Technical Reports of the Institute of Cetacean Research (2018) pp. 20–31

Technical Report (not peer reviewed)

Geographical distribution of whales in the Indo-Pacific region of the Antarctic based on JARPA and JARPAII sighting data collected in the period 1987/88–2008/09

Koji MATSUOKA* and Takashi HAKAMADA

Institute of Cetacean Research, 4–5 Toyomi-cho, Chuo-ku, Tokyo 104–0055, Japan

**Contact e-mail: matsuoka@cetacean.jp*

ABSTRACT

This paper examined the geographical and temporal pattern of distribution of several whale species in the Indo-Pacific region of the Antarctic during the austral summer. The analyses were based on sighting data collected systematically by JARPA and JARPAII surveys in the longitudinal sector 35°E–145°W, south of 60°S, between 1987/88 and 2008/09. A total of 353,134n.miles was surveyed in these Areas. Density Index of Whales (No. of individuals sighted/100 n.miles) was calculated and its geographical distribution plotted for each individual species. Antarctic minke whale was the species most frequently sighted, followed by killer, humpback, unidentified beaked, fin, sperm, southern bottlenose, blue, southern right and sei whales. The geographical pattern of distribution was described for each whale species. The large sighting data set collected systematically by JARPA and JARPAII in the Indo-Pacific region has made a substantial contribution to understanding the pattern of geographical distribution and habitat use of whales in the Antarctic ecosystem.

INTRODUCTION

One of the main sources of sighting data for assessing the population status of whale species in the Antarctic is the JARPA which was conducted between 1987/88 and 2004/05, and its second phase JARPAII conducted between 2005/06 and 2008/09.

The sighting data collected during the JARPA have been used for studying the distribution pattern and abundance estimation of several large whale species (Kishino *et al.*, 1991; Kasamatsu *et al.*, 2000; Matsuoka *et al.*, 2003; 2011; Branch *et al.*, 2004; Murase *et al.*, 2002; 2014).

The objective of this study was to investigate the pattern of geographical distribution of large whale species in the Indo-Pacific region of the Antarctic during the austral summer feeding season. The study was based on sighting data collected systematically by JARPA and JARPAII surveys.

MATERIAL AND METHODS

Research area

The research area comprised the Indo-Pacific region of the Antarctic, specifically the International Whaling Commission (IWC) Management Areas IIIE (35°E–70°E),

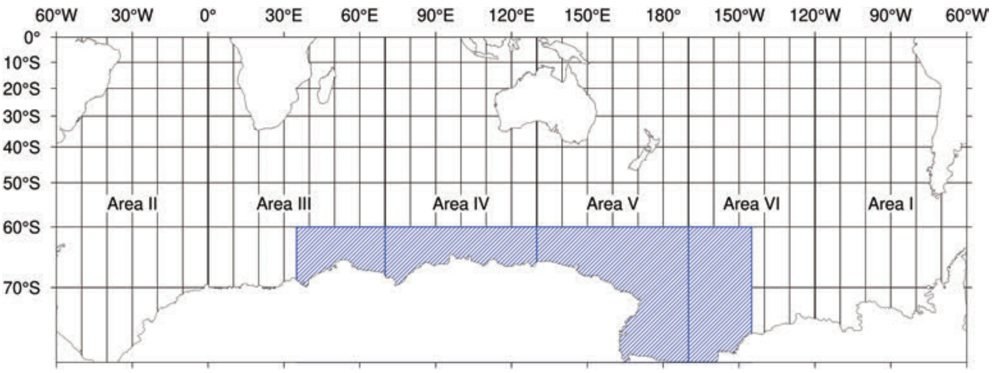


Figure 1. The IWC Antarctic Areas for the management of baleen whales (except Bryde′s whale), and the research Area of the JARPA and JARPAII surveys between 35°E and 145°W.

IV (70°E–130°E), V (130°E–170°W) and VIW (170°W–145°W), south of 60°S (Figure 1).

Sighting data

Primary sighting and effort data were collected by JARPA and JARPAII systematic surveys in the period 1987/88–2008/09. Surveys were conducted by sighting and sampling vessels (SSV) and dedicated sighting vessels (SV).

Sighting procedure

The sighting procedure in JARPAII (2005/06–2008/09) was not substantially changed with regard the procedures in JARPA (Nishiwaki *et al.*, 2014). The research vessels were equipped with top barrel, where three top men conducted sightings. On the upper bridge, a captain, a gunner, a helmsman and a researcher also conducted the sighting. The sighting activity was conducted under acceptable weather conditions (see below), from 30 minutes after sunrise to 30 minutes before the sunset.

Survey modes

Searching was conducted under closing and passing modes (Hakamada *et al.*, 2006). These modes were used under acceptable weather conditions (minke whale visibility of 2 n.miles or more and wind speed under 20 knots in the northern strata, and under 25 knots in the southern strata) (Nishiwaki *et al.*, 2014).

Confirmation of the sightings

When a sighting was made, the vessel closed to the school immediately in order to identify the species, estimate the school size and get other biological information (number of calves, estimated body length, etc.).

Density Index of Whales

The Density Index of Whales (DIW) (the number of individual whales sighted by 100 n.miles) was calculated by each Lat.1°× Long.1°grid squares.

RESULTS AND DISCUSSIONS

Searching efforts

A total of 353,134 n.miles was surveyed in Areas IIIE, IV, V and VIW, south of 60°S between 1989/90 and 2008/09. Figure 2 shows the distribution of the primary searching effort.

Distribution pattern of whales

Tables 1a and 1b show a summary of primary sightings of baleen and toothed whales, respectively. Table 2 shows the number of calves, observed mean school size and DIW, by species and month. Figures 3a–d show the maps of the DIW for i) blue, fin and sei whales; ii) Antarctic minke, dwarf minke and humpback whales; iii) southern right, sperm and southern bottlenose whales; and iv) unidentified beaked (*Ziphiidae*) and killer whales, respectively, by each Lat.1°× Long.1°grid squares. Figure 4 shows the monthly change in DIW for most of the species.

A description of the geographical distribution by whale species is presented and discussed below.

