,898	1.0	2726.8	0.037	1.10	1.189	0.16	1.303	0.09	0.020	47	1.111
	NE	347,440	6.0	1871.8	0.321	0.37	1.027	0.14	1.546	0.07	0.241	437	0.382
	SW	62,355	21.7	1635.0	1.328	0.37	1.189	0.16	1.303	0.09	0.728	454	0.387
	SE	208,511	25.6	1529.8	1.673	0.21	1.027	0.14	1.546	0.07	1.260	417	0.230
	Total	851,204	54.3	7763.4	0.700	0.18					0.159	1,354	0.196
1992/93	NW	332,682	5.0	2299.3	0.217	1.43	0.712	0.16	2.000	0.08	0.305	1,016	1.435
	NE	290,526	9.0	1661.5	0.542	0.86	0.712	0.16	2.000	0.08	0.761	2,210	0.868
	SW	43,572	5.0	1907.4	0.262	0.49	0.712	0.16	2.000	0.08	0.368	160	0.507
	SE	180,745	4.0	2256.3	0.177	0.64	0.712	0.16	2.000	0.08	0.249	450	0.653
	Total	847,525	23.0	8124.5	0.283	0.48					0.453	3,837	0.633
1994/95	NW	194,879	14.0	3229.4	0.433	0.75	1.793	0.08	1.658	0.06	0.200	390	0.749
	NE	303,617	26.1	2554.1	1.022	0.41	1.320	0.15	2.000	0.12	0.774	2,351	0.430
	SW	40,116	41.6	2469.0	1.687	0.20	1.793	0.08	1.658	0.06	0.780	313	0.209
	SE	175,421	5.0	1293.0	0.386	0.52	1.320	0.15	2.000	0.12	0.293	513	0.531
	Total	714,033	86.7	9545.5	0.909	0.20					0.500	3,567	0.308
1996/97	NW	305,819	1.0	2784.6	0.036	1.68	1.520	0.19	1.632	0.12	0.019	59	1.694
	NE	363,668	14.0	3133.4	0.446	0.36	1.381	0.19	1.700	0.06	0.274	997	0.375
	SW	40,130	17.5	3124.4	0.560	0.37	1.520	0.19	1.632	0.12	0.301	121	0.393
	SE	208,224	6.0	2098.5	0.286	0.50	1.381	0.19	1.700	0.06	0.176	366	0.515
	Total	917,841	38.5	11140.9	0.345	0.23					0.168	1,543	0.281
1998/99	NW	321,375	12.0	1830.6	0.656	0.53	0.639	0.42	1.684	0.08	0.864	2,776	0.623
	NE	311,050	21.9	1226.9	1.785	0.39	0.575	0.56	0.773	0.07	1.200	3,732	0.491
	SW	45,455	30.8	2333.5	1.320	0.43	0.639	0.42	1.684	0.08	1.739	791	0.500
	SE	52,553	34.9	1561.0	2.233	0.15	1.046	0.13	1.787	0.08	1.907	1,002	0.167
	Total	730,433	99.6	6952.0	1.432	0.18					1.136	8,301	0.308
2000/01	NW	249,712	43.2	3751.9	1.153	0.39	1.368	0.13	1.762	0.07	0.742	1,854	0.396
	NE	334,377	44.3	3941.1	1.124	0.29	1.668	0.13	1.956	0.07	0.659	2,204	0.305
	SW	64,854	30.5	3152.9	0.968	0.22	0.780	0.42	1.645	0.07	1.021	662	0.361
	SE	105,458	0.0	3320.2	-	-	-	-	-	-	-	-	-
	Total	754,401	118.1	14166.1	0.833	0.19					0.626	4,720	0.217
2002/03	NW	257,084	12.0	2777.2	0.432	0.39	1.291	0.13	1.548	0.09	0.259	666	0.404
	NE	338,026	58.0	5077.1	1.142	0.18	1.902	0.09	1.672	0.05	0.502	1,697	0.188
	SW	65,671	18.8	2209.8	0.852	0.33	1.291	0.13	1.548	0.09	0.511	335	0.342
	SE	58,424	3.0	2111.9	0.142	0.49	1.902	0.09	1.672	0.05	0.062	36	0.492
	Total	719,205	91.8	12176.0	0.754	0.14					0.380	2,735	0.159
2004/05	NW	286,315	19.5	970.0	2.015	0.78	1.688	0.20	2.050	0.08	1.224	3,504	0.791
	NE	352,024	85.8	3,381.8	2.537	0.20	1.295	0.08	1.583	0.46	1.551	5,460	0.309
	SW	58,086	16.0	856.7	1.873	0.23	1.437	0.23	1.686	0.10	1.099	638	0.270
	SE	217,373	10.0	8,158.7	0.123	0.57	1.295	0.08	1.583	0.46	0.075	163	0.629
	Total	913,798	131.4	13,367	0.983	0.18	-	-	-	-	1.069	9,765	0.333

