Full paper

DENSITY DISTRIBUTION OF SEVERAL MAJOR WHALE SPECIES IN THE INDO-PACIFIC REGION OF ANTARCTIC USING JARPA AND JARPAII SIGHTING DATA OBTAINED THROUGH 1987/88–2008/09 SEASONS

Koji MATSUOKA* and Takashi HAKAMADA

Institute of Cetacean Research, 4–5 Toyomi-cho, Chuo-ku, Tokyo 104–0055, Japan
*(*Corresponding author: matsuoka@cetacean.jp)*

Abstract

This paper examined the geographical 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 of 35°E–145°W, south of 60°S, between 1987/88 and 2008/09. The searching effort comprised a total of 353,134 n.miles. The 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. Density index of whales (DIW: no. of individuals sighted/100 n.miles) was calculated using all primary effort and sightings data and its geographical distribution plotted on maps with Lat. 1 degree × Long. 1 degree squares for each species. These maps are more detailed compared to those of the previous maps which used 5° × 5°squares in the 1960s. The geographical distribution was described for each whale species together with some features of their distribution. For example, sei, dwarf minke, humpback and southern bottlenose whales were not sighted in the Ross Sea, distribution areas of southern right whales were limited to the sector 80°E and 135°E, and high-density areas of humpback whales were observed between 80°E and 110°E. The large scale and long-term sighting data set has made a substantial contribution to understanding the geographical distribution patterns and habitat use of whales in the Antarctic ecosystem.

Key words: Antarctic, distribution, baleen whales, toothed whales.

Introduction

One of the main sources of large scale and long-term sighting data for assessing the population status of whale species in the Antarctic is the JARPA (Japanese Whale Research Program under Special Permit in the Antarctic), the first phase of which was conducted between 1987/88 and 2004/05, with its second phase, JARPAII (sighting component), conducted between 2005/06 and 2008/09. One of the features of JARPA and JARPAII is that, unlike the IWC/IDCR (International Whaling Commission/International Decade for Cetacean Research)-SOWER (Southern Ocean Whale and Ecosystem Research) programmes conducted from 1978/79 to 2009/10 (Matsuoka *et al.*, 2003a), surveys have been repeated in the same area and in the same months every second season over a long period. Current distribution maps are more detailed for each Area compared to those of the IDCR/SOWER maps which had covered the area only three times for each set of circumpolar data on whales. Therefore, the JARPA and JARPAII surveys facilitate description of the extent of detailed local distribution of whales.

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

The objective of this study was to investigate the geographical distribution patterns 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 the JARPA and JARPAII surveys.

Materials and Methods

Research area

The research area comprised the Indo-Pacific region of the Antarctic every year, specifically the IWC Management Areas IIIE (35°–70°E), IV (70°–130°E), V (130°E–170°W) and VIW (170°–145°W), south of 60°S (Fig. 1). Each individual survey was conducted from December to March during austral summer (Fig. 2).

These Areas were divided into two sectors (western sector and eastern sector). Each sector was also divided into two strata (northern and southern strata), along 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 for the Prydz Bay and the Ross Sea regions. The Prydz Bay is defined as south of 66°S, and the Ross Sea is defined as south of 69°S. There are no stratifications for Areas IIIE and VIW in JARPA. In JARPAII, there are stratifications for Areas IIIE and VIW which are the same as in Area IV (Fig. 3).