Blue whale

Blue whale had the 8th rank of DIW among the ten species sighted in the research area (Table 2). They were

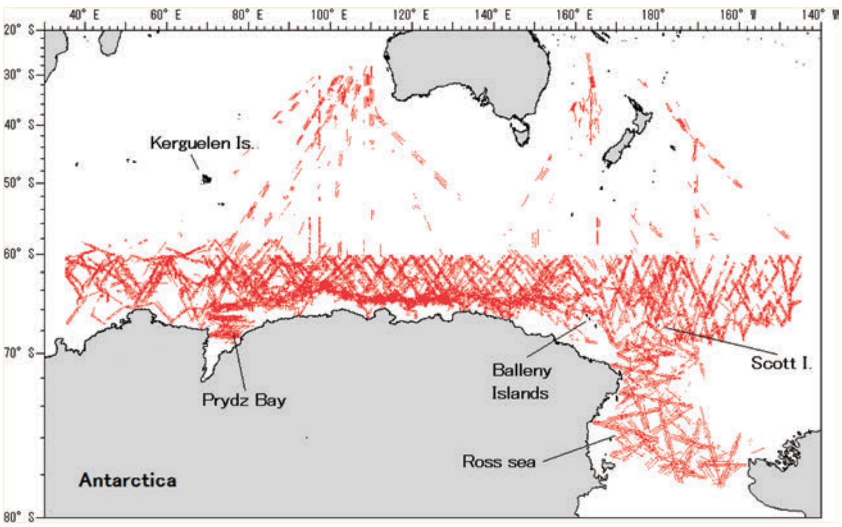


Figure 2. Searching efforts (red line) by JARPA and JARPAII surveys in the period 1987/88–2008/09, including transit sighting survey in middle latitude.

Table 1a

Summary of baleen whale species sighted in the Indo-Pacific region of the Antarctic.

No.	Season	Effort	Blue whale			Fin whale			Sei whale			Ant. minke whale			Humpback whale			S. right whale		
		(n.miles)	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf
1	1987/88	8,860.6	0	0	0	3	3	0	1	1	0	237	719	0	35	76	0	1	1	0
2	1988/89	10,806.7	2	3	0	7	16	0	0	0	0	353	768	0	1	2	0	0	0	0
3	1989/90	16,423.2	5	9	0	5	20	0	0	0	0	758	1,968	0	121	210	11	2	2	0
4	1990/91	14,660.0	4	6	0	33	67	0	0	0	0	740	1,713	0	58	90	0	0	0	0
5	1991/92	17,844.1	3	3	0	8	34	0	2	2	0	597	2,030	1	177	321	7	26	30	0
6	1992/93	13,924.9	7	9	0	15	27	1	2	4	0	1,024	3,228	0	28	56	5	3	4	0
7	1993/94	17,957.3	5	9	0	9	26	0	0	0	0	688	1,619	0	133	220	1	11	14	0
8	1994/95	14,047.7	13	20	1	73	241	1	2	5	0	823	2,453	0	131	228	9	0	0	0
9	1995/96	21,466.7	9	16	0	60	214	1	0	0	0	887	2,008	0	325	562	10	8	8	0
10	1996/97	17,783.2	7	9	0	37	82	1	1	1	0	853	2,610	0	114	200	3	0	0	0
11	1997/98	21,594.4	16	25	0	18	57	0	0	0	0	672	1,373	0	577	1,122	2	34	37	0
12	1998/99	8,066.5	4	7	1	45	222	1	0	0	0	826	2,665	0	106	203	7	0	0	0
13	1999/2000	16,341.5	25	53	2	66	356	3	0	0	0	1,507	6,581	0	661	1,269	5	3	3	0
14	2000/01	20,421.3	10	18	0	114	374	0	7	13	0	1,907	4,949	0	191	341	3	2	2	0
15	2001/02	19,767.4	17	26	1	143	983	2	1	2	0	1,867	4,374	0	1219	2,387	5	15	22	1
16	2002/03	18,126.2	5	10	0	52	216	0	8	14	0	2,420	6,531	0	145	228	4	0	0	0
17	2003/04	19,287.4	32	61	0	109	446	0	0	0	0	1,092	3,250	0	1690	3,134	5	1	2	1
18	2004/05	18,486.7	12	16	0	49	118	1	1	1	0	1,663	4,278	0	197	336	2	2	2	0
19	2005/06	16,372.7	24	38	2	188	748	1	2	3	0	1,657	4,375	0	1702	3,200	22	53	73	4
20	2006/07	11,968.8	7	12	1	37	253	0	0	0	0	969	2,169	0	160	283	13	0	0	0
21	2007/08	14,575.3	43	84	1	48	134	4	2	2	0	823	1,702	0	1314	2,536	7	72	96	0
22	2008/09	14,351.4	14	28	1	109	440	2	5	7	0	1,870	4,668	0	339	587	8	0	0	0
	Total	353,134	264	462	10	1,228	5,077	18	34	55	0	24,233	66,031	1	9,424	17,591	129	233	296	6

Table 1b

Summary of toothed whale species sighted in the Indo-Pacific region of the Antarctic.

No.	Season	Effort	Sperm whale			S. bottlenose whale			Unid. beaked whales			Killer whale		
		(n.miles)	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf
1	1987/88	8,860.6	6	6	0	3	5	0	87	218	0	20	194	0
2	1988/89	10,806.7	81	91	0	2	4	0	65	143	0	31	189	0
3	1989/90	16,423.2	204	215	0	23	46	0	281	514	0	69	859	0
4	1990/91	14,660.0	175	188	0	13	26	0	241	421	1	32	870	2
5	1991/92	17,844.1	225	233	0	29	51	0	181	304	1	53	805	0
6	1992/93	13,924.9	105	108	0	10	19	0	202	361	0	82	1,130	0
7	1993/94	17,957.3	321	336	0	145	243	0	205	337	0	56	399	1
8	1994/95	14,047.7	133	135	0	74	146	1	168	263	0	35	281	1
9	1995/96	21,466.7	341	352	0	137	273	1	161	284	0	109	1,282	1
10	1996/97	17,783.2	121	128	0	75	128	0	78	144	1	50	539	4
11	1997/98	21,594.4	295	302	0	222	409	0	197	338	0	82	931	9
12	1998/99	8,066.5	49	50	0	23	53	0	35	54	0	35	409	5
13	1999/2000	16,341.5	195	204	0	138	251	0	110	188	0	109	2,011	7
14	2000/01	20,421.3	100	106	0	72	121	0	173	272	0	72	1,471	2
15	2001/02	19,767.4	269	272	0	126	226	0	134	205	0	79	939	0
16	2002/03	18,126.2	128	129	0	97	168	0	113	154	0	63	953	0
17	2003/04	19,287.4	222	223	0	154	274	0	208	338	0	120	1,348	0
18	2004/05	18,486.7	105	108	0	44	78	0	89	159	0	78	1,472	3
19	2005/06	16,372.7	181	182	0	88	179	0	135	244	0	100	1,563	3
20	2006/07	11,968.8	63	63	0	51	80	0	66	88	0	44	394	0
21	2007/08	14,575.3	280	280	0	79	157	1	102	155	0	62	790	0
22	2008/09	14,351.4	75	76	0	32	61	0	77	140	0	38	788	14
	Total	353,134.0	3,674	3,787	0	1,637	2,998	3	3,108	5,324	3	1,419	19,617	52

widely distributed in the research area in both northern and southern strata. High density values of this species were observed in Areas IIIE, particularly between 45°E and 65°E (Figure 3a). They were rarely found in the Prydz Bay. Blue whales were sighted within the Ross Sea between 70°S and 77°S. A total of 286 schools (495 individuals) including eleven calves were sighted south of 60°S (Table 2). Observed mean school size was 1.73 individuals. The DIW of this species was 0.140 for the whole period and the indices were almost stable from December to March (Table 2 and Figure 4).