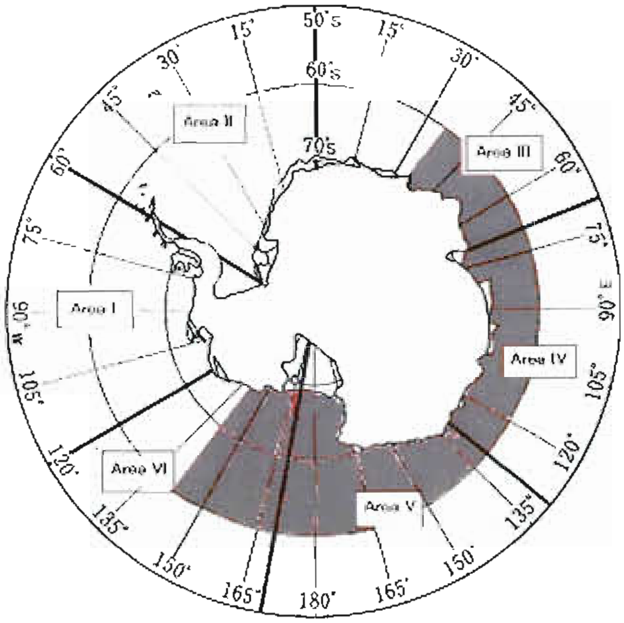


Fig. 1a. The IWC Antarctic Areas for the management of baleen whales (except Bryde's whale) and research Area of the JARPA surveys between 35°E and 145°W (colored). Areas III east (IIIE: 35°E-70°E), IV(70°E-130°E), V (130°E-170°W) and VI west (VIW: 170°W -145°W).

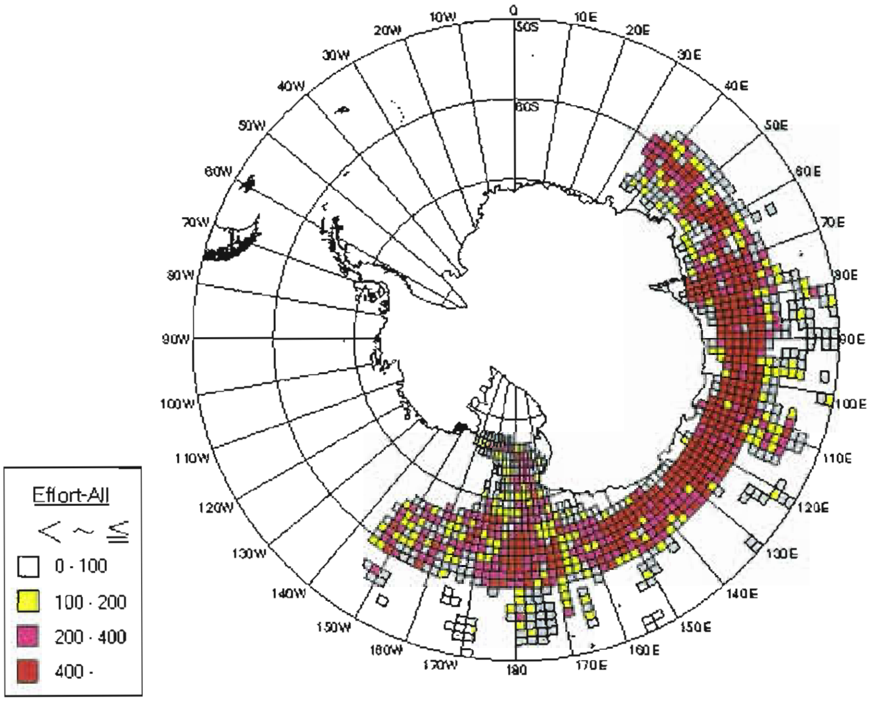


Fig. 1b. Map of the the searching efforts by Lat. 1°× Long. 2°square in the JARPA1987/88-2004/05 seasons, including middle latitude transit sighting survey. Research area was covered uniformly.

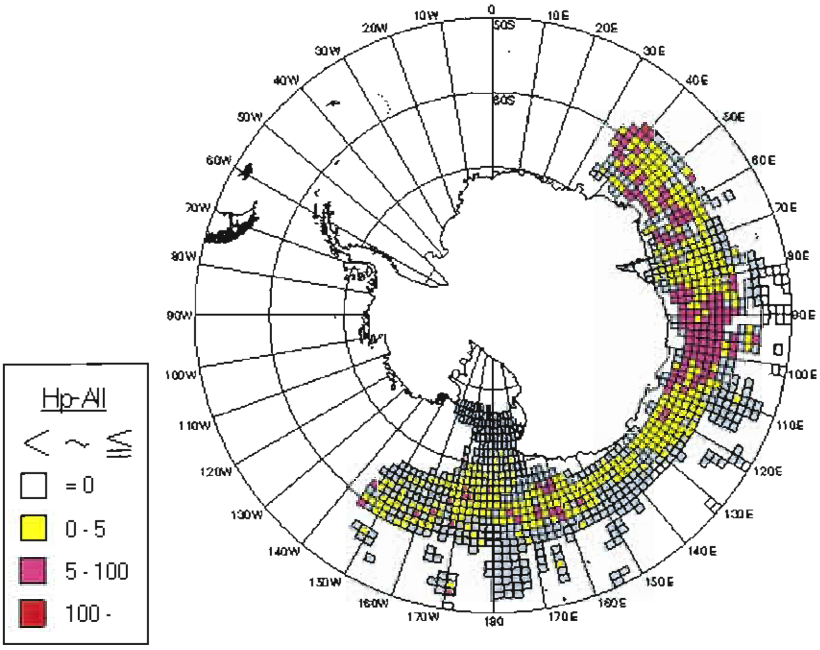


Fig.1c. Map of the Density Index (number of primary sightings of whales / 100 n.mile) of humpback whales during JARPA -1987/88-2004/05 seasons by Lat.1°× Long.2°square.