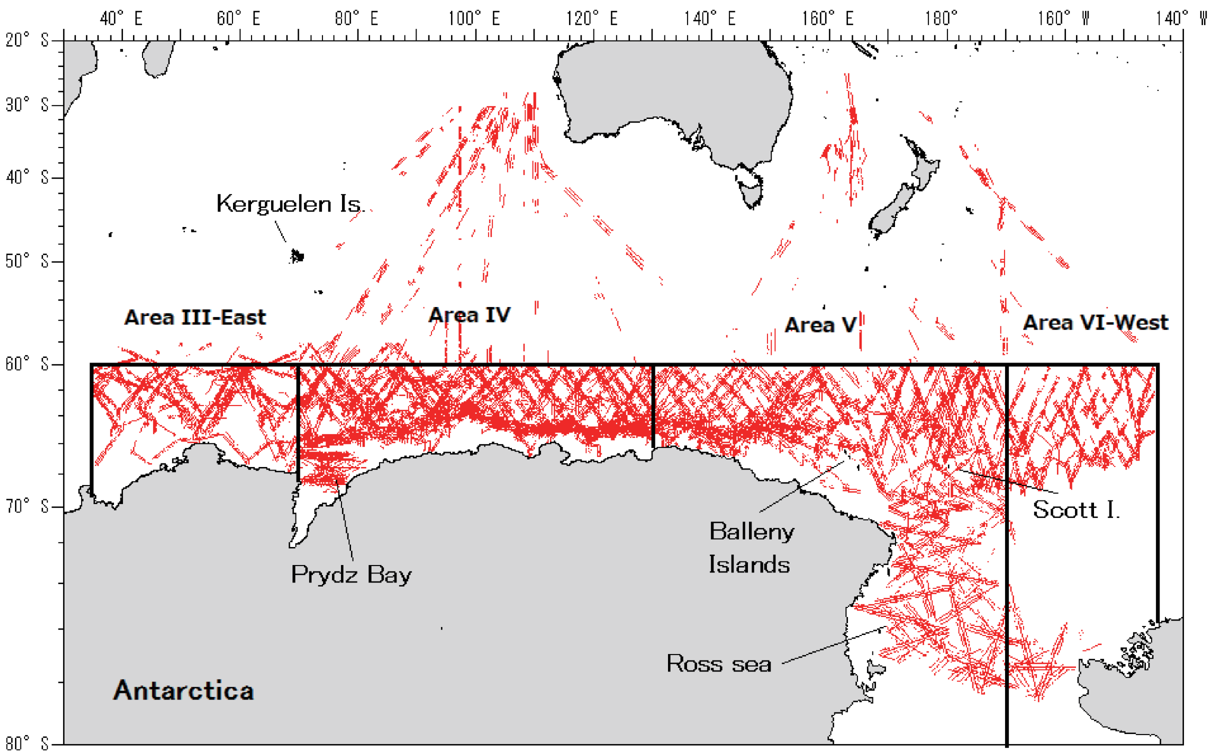

Fig. 1. The main research area of the JARPA and JARPAII surveys between 35°E and 145°W, south of 60°S with searching efforts (red lines) in the period 1987/88–2008/09, including the transit sighting surveys between low latitude and Antarctic regions with the IWC Antarctic Areas for the management of baleen whales (except Bryde's whale).

Sighting data

The collection procedures and analyses of sighting data that have been used in JARPA are very similar to those used in IWC/IDCR-SOWER cruises. Activities aboard the ship are classified into two principal groups: On-effort and Off-effort. On-effort activities are times when full search effort is being executed and conditions (such as weather and sea conditions) are within acceptable parameters to conduct research. Off-effort activities are all activities that are not On-effort. All sightings recorded while the ship is On-effort are classified as Primary sightings. All other sightings are Secondary sightings.

Primary search effort is only conducted in acceptable weather conditions. These conditions are defined as visibility better than 2.0 n.miles, with wind speed less than 20 knots and Beaufort sea state less than 6. These conditions are used as guidelines; in some circumstances, less severe conditions may still be inappropriate for search effort. The sighting procedure in JARPAII (2005/06–2008/09) did not differ substantially from JARPA (Hakamada *et al.*, 2006; Nishiwaki *et al.*, 2014).

The research vessels (ship length averages about 70 meters) were equipped with a top barrel (almost 20 meters from the sea level), from which three men conducted sighting observations. On the upper bridge (almost 11.5 meter from the sea level), a captain, a gunner, a helmsman and a researcher also conducted sightings. The sighting activity was carried out from 30 minutes after sunrise to 30 minutes before sunset. The survey ship speed averages about 11.5 knots.

When a sighting is made, the topman (or upper bridge observer) gives an estimate of the distance and angle to the sighting and the ship turns immediately, regardless of the angle to the sighting. The whales were approached and the species, number of animals and number of calves (if present) determined. In order to save valuable research time, closure to the sighting position of whales that can be positively identified as long-diving species (such as sperm whales or beaked whales) may be abandoned if it is considered that the animals have dived.