Two subspecies of blue whales exist in Southern Hemisphere: the Antarctic (or true) blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*B. m. brevicauda*) (Mackintosh, 1966; Ichihara, 1966; Rice, 1998). A complete review of spatial and seasonal distribution, densities and movements of blue whales is provided by Branch (2007) and Branch *et al.* (2007). These studies indicated that there is little evidence that pygmy blue whales migrate into high latitudes of the Antarctic. Less than 1% of the records south of 52°S were of this subspecies. There is no current evidence of population structure in Antarctic blue whales. The latest abundance estimate of this species (south of 60°S, 35°E–145°W) was 1,223 whales (CV=0.345) in 2007/08+2008/09 seasons, and the abundance trend was 8.2% (95% CI: 3.9%, 12.5%) between 1995/96 and 2008/09 for combined Areas IIIE+IV+V+VIW based on JARPAII data (Matsuoka and Hakamada, 2014). There is a need for continued monitoring of the abundance and abundance trend of this species, especially because they provide an excellent opportunity to improve our understanding of the dynamics of baleen whale populations recovering from low levels.

Fin whale

Fin whale had the 5th rank of DIW among the ten species sighted in the research area. A total of 1,268 schools (5,209 individuals) including 20 calves, were sighted (Table 2). Observed mean school size was 4.11 individuals. This species was more frequently encountered in Areas V and VIW than in Areas IIIE and IV in both northern and southern strata. High density areas were observed in Areas IIIE, particularly between 55°E and 65°E, VW, between 140°E and 160°E and VE between 163°E and 170°W (Figure 3a). The DIW of this species was 1.475 for the whole period and the indices increased from December to March (Figure 4).

In the Antarctic feeding grounds, fin whales occur year-round but higher density is found from November to May (Kasamatsu *et al.*, 1996; Mackintosh, 1966). Whales can be found as far south as 65°S–70°S, but the majority of the population seems to occur north of 60°S (Miyashita *et al.*, 1995). Catches occurred throughout the Antarctic, but the majority of whales (~73%) were taken in the IWC Management Areas II and III. Sighting data suggest that spatial distribution varies across ocean basins (Kasamatsu *et al.*, 1996).

Sei whale

Sei whale was rarely sighted in the research area. A total of 36 schools (59 individuals) were sighted south of 60°S (Table 2) and no calves were observed. Observed mean

Table 2

Summary of sighting information in the whole research area in the period 1987/88–2008/09, by whale species and month. Sch.: number of primary sightings of schools; Ind.: number of primary sightings of individuals; Calf: number of calves; Mss: mean school size (Ind./Sch.); DIS: Density Index (schools/100 n.miles); DIW: Density Index (individuals/100 n.miles).

Species	All Areas (IIIE, IV, V and VIW; south of 60°S, 35°E–145°W)						Order of DIW	Dec. DIW	Jan. DIW	Feb. DIW	Mar. DIW
	Sch.	Ind.	Calf	Mss	DIS	DIW					
Blue whale	286	495	11	1.73	0.081	0.140	8	0.281	0.092	0.101	0.102
Fin whale	1,268	5,209	20	4.11	0.359	1.475	5	1.323	0.794	1.760	3.059
Sei whale	36	59	0	1.64	0.010	0.017	10	0.002	0.004	0.020	0.044
Antarctic minke whale	25,507	69,076	0	2.71	7.223	19.561	1	10.173	14.301	33.331	19.436
Humpback whale	10,036	18,770	137	1.87	2.842	5.315	3	3.425	4.842	7.337	6.708
Southern right whale	235	298	6	1.27	0.067	0.084	9	0.001	0.014	0.156	0.292
Sperm whale	3,810	3,926	0	1.03	1.079	1.112	6	1.500	1.272	0.992	0.292
S. bottlenose whale	1,666	3,045	3	1.83	0.472	0.862	7	0.932	0.974	0.787	0.570
Unid. beaked whale	3,175	5,457	3	1.72	0.899	1.545	4	1.864	1.594	1.123	1.209
Killer whale	1,472	20,569	59	13.97	0.417	5.825	2	1.935	5.692	9.303	6.624

school size was 1.64 individuals. This species occurred more frequently in Areas V and VIW than in Areas IIIE and IV in the northern strata (Figure 3a). The DIW of this species was 0.017 for the whole period.

In summer, sei whales do not venture into higher latitude waters near the Antarctic continent as much as some other baleen whales (Horwood, 1987; Miyashita *et al.*, 1995). The majority of the population occurs between 40°S and 60°S, usually north of the Antarctic Convergence. Juveniles are found further north than