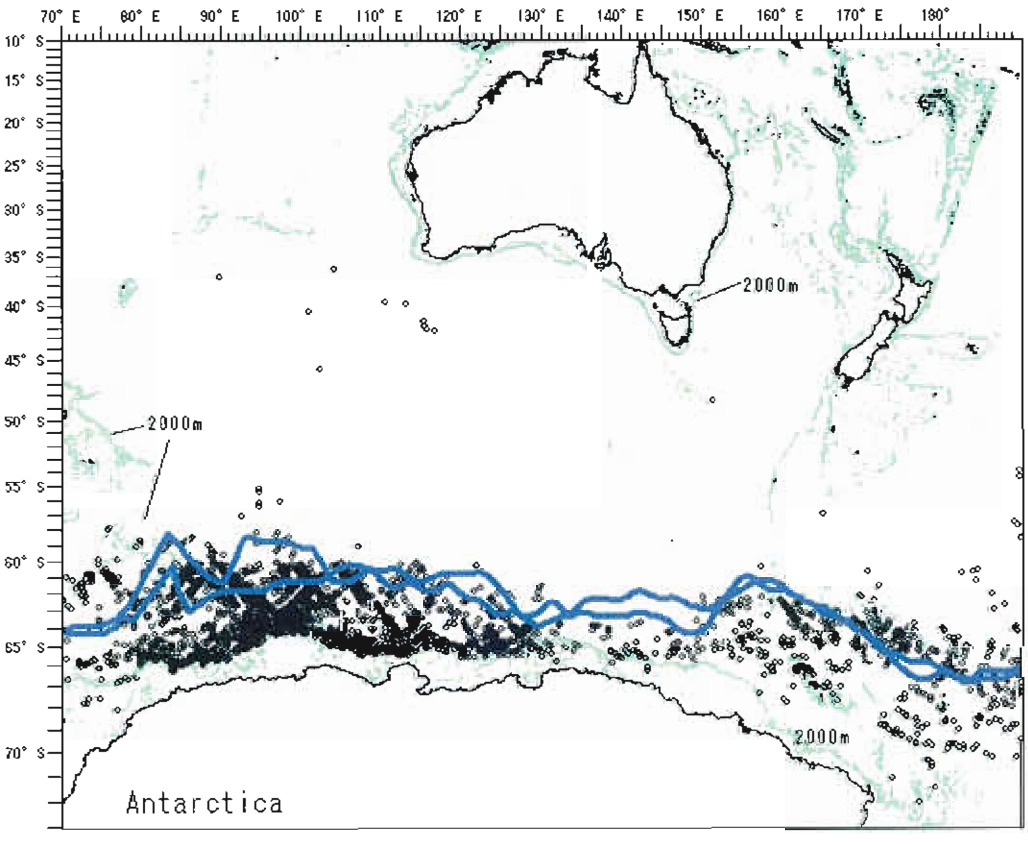


Fig.2a. Position of the primary sightings for humpback whales in JARPA surveys between 1989/90 and 2004/05 seasons including transit surveys with bottom topography. Bold line show the observed Southern boundary of the Antarctic Circumpolar Current in 1997/98 and 1999/2001 seasons.

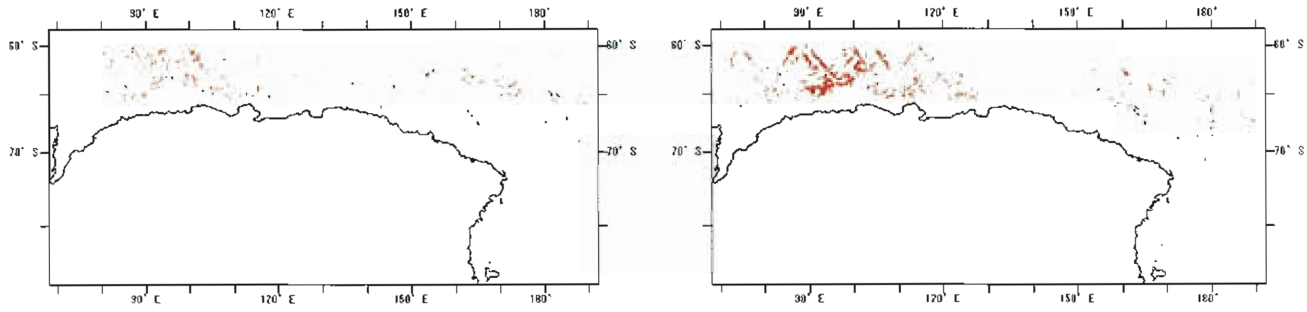


Fig.2b. Position of the primary sightings of humpback whales in the first half of JARPA in the south of 60°S Areas IV and V by three sighting and sampling vessels. In the first half between 1989/90 and 1996/97 seasons (Left). In the later half between 1997/98 and 2004/05 seasons (Right).