In addition, using the round-trip transit sighting surveys were also conducted every season between low latitude and Antarctic regions, although the searching effort was low compared to that south of 60°S (Fig. 1).

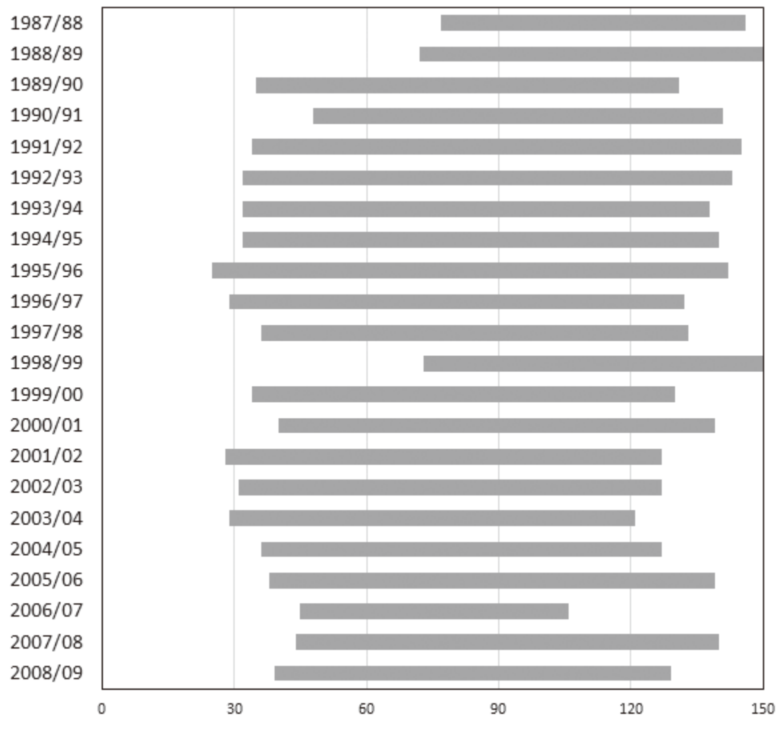

Fig. 2. Start and end dates of JARPA and JARPA II surveys (1989/90–2008/09) in the research area.