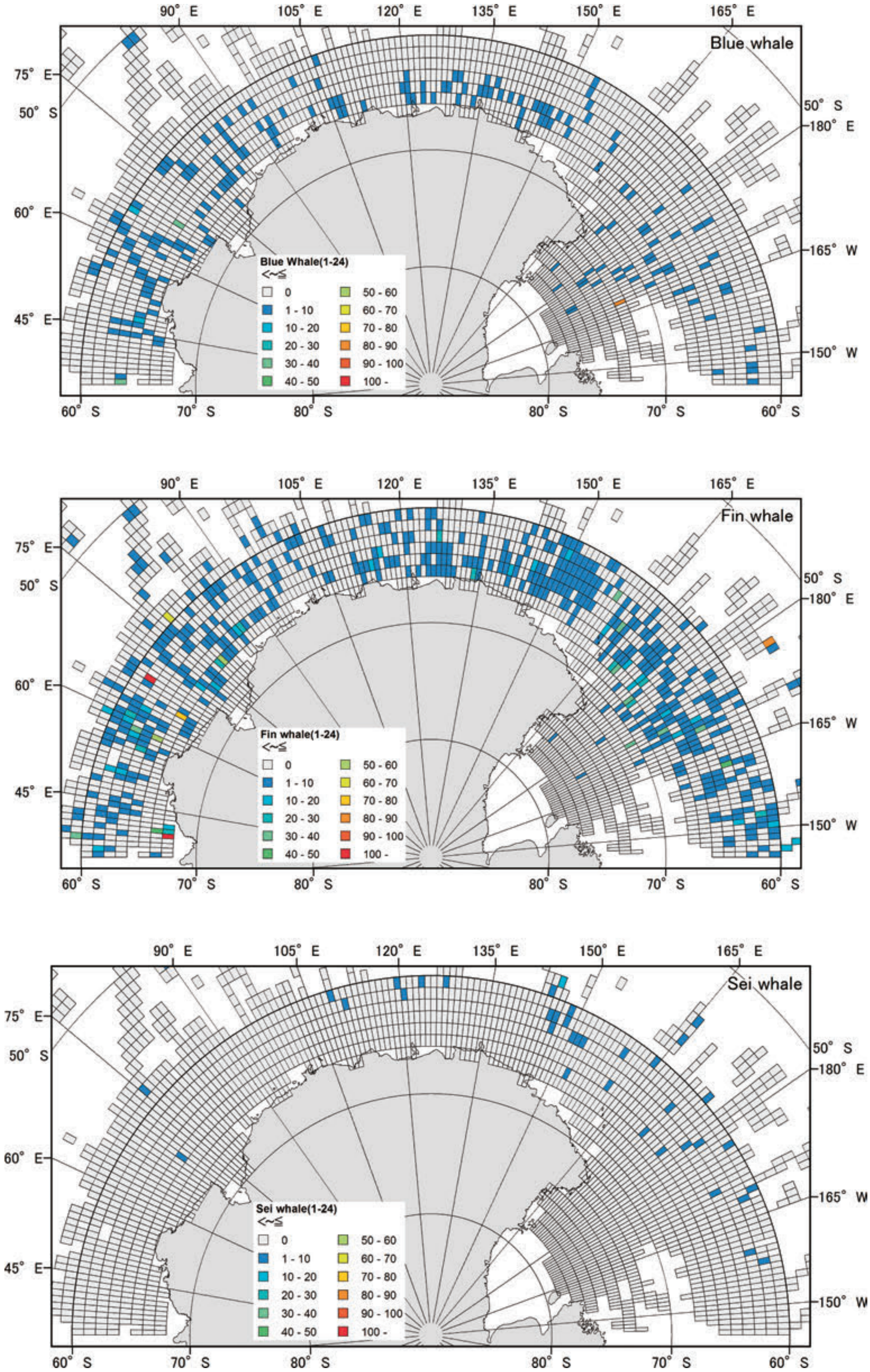


Figure 3a. DIW of blue (top), fin (middle) and sei (bottom) whales in the Indo-Pacific region of the Antarctic, by Lat.1°× Long.1°square (whole research period).

mature individuals. Occurrence in low latitude wintering grounds has been recorded from March to December, but abundance peaks from June/July to August/September (Horwood, 1987). In late spring and summer, abundance peaks in November between 30°S and 50°S. As the season progresses relatively more whales are observed south of 40°S and abundance between 50°S and 60°S increases consistently until March (Horwood, 1987). The results in the present study are consistent with those of previous studies.

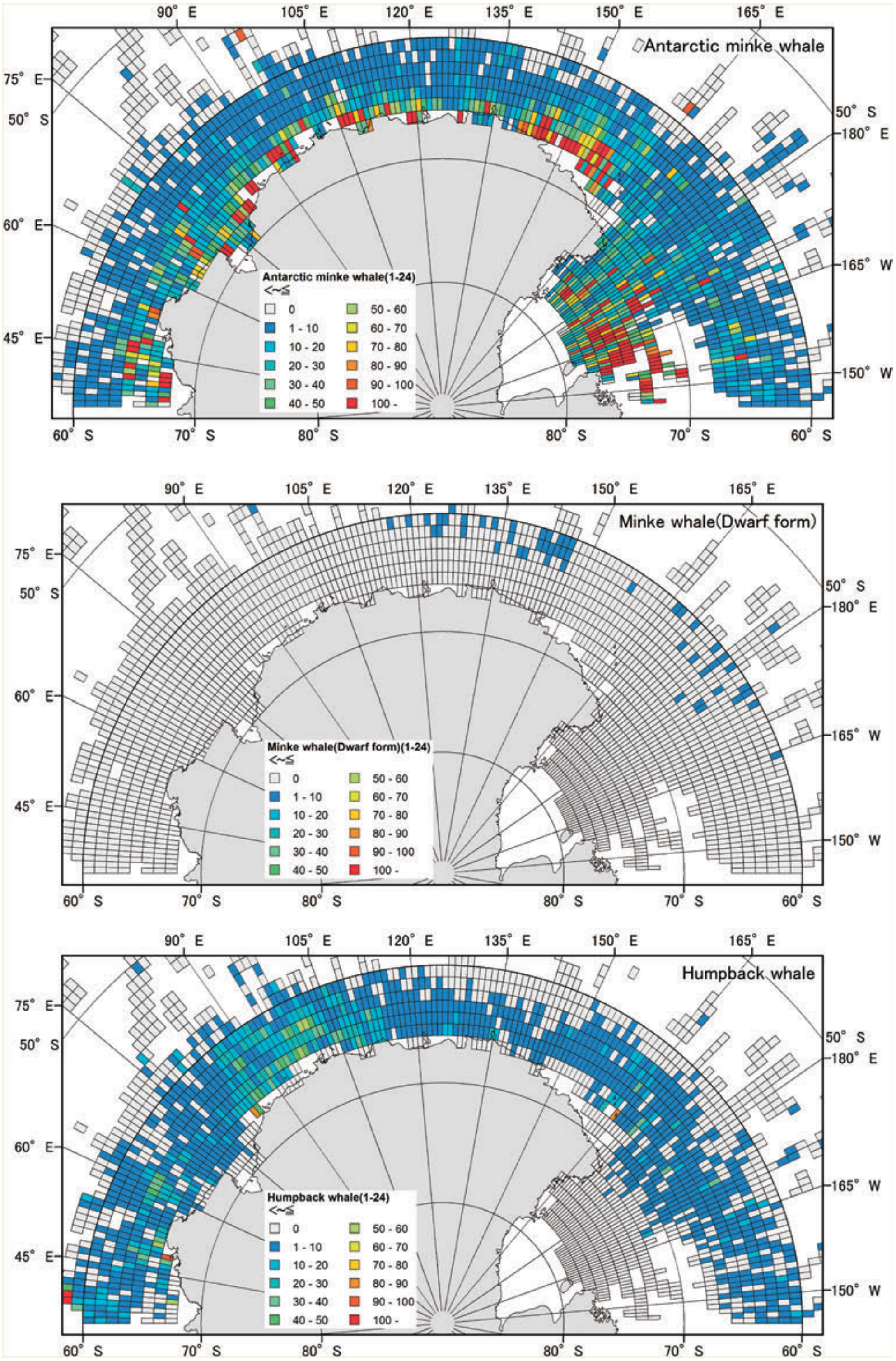


Figure 3b. DIW of Antarctic minke (top), dwarf minke (middle) and humpback (bottom) whales in the Indo-Pacific region of the Antarctic, by Lat.1°× Long.1°square (whole research period).