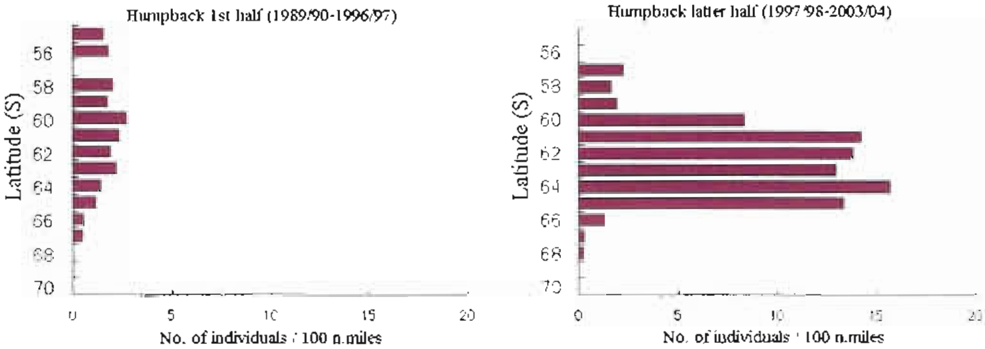


Fig.2c. Comparison of the latitudinal density Index (number of primary sightings of whales / 100 n.mile) between the first half of JARPA (Left: 1989/90-1996/97) and the later half of JARPA (Right: 1997/98-2003/04) in Area IV. Average of the latitude was 60°30'S in the half of surveys, and was 6230'S in the seeond half of the surveys.