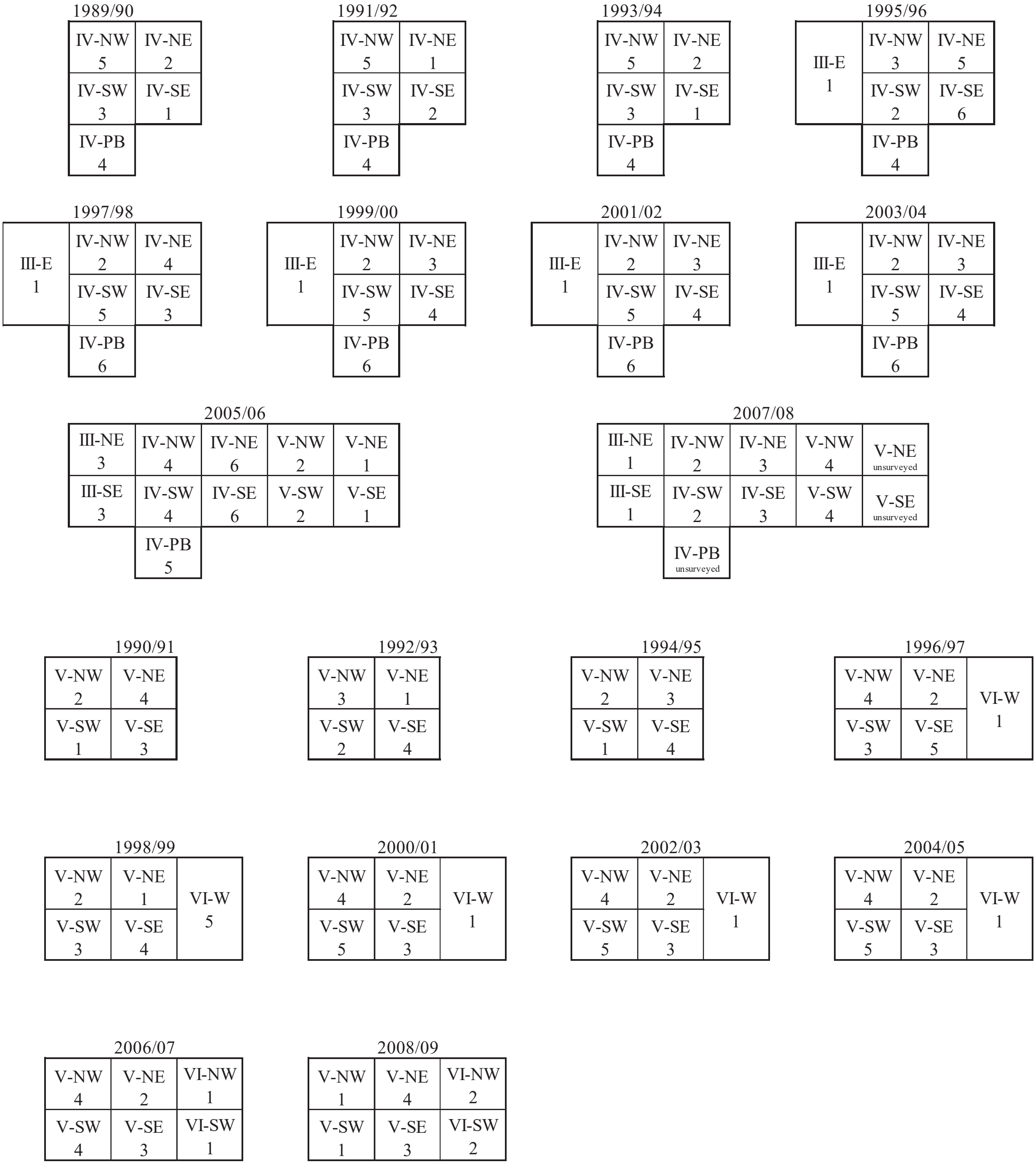

Fig. 3. Survey order by strata for the period from 1989/90 to 2008/09 seasons. Key: III=Area III, IV=Area IV, V=Area V, VI=Area VI, E=East, W=West, NW=North-West, NE=North-East, SW=South-West, SE=South-East, PB= Prydz Bay. A common number in a season indicates that two strata were surveyed in the same period. V-NE, V-SE and IV-PB strata could not be surveyed at all in 2007/08 season (Hakamada and Matsuoka, 2014a).

Density index of whales and mean school size

The Density Index of Whales (DIW), i.e. the number of individual whales sighted per 100 n.miles, was calculated for each Lat.1° × Long.1° grid square. The mean school size (Mss) in this study is the arithmetic mean (i.e. number of animals divided by number of schools).

Results and Discussion

Searching efforts

A total of 353,134 n.miles were surveyed in Areas IIIE, IV, V and VIW, south of 60°S, between 1989/90 and 2008/09. Fig. 4 shows the distribution of the primary searching effort (n.miles). All grid squares were searched and the research area south of 60°S was completely covered.

Distribution of whales

Tables 1a and 1b show a summary of the primary sightings of baleen and toothed whales, respec-