Antarctic minke whale
This was the most frequently sighted species throughout the surveys. A total of 25,507 schools (69,076 individuals) were sighted south of 60°S (Table 2). No calves were observed. Observed mean school size was 2.71 individuals. High density areas were observed along the ice-edge, especially the Ross Sea and Prydz Bay (Figure 3b). The DIW of this species for the whole period was the highest (19.561). The indices increased from December to February and decreased in March (Figure 4).

In the austral summer the majority of Antarctic minke whales congregate in the Southern Ocean, with greatest densities close to and within the pack ice, and lower densities with increasing distance from the ice (Kasamatsu *et al.*, 2000; Hakamada and Matsuoka, 2014a), including some north of 60°S. Antarctic minke whales are noticeably well adapted to living within the ice (Ainley *et al.*, 2007), but the exact proportion of Antarctic minke whales found within the pack ice, and in polynyas, is currently a source of debate. It is possible that a large proportion of the population is found within the pack ice, out of reach of vessel-based sighting surveys (Murase *et al.*, 2005; 2014; Shimada and Kato, 2007).

Dwarf minke whale
Distribution of this species was limited within the research area. There are two separated areas of distribution, between 120°E and 147°E, and between 165°E and 170°W in the northern stratum (mainly between 60°S and 63°S), south of Australia and New Zealand (Figure 3b). The dwarf minke whale has a white band on the flipper that distinguishes it from the Antarctic minke whale, but was only fairly recently identified as separate from Antarctic minke whales (Best, 1985). On available information, only a small percentage of minke whales in the Antarctic (south of 60°S) are dwarf minke whales. For example, in the IDCR/SOWER surveys from 1993/94–1997/98 only 0.2% of the identified sightings were dwarf minke whales (2 out of 906). No formal analysis has been conducted but it is probable that less than 1% of the minke whales south of 60°S are dwarf minke whales (Branch and Butterworth, 2001).

Humpback whale
Humpback whale had the 3rd rank among the ten species sighted in the research area. A total of 10,036 schools (18,770 individuals) including 137 calves were sighted (Table 2). Observed mean school size was 1.87 individuals. They were widely distributed in the research area in both northern and southern strata. They were rarely found within the Prydz Bay and the Ross Sea and no sighting occurred south of 73°S. High density values of this species were observed between 85°E and 110°E (Figure 3b). The DIW of this species was 5.315 for the whole period. Indices increased from December to February and decreased in March (Figure 4).

IDCR/SOWER circumpolar surveys encountered humpback whales more frequently in the sectors 20–40°E, 80°E–100°E and 150°E–180°E (Branch, 2011). The current distribution map of this species suggests that humpback whales are encountered more frequently in the sector 80°E–100°E because of its high productivity. In the sector 80°E and 100°E, large scale distribution changes were observed (Matsuoka *et al.*, 2011; Murase *et al.*, 2014; Hakamada and Matsuoka, 2014b). It has been suggested that such changes are related to changing oceanographic conditions such as the effect of the regime shift in the global sea-surface temperatures in relation to El Nino-southern oscillation events (Watanabe *et al.*, 2014; Naganobu *et al.*, 2014). This should be further investigated in the future.

Southern right whale
A total of 235 schools (298 individuals) involving six calves were sighted (Table 2). Distribution area of this species was limited to the sector 80°E and 135°E, south of Western Australia (Figure 3c). The DIW of this species was 0.084 for the whole period. Indices increased from December to March (Figure 4). In summer southern right whales migrate south but generally not as far south as other baleen whale species. They appear to occur near the subtropical convergence in summer (January to March) at around 40°S–50°S (Ohsumi and Kasamatsu, 1985), but there are records of animals much further south (e.g. around 60°S–65°S south of Australia (Bannister *et al.*, 1999; 2008). The present distribution map of this species is consistent with these previous studies. The population estimate for the coastal area of Western Australia was 2,400 in 2006 (Bannister, 2008). A current estimate in Area IV south of 60°S is 1,557 individuals (95% CI: 871–2,783) in the 2007/08 season based on JARPAII data (Matsuoka and Hakamada, 2014).

Sperm whale
Sperm whale had the 6th rank among the ten species sighted in the research area. A total of 3,810 schools (3,926 individuals) were sighted. No calves were observed (Table 2). Single large males were mainly sighted (96.5%) and consequently the observed mean school size was 1.03. They were widely distributed in the research