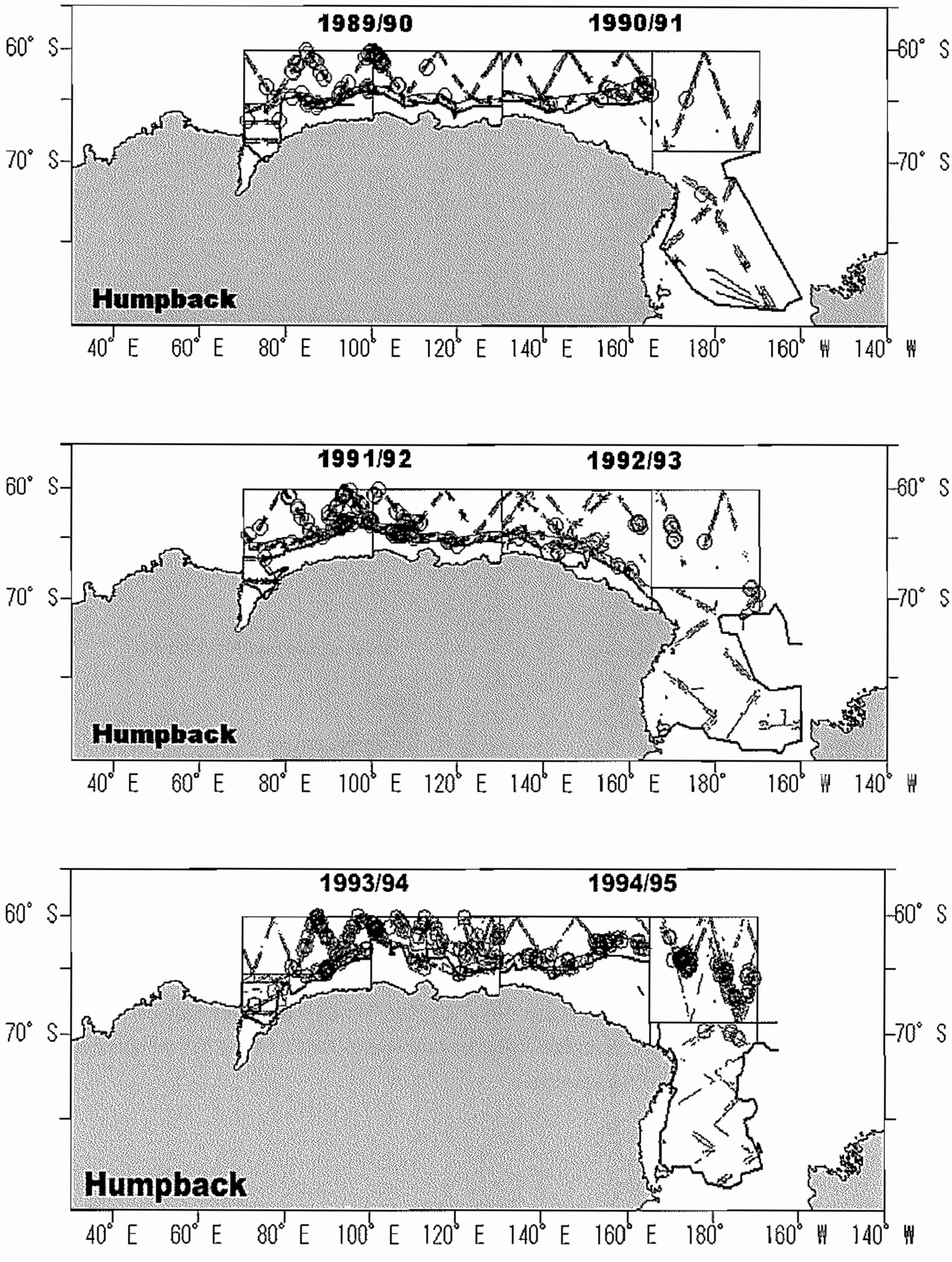


Fig. 3. Distribution of the searching effort and position of the primary school sightings of humpback whales between 1989/90 and 2004/05 seasons which used in this analyses. Black line shows the on efforts. Bold line shows the estimated ice edge line. The circles show the primary schools of humpback whales sighted.

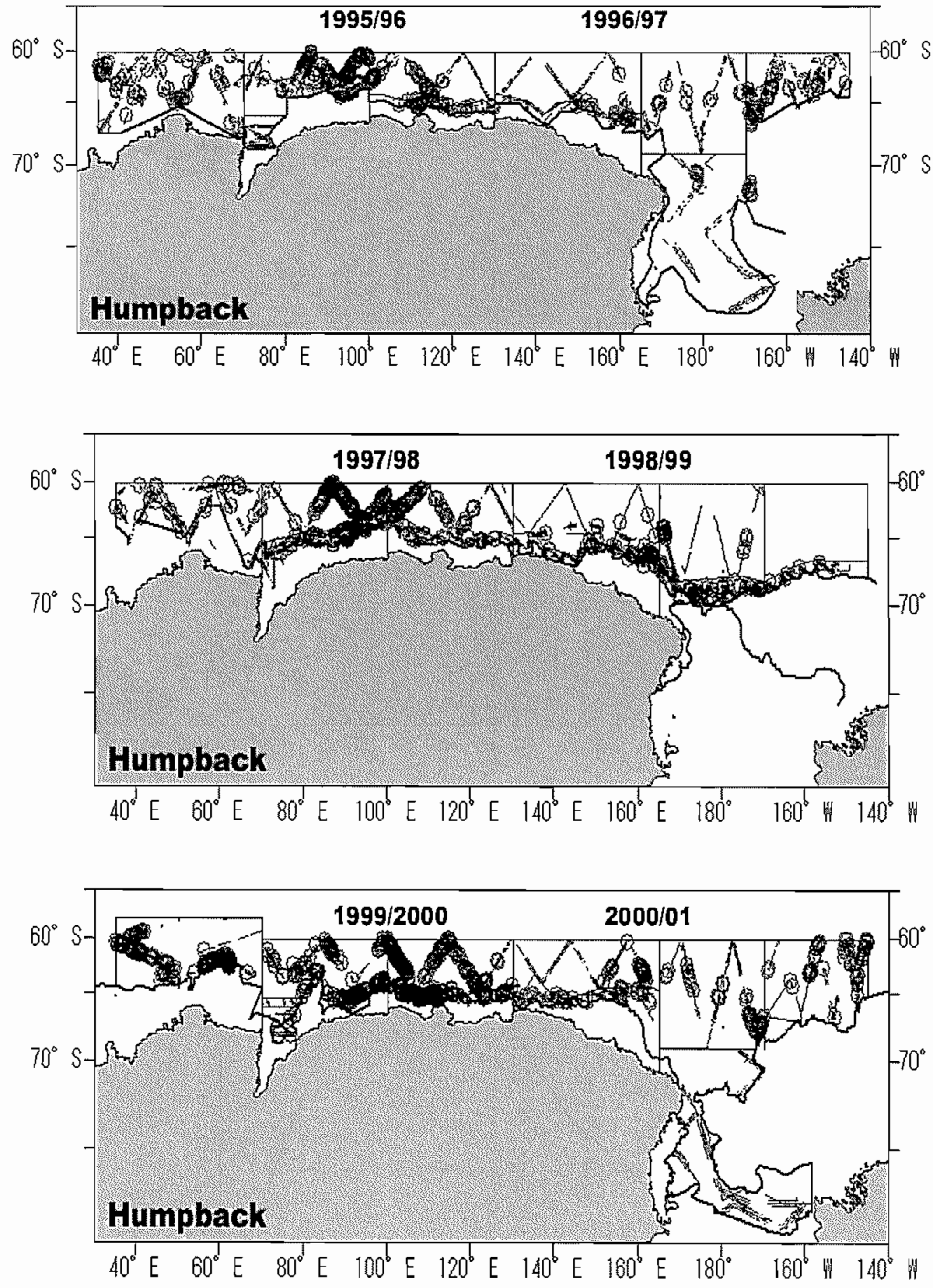
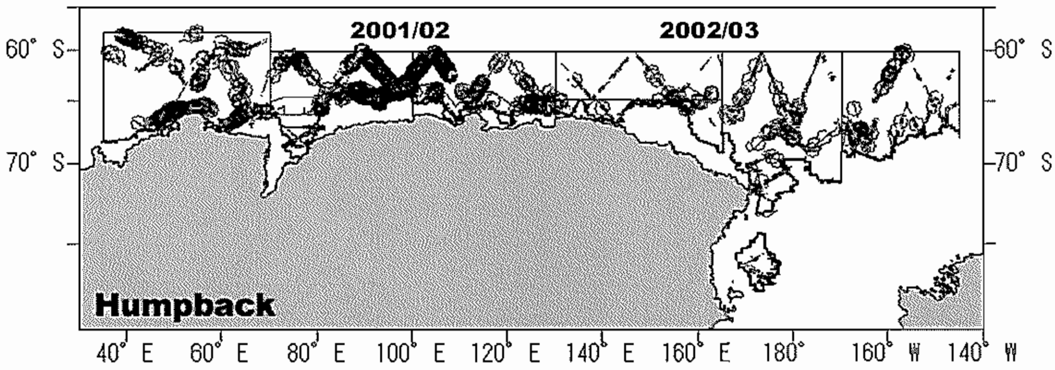