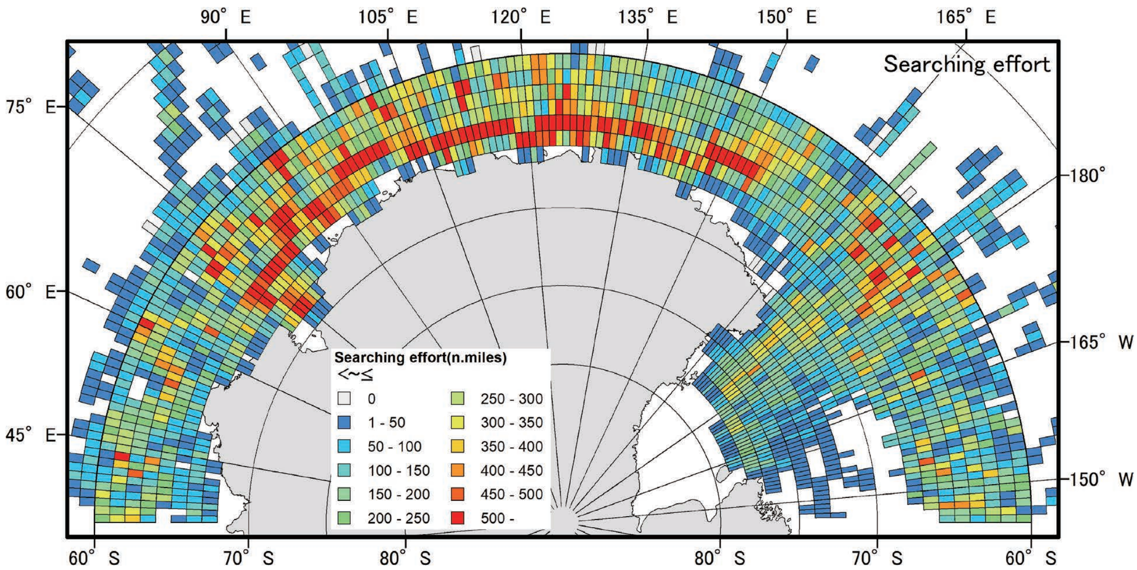

Fig. 4. Distribution of the primary searching effort by Lat.1° × Long.1° squares in JARPA and JARPAII surveys in the period 1987/88–2008/09 seasons.

Table 1a. Summary of baleen whale species sighted in the Indo-Pacific region of the Antarctic.