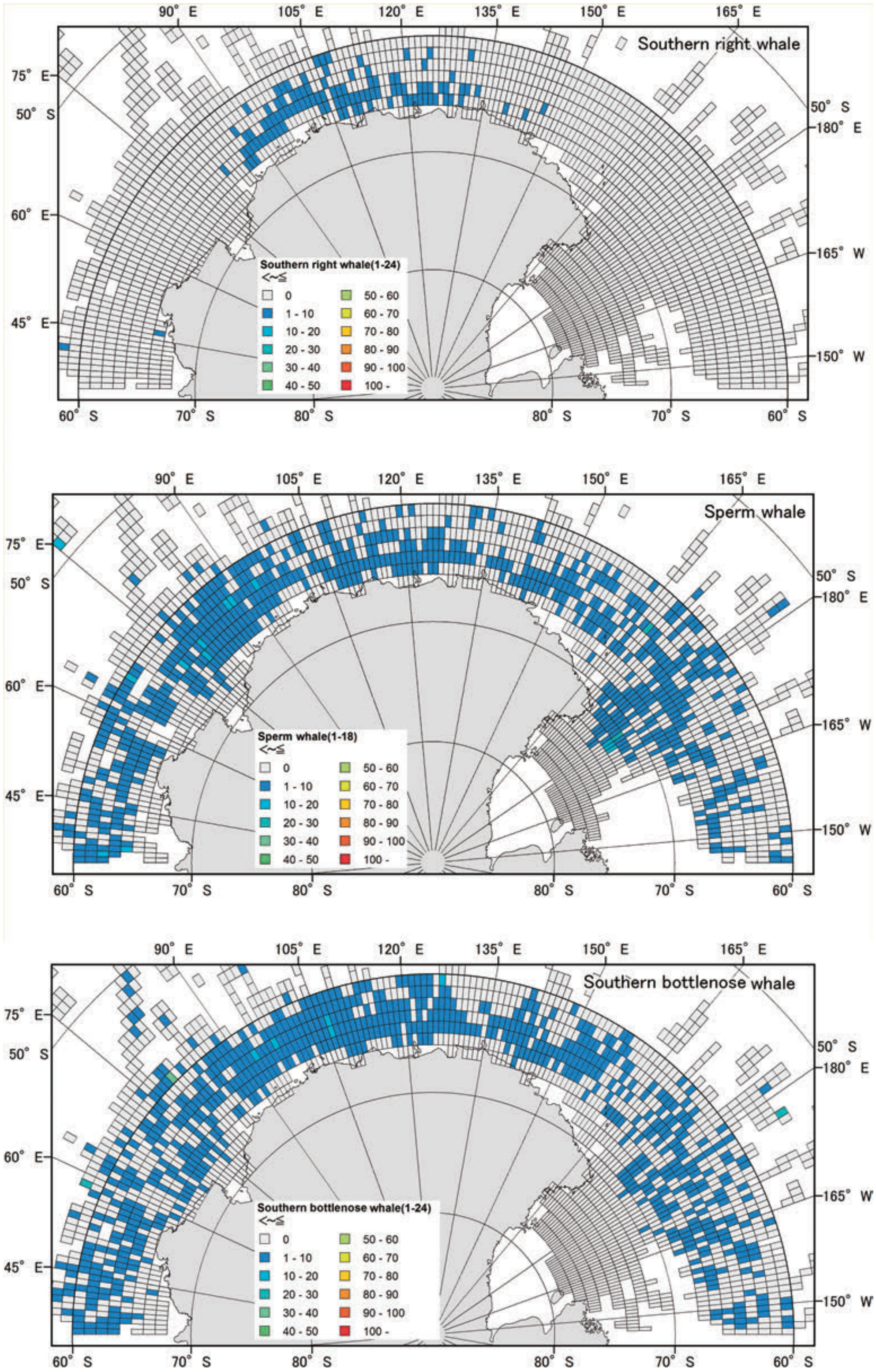


Figure 3c. DIW of southern right (top), sperm (middle) and southern bottlenose (bottom) whales in the Indo-Pacific region of the Antarctic, by Lat.1°× Long.1°square (whole research period).

area. High density values of sperm whales were observed in Area IV (between 70°E and 100°E) and Area V (between 170°E and 170°W, in the mouth of the Ross Sea (Figure 3c). They tended to be concentrated on the Antarctic continental slope, on the southern Kerguelen Plateau, and around the mouth of the Ross Sea, where most frequently the depth was between 1,000 m and 4,000 m. They were rarely found within the Prydz Bay and the Ross Sea (Figure 3c). There were no sightings south of 74°S in the Ross Sea. The DIW of this species was 1.081 for the whole period. The indices decreased from December to March (Figure 4).

Southern bottlenose whale

Southern bottlenose whale had the 7th rank among the ten species sighted in the research area. A total of 1,666 schools (3,045 individuals) including three calves were sighted (Table 2). They were widely distributed in the research area but were rarely sighted within the Prydz Bay and the Ross Sea. High density values of this whale were observed between 85°E and 130°E (Figure 3c). Observed mean school size was 1.83 individuals. The DIW of this species was 0.862 for the whole period. Indices decreased from December to March (Figure 4).

Unidentified beaked whales

Unidentified beaked whales had the 4th rank among the ten species sighted in the research area. A total of 3,175 schools (5,457 individuals) including three calves were sighted (Table 2). The sightings were recorded as unidentified species of beaked whales. This 'unidentified beaked whales' possibly included southern bottlenose whale (*Hyperoodon planifrons*), Arnoux's beaked whale (*Berardius arnuxii*), strap-toothed whale (*Mesoplodon layardii*) and Grey's beaked whale (*M. grayi*). Distribution pattern of the unidentified beaked whales was consistent with that of southern bottlenose whales (Figure 3d).

Killer whale

Killer whale had the 2nd rank among the ten species sighted in the research area. A total of 1,472 schools (20,569 individuals) including 59 calves were sighted (Table 2). Observed mean school size was 13.97 individuals. The DIW of this species was 5.825 for the whole period (Table 2). They were widely distributed in the research area and were more frequently sighted in the southern stratum. High density areas were observed within the Prydz Bay and the Ross Sea (Figure 3d).

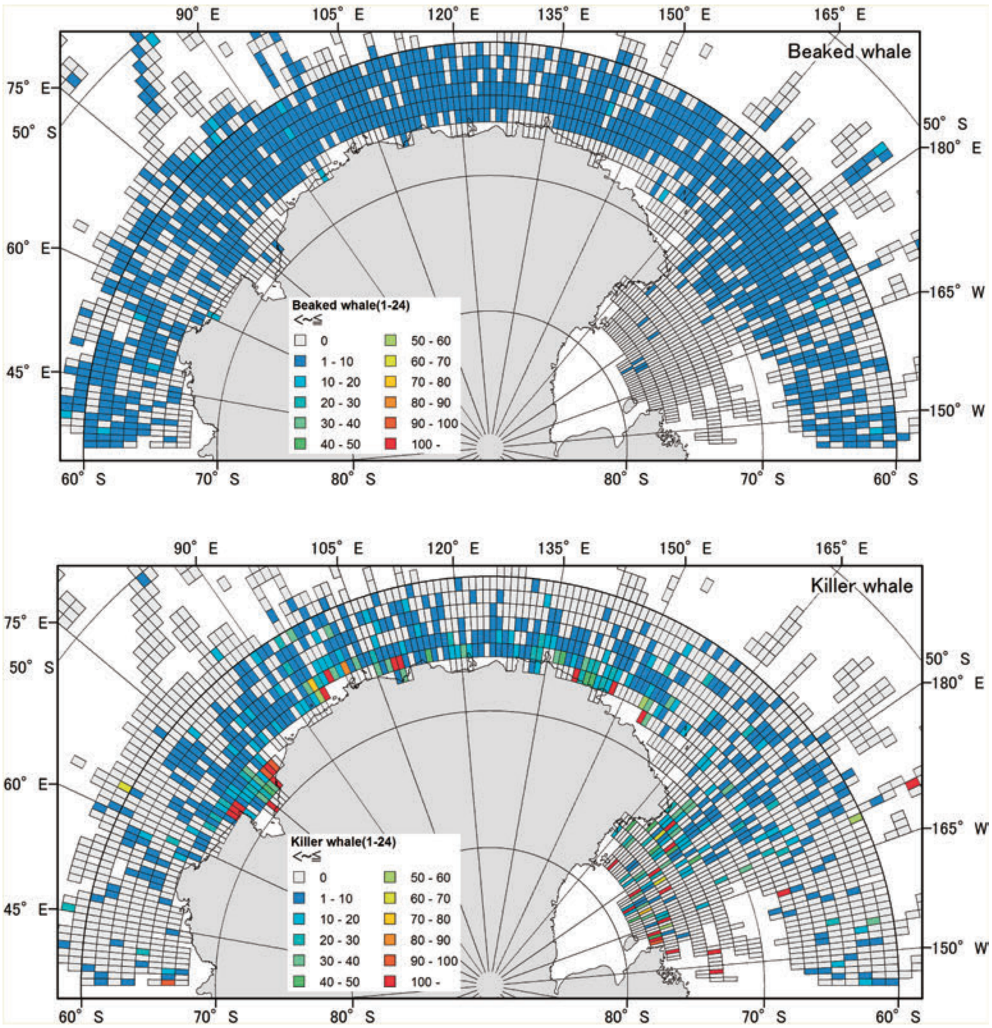
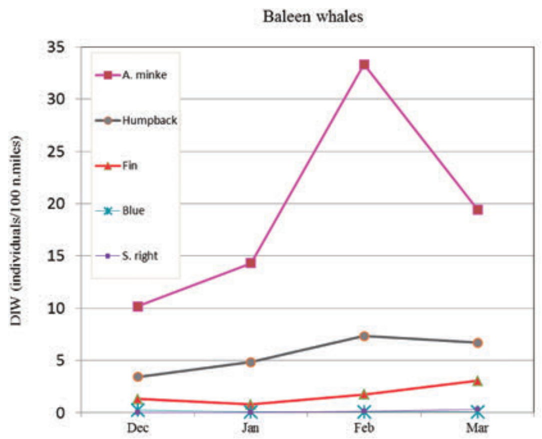