Fig. 3. (Continued)



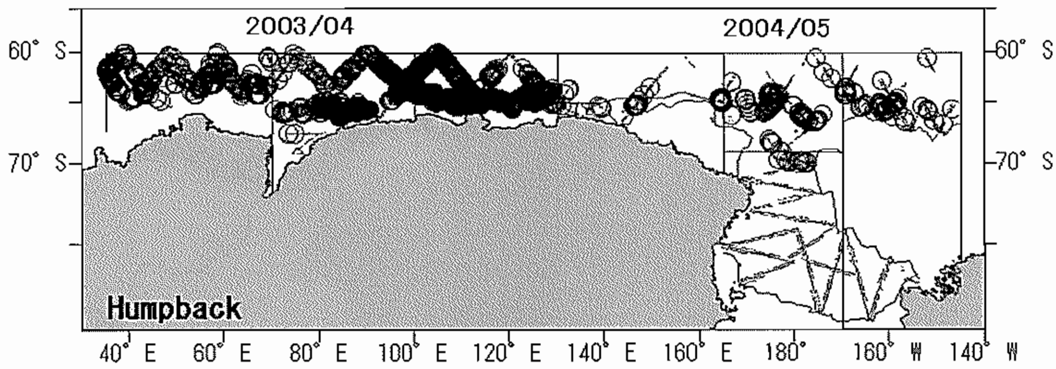


Fig. 3. (Continued)

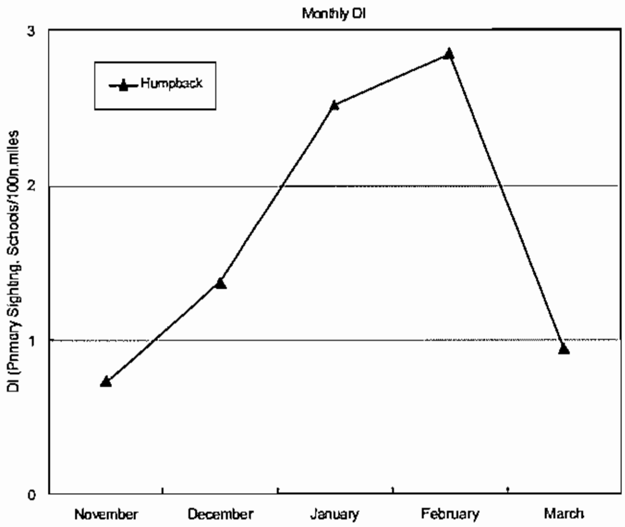


Fig. 4. Monthly change of the density index (DI: whales / 100 n.miles) for humpback whales in the research area by JARPA sighting data between 1989/90 and 2004/05 seasons.