No.	Season	Research area	Effort (n.miles)	Blue whale			Fin whale			Sei whale			Ant. minke whale			Dwarf minke whale			Humpback whale			S. right whale		
				sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf
1	1987/88	IV	8,860.6	0	0	0	3	3	0	1	1	0	237	719	0	1	2	0	35	76	0	1	1	0
2	1988/89	V	10,806.7	2	3	0	7	16	0	0	0	0	353	768	0	5	5	0	1	2	0	0	0	0
3	1989/90	IV	16,423.2	5	9	0	5	20	0	0	0	0	758	1,968	0	3	3	0	121	210	11	2	2	0
4	1990/91	V	14,660.0	4	6	0	33	67	0	0	0	0	740	1,713	0	6	6	0	58	90	0	0	0	0
5	1991/92	IV	17,844.1	3	3	0	8	34	0	2	2	0	597	2,030	0	0	0	0	177	321	7	26	30	0
6	1992/93	V	13,924.9	7	9	0	15	27	1	2	4	0	1,024	3,228	0	7	7	0	28	56	5	3	4	0
7	1993/94	IV	17,957.3	5	9	0	9	26	0	0	0	0	688	1,619	0	4	4	0	133	220	1	11	14	0
8	1994/95	V	14,047.7	13	20	1	73	241	1	2	5	0	823	2,453	0	6	6	0	131	228	9	0	0	0
9	1995/96	IIIE, IV	21,466.7	9	16	0	60	214	1	0	0	0	887	2,008	0	2	2	0	325	562	10	8	8	0
10	1996/97	V, VIW	17,783.2	7	9	0	37	82	1	1	1	0	853	2,610	0	9	9	0	114	200	3	0	0	0
11	1997/98	IIIE, IV	21,594.4	16	25	0	18	57	0	0	0	0	672	1,373	0	2	2	0	577	1,122	2	34	37	0
12	1998/99	V, VIW	8,066.5	4	7	1	45	222	1	0	0	0	826	2,665	0	3	3	0	106	203	7	0	0	0
13	1999/2000	IIIE, IV	16,341.5	25	53	2	66	356	3	0	0	0	1,507	6,581	0	0	0	0	661	1,269	5	3	3	0
14	2000/01	V, VIW	20,421.3	10	18	0	114	374	0	7	13	0	1,907	4,949	0	27	27	0	191	341	3	2	2	0
15	2001/02	IIIE, IV	19,767.4	17	26	1	143	983	2	1	2	0	1,867	4,374	0	0	0	0	1,219	2,387	5	15	22	1
16	2002/03	V, VIW	18,126.2	5	10	0	52	216	0	8	14	0	2,420	6,531	0	6	6	0	145	228	4	0	0	0
17	2003/04	IIIE, IV	19,287.4	32	61	0	109	446	0	0	0	0	1,092	3,250	0	2	2	0	1,690	3,134	5	1	2	1
18	2004/05	V, VIW	18,486.7	12	16	0	49	118	1	1	1	0	1,663	4,278	0	0	0	0	197	336	2	2	2	0
19	2005/06	IIIE, IV	16,372.7	24	38	2	188	748	1	2	3	0	1,657	4,375	0	0	0	0	1,702	3,200	22	53	73	4
20	2006/07	V, VIW	11,968.8	7	12	1	37	253	0	0	0	0	969	2,169	0	1	1	0	160	283	13	0	0	0
21	2007/08	IIIE, IV	14,575.3	43	84	1	48	134	4	2	2	0	823	1,702	0	0	0	0	1,314	2,536	7	72	96	0
22	2008/09	V, VIW	14,351.4	14	28	1	109	440	2	5	7	0	1,870	4,668	0	0	0	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	0	84	85	0	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	Research area	Effort (n.miles)	Sperm whale			S. bottlenose whale			Unid. beaked whales			Killer whale		
				sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf	sch.	ind.	calf
1	1987/88	IV	8,860.6	6	6	0	3	5	0	87	218	0	20	194	0
2	1988/89	V	10,806.7	81	91	0	2	4	0	65	143	0	31	189	0
3	1989/90	IV	16,423.2	204	215	0	23	46	0	281	514	0	69	859	0
4	1990/91	V	14,660.0	175	188	0	13	26	0	241	421	1	32	870	2
5	1991/92	IV	17,844.1	225	233	0	29	51	0	181	304	1	53	805	0
6	1992/93	V	13,924.9	105	108	0	10	19	0	202	361	0	82	1,130	0
7	1993/94	IV	17,957.3	321	336	0	145	243	0	205	337	0	56	399	1
8	1994/95	V	14,047.7	133	135	0	74	146	1	168	263	0	35	281	1
9	1995/96	IIIE, IV	21,466.7	341	352	0	137	273	1	161	284	0	109	1,282	1
10	1996/97	V, VIW	17,783.2	121	128	0	75	128	0	78	144	1	50	539	4
11	1997/98	IIIE, IV	21,594.4	295	302	0	222	409	0	197	338	0	82	931	9
12	1998/99	V, VIW	8,066.5	49	50	0	23	53	0	35	54	0	35	409	5
13	1999/2000	IIIE, IV	16,341.5	195	204	0	138	251	0	110	188	0	109	2,011	7
14	2000/01	V, VIW	20,421.3	100	106	0	72	121	0	173	272	0	72	1,471	2
15	2001/02	IIIE, IV	19,767.4	269	272	0	126	226	0	134	205	0	79	939	0
16	2002/03	V, VIW	18,126.2	128	129	0	97	168	0	113	154	0	63	953	0
17	2003/04	IIIE, IV	19,287.4	222	223	0	154	274	0	208	338	0	120	1,348	0
18	2004/05	V, VIW	18,486.7	105	108	0	44	78	0	89	159	0	78	1,472	3
19	2005/06	IIIE, IV	16,372.7	181	182	0	88	179	0	135	244	0	100	1,563	3
20	2006/07	V, VIW	11,968.8	63	63	0	51	80	0	66	88	0	44	394	0
21	2007/08	IIIE, IV	14,575.3	280	280	0	79	157	1	102	155	0	62	790	0
22	2008/09	V, VIW	14,351.4	75	76	0	32	61	0	77	140	0	38	788	14
-	Total	-	353,134	3,674	3,787	0	1,637	2,998	3	3,108	5,324	3	1,419	19,617	52