Figure 3d. DIW of unidentified beaked (top) and killer (bottom) whales in the Indo-Pacific region of the Antarctic, by Lat.1°× Long.1°square (whole research period).



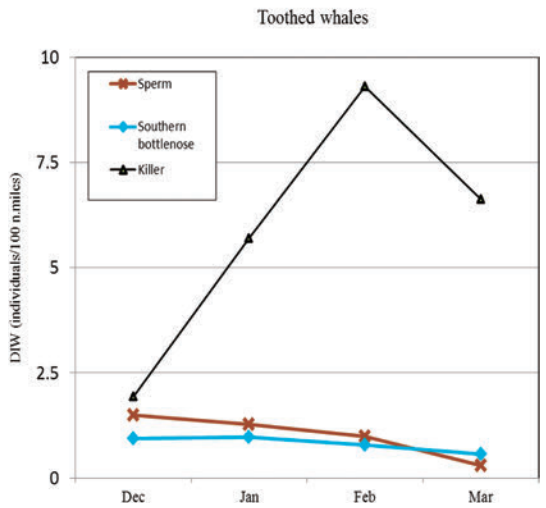


Figure 4. Monthly change of DIW for baleen (top) and toothed (bottom) whales in the whole research area and period.

Relationship between pattern of distribution and oceanographic conditions

There is a common pattern for several whale species to concentrate mainly in the sector 80°E and 110°E, south of 60°S. 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 Antarctic Circumpolar Current (ACC) which seemed to be caused by large scale up-welling with nutritious bottom waters resulting from the bottom shape of the southern Kerguelen Plateau (Watanabe *et al.*, 2006; 2014; Naganobu *et al.*, 2014). 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 1999/2000 JARPA survey, a high density of *Euphausiids* was reported between 100°E and 120°E (Murase *et al.*, 2002). Humpback, southern right, large male sperm and southern bottlenose whales used this longitudinal sector between 80°E and 100°E as their key feeding area during December to March. It is necessary to further investigate the relationship between whale distribution and oceanographic condition shifts such as the effect of the regime shift in the global sea-surface temperatures in relation to El Nino-southern oscillation events (Matsuoka *et al.*, 2003; Watanabe *et al.* 2014; Naganobu *et al.*, 2006; 2014).

ACKNOWLEDGEMENTS

We thank all researchers, captains, officers and crew members that participated in the JARPA and JARPAII surveys from which the data used in the present study were collected. We also thank S. Suzuki for help in drawing some of the figures.

REFERENCES

Ainley, D.G., Dugger, K.M., Toniolo, V. and Gaffney, I. 2007. Cetacean occurrence patterns in the Amundsen and southern Bellingshausen Sea sector, Southern Ocean. *Marine Mammal Science* 23 (2): 287–305.

Bannister, J.L., Pastene, L.A. and Burnell, S.R. 1999. First record of movement of a southern right whale (*Eubalaena australis*) between warm water breeding grounds and the Antarctic Ocean, south of 60°S. *Marine Mammal Science* 15 (4): 1337–1342.

Bannister, J.L. 2008. Population trend in right whales off south-eastern Australia 1993–2007. Paper SC/60/BRG14 presented to the IWC Scientific Committee, June 2008 (unpublished). 13 pp. [Available from the IWC Secretariat].

Best, P.B. 1985. External characters of southern minke whales and the existence of a diminutive form. *Sci. Rep. Whales Res. Inst.* 36: 1–33.

Bindoff, N.L., Rosenburg, M.A. and Warner, M.J. 2000. On the circulation and water masses over the Antarctic continental slope and rise between 80°E and 150°E. *Deep-Sea Research II*: Tropical Studies in Oceanography 47: 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.

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.

Branch, T.A. 2007. Abundance of Antarctic blue whales south of 60°S from three complete circumpolar sets of surveys. *J. Cetacean Res. Manage*. 9 (3): 87–96.

Branch, T.A., Stafford, K.M., Palacios, D.M., Allison, C., Bannister, J.L., Burton, C.L.K., Cabrera, E., Carlson, C.A., Galletti Vernazzani, B., Gill, P.C., Hucke-Gaete, R., Jenner, K.C.S., Jenner, M.-N.M., Matsuoka, K., Mikhalev, Y.A., Miyashita, T., Morrice, M.G., Nishiwaki, S., Sturrock, V.J., Tormosov, D., Anderson, R.C., Baker, A.N., Best, P.B., Borsa, P., Brownell Jr, R.L., Childerhouse, S., Findlay, K.P., Gerrodette, T., Ilangakoon, A.D., Joergensen, M., Kahn, B., Ljungblad, D.K., Maughan, B., Mccauley, R.D., Mckay, S., Norris, T.F., Oman Whale and Dolphin Research Group, Rankin, S., Samaran, F., Thiele, D., Van Waerebeek, K. and Warneke, R.M. 2007. Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. *Mammal Rev*. 37 (2): 116–175.

Branch, T.A. 2011. Humpback abundance south of 60°S from three completed sets of IDCR/SOWER circumpolar surveys. *J. Cetacean Res. Manage*. (Special Issue) 3: 53–69.

Hakamada, T., Matsuoka, K. and Nishiwaki, S. 2006. An update of Antarctic minke whales abundance estimate based on JARPA data. Paper SC/D06/J6 presented to the JARPA Review Meeting, December 2006 (unpublished). 34 pp+Addendum 2 pp. [Available from the IWC Secretariat].