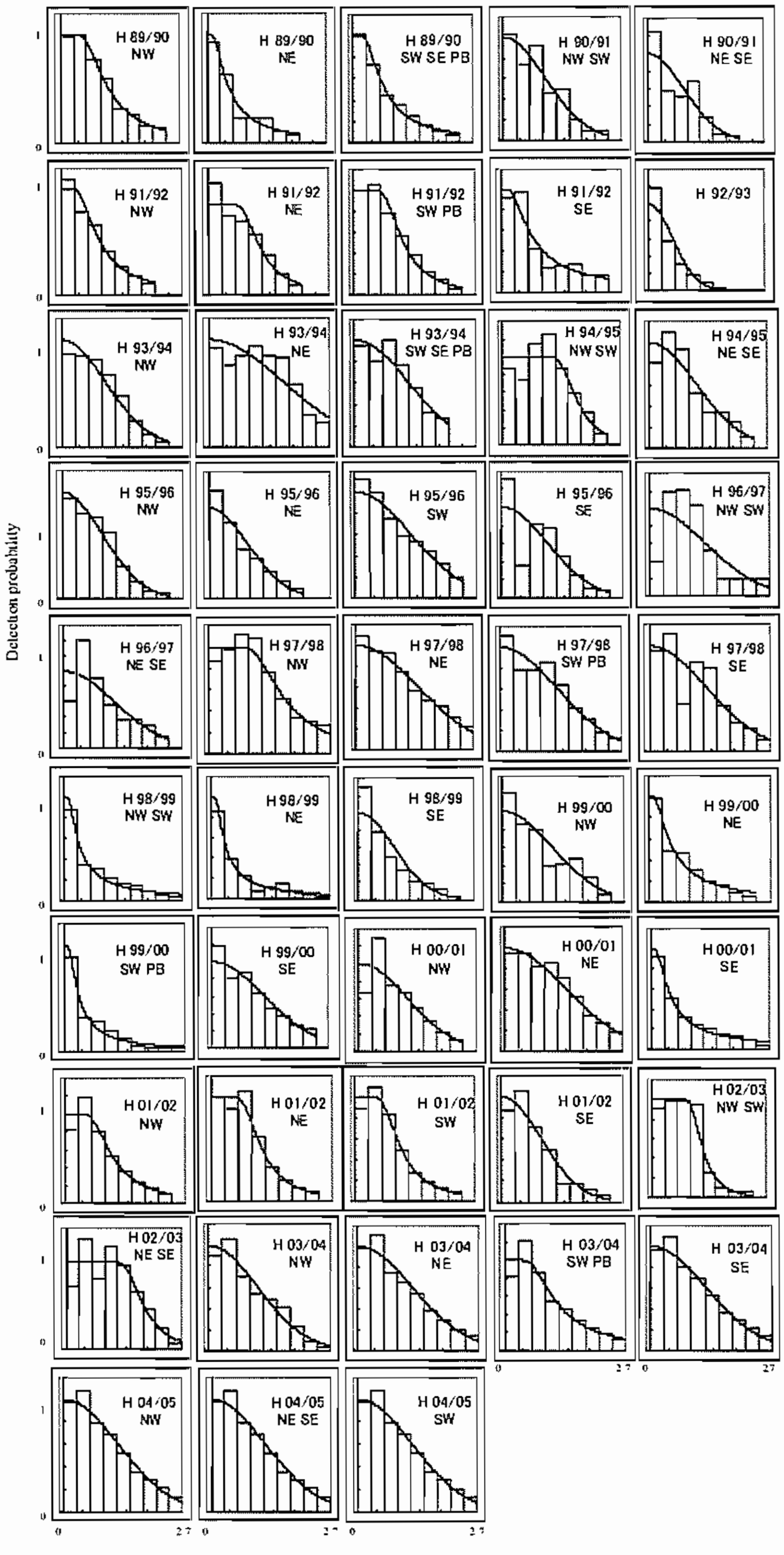
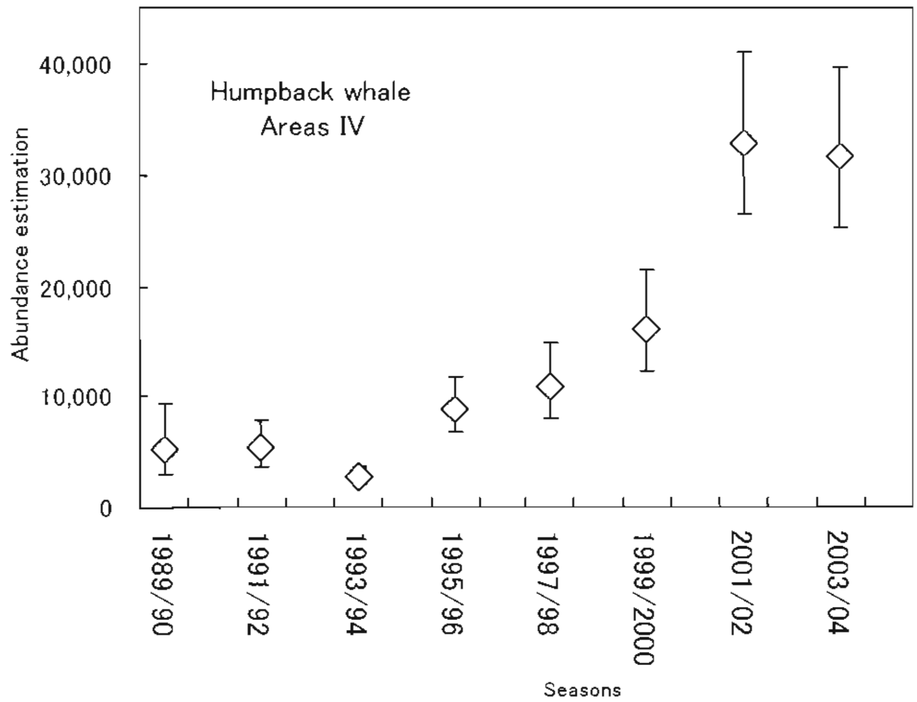


Fig. 5. Detection probability function of bumpback whale in Areas IV and V surveyed from 1989/90 to 2004/2005 seasons in relation to Table 3a and 3b.



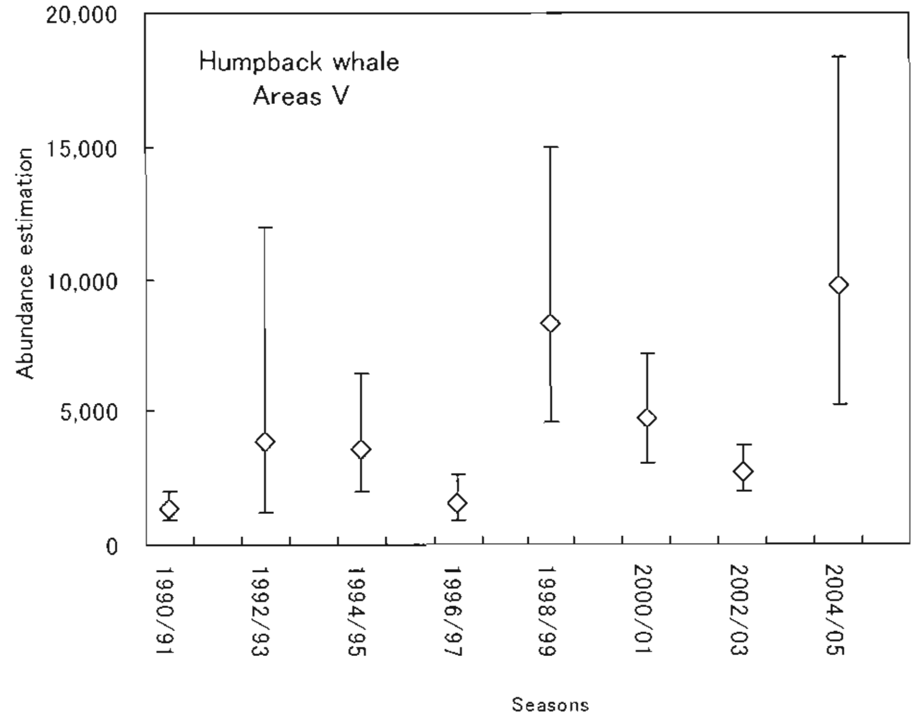


Fig. 6. Abundance estimates of humpback whale in Areas IV and V (south of 60°S) surveyed during January to February, between 1989/90 and 2004/2005 seasons (over 16 years). Vertical lines show 95% confidential intervals.

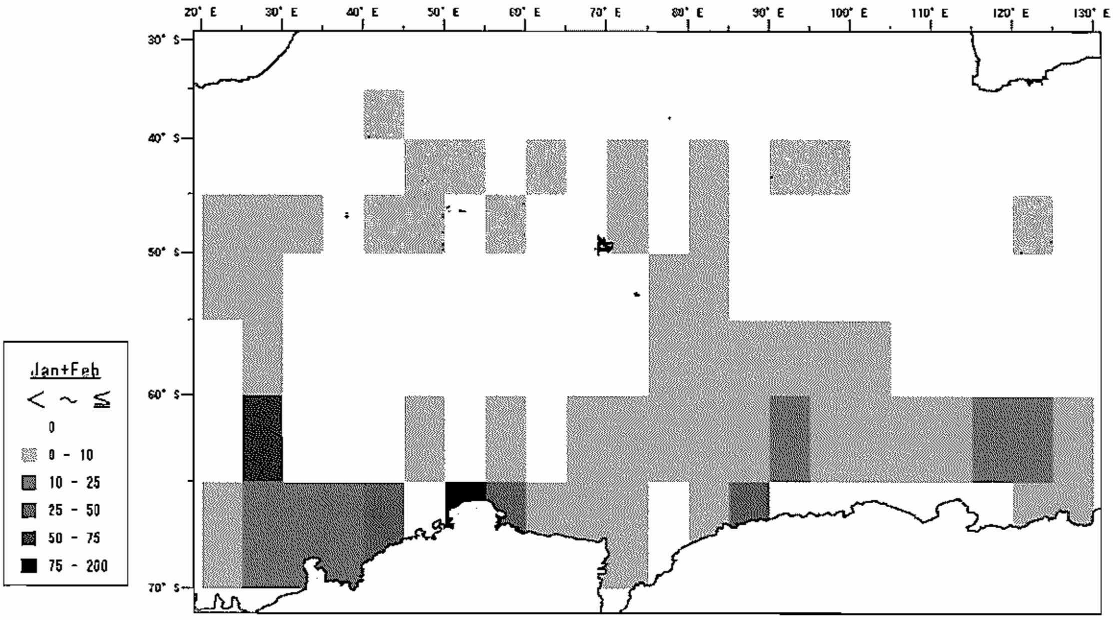


Fig. 7. Humpback whales sighted per 10,000 nautical miles of sighting effort by Lat.5°× Long.5°square in 1965/66 to 1984/85, in January and February. Secondary sightings ineluded (Miyashita ct al., 1995).