Hakamada, T. and Matsuoka, K. 2014a. Estimates of abundance and abundance trend of the Antarctic minke whale in Areas IIIE–VIW, south of 60°S, based on JARPA and JARPAII sighting data (1989/90–2008/09). Paper SC/F14/J3 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 41 pp. [Available from the IWC Secretariat].

Hakamada, T. and Matsuoka, K. 2014b. Estimates of abundance and abundance trend of the humpback whale in Areas IIIE–VIW, south of 60°S, based on JARPA and JARPAII sighting data (1989/90–2008/09). Paper SC/F14/J4 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 36 pp. [Available from the IWC Secretariat].

Horwood, J. 1987. *The Sei Whale: Population Biology, Ecology and Management*. Croom Helm, London. 375 pp.

Ichihara, T. 1966. The pygmy blue whale, *Balaenoptera musculus brevicauda*, a new subspecies from the Antarctic. pp. 79–113. *In*: K.S. Norris (ed.) *Whales, dolphins, and porpoises*. University of California Press, Berkeley, CA. 789 pp.

Kasamatsu, F., Joyce, G., Ensor, P. and Mermoz, J. 1996. Current occurrence of baleen whales in Antarctic waters. *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 Biol.* 23: 466–473.

Kishino, H., Kato, H., Kasamatsu, F. and Fujise, Y. 1991. Detection heterogeneity and estimation of population characteristics from the field survey data: 1987/88 Japanese feasibility study of the Southern Hemisphere minke whales. *Ann. Inst. Statist. Math*. 43: 435–453.

Mackintosh, N.A. 1966. Distribution of southern blue and fin whales. pp. 125–144. *In*: K.S. Norris (ed.) *Whales, dolphins, and porpoises*. University of California Press, Berkeley, CA. 789 pp.

Matsuoka, K., Watanabe, T., Ichi, T., Shimada, H. and Nishiwaki, S. 2003. Large whale distributions (south of 60°S, 35°E–130°E) in relation to the southern boundary of the ACC. pp. 26–30. *In*: A.H.L. Huiske, W.W.C. Gieskes, J. Rozema, R.M.L. Schrno, S.M. van der Vies and W.J. Wolff (eds.) *Antarctic Biology in a Global Context*. Backhuys Publishers, Leiden, The Netherlands. 338 pp.

Matsuoka, K., Hakamada, T., Kiwada, H., Murase H. and Nishiwaki, S. 2011. Abundance estimates and trends for humpback whales (*Megaptera novaeanglie*) in the Antarctic Areas IV and V based on JARPA sighting data. *J. Cetacean Res. Manage*. (Special Issue) 3: 75–94.

Matsuoka, K. and Hakamada, T. 2014. Estimates of abundance and abundance trend of the blue, fin and southern right whales in Areas IIIE–VIW, south of 60°S, based on JARPA and JARPAII sighting data (1989/90–2008/09). Paper SC/F14/J5 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 27 pp. [Available from the IWC Secretariat].

Miyashita, T., Kato, H. and Kasuya, T. (eds.) 1995. *Worldwide Map of Cetacean Distribution based on Japanese Sighting Data (Volume 1)*. National Research Institute of Far Seas Fisheries, Shimizu, Japan. 140 pp.

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.

Murase, H., Shimada, H. and Kitakado, T. 2005. Alternative estimation of Antarctic minke whale abundance taking account of possible animals in the unsurveyed large polynya using GAM-based spatial analysis: A case study in Area II in 1997/98 IWC/SOWER. Paper SC/57/IA6 presented to the IWC Scientific Committee, May–June 2005 (unpublished). 20 pp. [Available from the IWC Secretariat].

Murase, H., Matsuoka, K., Hakamada, T. and Kitakado, T. 2014. Preliminary analysis of changes in spatial distribution of Antarctic minke and humpback whales in Area IV during the period of JARPA and JARPAII from 1989 to 2006. Paper SC/F14/J18 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 17 pp. [Available from the IWC Secretariat].

Naganobu, M., Nishiwaki, S., Yasuma, H., Matsukura, R., Takao, Y., Taki, K., Hayashi, T., Watanabe, Y., Yabuki, T., Yoda, Y., Noiri, Y., Kuga, M., Yoshikawa, K., Kokubun, N., Murase, H., Matsuoka, K. and Ito, K. 2006. Interactions between oceanography, krill and baleen whales in the Ross Sea and Adjacent Waters: An overview of *Kaiyo Maru*-JARPA joint survey in 2004/05. Paper SC/D06/J23 presented to the JARPA Review Meeting, December 2006 (unpublished). 33 pp. [Available from the IWC Secretariat].

Naganobu, M., Matsuoka, K. and Kutsuwada, K. 2014. Consideration on the Kerguelen-Davis Oscillation Index

(KDOI) influencing variability on environmental ecosystem in the Prydz Bay Region, east Antarctic: data exploration. Paper SC/F14/J21 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 12 pp. [Available from the IWC Secretariat].

Nishiwaki, S., Ishikawa, H., Goto, M., Matsuoka, K. and Tamura, T. 2014. Review of general methodology and survey procedure under the JARPAII. Paper SC/F14/J2 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 34 pp. [Available from the IWC Secretariat].

Ohsumi, S. and Kasamatsu, F. 1985. Recent off-shore distribution of the southern right whale in summer. *Rep. Int. Whal. Commn* (Special Issue) 10: 177–185.

Rice, D.W. (ed.) 1998. *Marine mammals of the world: systematics and distribution*. Society for Marine Mammalogy, Lawrence, KS. 231 pp.

Shimada, H. and Kato, A. 2007. Population assessment of the Antarctic minke whale within and out ice field using a sighting data by the Ice Breaker and the IWC SOWER vessels in 2004/2005. Paper SC/59/IA16 presented to the IWC Scientific Committee, May 2007 (unpublished). 8 pp. [Available from the IWC Secretariat].

Watanabe, T., Yabuki, T., Suga, T., Hanawa, K., Matsuoka, K. and Kiwada, H. 2006. Results of oceanographic analyses conducted under JARPA and possible evidence of environmental changes. Paper SC/D06/J30 presented to the JARPA Review Meeting, December 2006 (unpublished). 13 pp. [Available from the IWC Secretariat].

Watanabe, T., Okazaki, M. and Matsuoka, K. 2014. Results of oceanographic analyses conducted under JARPA and JARPAII and possible evidence of environmental changes. Paper SC/F14/J20 presented to the IWC/SC Review Workshop of the Japanese Whale Research Program under Special Permit in the Antarctic-Phase II (JARPAII), February 2014 (unpublished). 10 pp. [Available from the IWC Secretariat].