Table 2. Summary of sighting information for the whole research area in the period 1987/88-2008/09, for 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 60S, 35E-145W)						Order of	Dec.	Jan.	Feb.	Mar.
	Sch.	Ind.	Calf	Mss	DIS	DIW	DIW	DIW	DIW	DIW	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	11	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
Dwarf minke whale	84	85	0	1.01	0.024	0.024	10	0.008	0.031	0.039	0.008
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
Southern 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

tively for each individual survey. Table 2 shows the summary of sighting data for each species such as the number of calves and the observed mean school size. Total DIW for each species were the total numbers of sighted individuals divided by the total effort and multiplied by 100. Monthly DIW were obtained similarly. Figs. 5a–5d show the maps of the DIW for Antarctic blue (*Balaenoptera musculus intermedia*), fin (*B. physalus*) and sei (*B. borealis*), Antarctic minke (*B. bonaerensis*), dwarf minke (*B. a. subsp.*), humpback (*Megaptera novaeangliae*), southern right (*Eubalaena australis*), sperm (*Physeter macrocephalus*), southern bottlenose (*Hyperoodon planifrons*), unidentified beaked (Ziphiidae) and killer (*Orcinus orca*) whales, for each Lat.1° × Long.1° grid square. Figs. 6a and 6b show the longitudinal band of DIW for each species. Figs. 7a and 7b show the latitudinal band of DIW for each species. Fig. 8 shows a plot with time trends of DIW for each species. Fig. 9 shows the monthly change in DIW for most of the species.

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

Blue whale

Blue whale ranked 8th for DIW among the ten species sighted in the research area (Table 2). Blue whales were widely distributed in the research area, not only in the northern stratum, but also in the southern stratum. High density values were recorded for this species in Area IIIE, particularly between 45°E and 65°E (Fig. 5a). Blue whales were rarely found in Prydz Bay, but were sighted in 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. Sighting rate of a mother and calf pair was 3.85% (11 out of 286 schools) which is the highest number compared to other baleen whale species in the Antarctic. A high-density area was observed between 35°E and 65°E (Fig. 6a). The DIW of this species was 0.140 for the whole survey period and the indices were almost stable from December to March (Table 2; Fig. 9). Previous studies have noted that blue whales are more common close to the ice edge than in more northerly waters (e.g. Kasamatsu *et al.*, 2000). This appears to be true for 110°E eastward, although there are blue whale sightings at or around 60°S in the region 45°E–110°E (Figs. 6a and 7a). Similar distribution pattern was observed by Branch (2007).

Two subspecies of blue whales exist in the 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). Complete reviews of the spatial and seasonal distributions, as well as densities and movements of blue whales has been provided by Kato *et al.* (1995), Branch (2007) and Branch *et al.* (2007), respectively. These studies indicated that there is little evidence that pygmy blue whales migrate to high latitudes of the Antarctic, with less than 1% of the records south of 52°S being of this subspecies. There have been a couple of genetic studies reporting some population structure in Antarctic blue whales (Sremba *et al.*, 2012, Attard *et al.*, 2016), but there is limited evidence for multiple separate populations in these papers.

The latest abundance estimate of this species (south of 60°S, 35°E–145°W) was 1,223 whales (CV = 0.345) in the 2007/08 and 2008/09 seasons, and the abundance trend was 8.2% (95% CI: 3.9%, 12.5%) between 1995/96 and 2008/09 combined for Areas IIIE, IV, V and VIW, based on JARPA and JARPAII data (Matsuoka and Hakamada, 2014). In this study, no formal analysis has been conducted but it is probable that the trend of DIW is increasing (Fig. 8). There is a need for continued monitoring of the abundance and abundance trends of this species, especially because it provides an excellent opportunity to improve our understanding of the dynamics of baleen whale populations recovering from low levels.

Fin whale

Fin whales ranked 5th for 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 and IV, particularly between 55°E and 80°E, and in Area V between 163°E and 170°W (Figs. 5a and 6a). Fin whales tended to be distributed more northerly than blue whales (Fig. 7a). The DIW of this species was 1.475 for the whole period and the indices increased from December to March (Fig. 9).

In the summer feeding grounds in the Antarctic, fin whales occur year-round, but a higher density is found from November to May (Kasamatsu *et al.*, 1996; Mackintosh, 1966). These whales can be found as far south as 65−70°S, but most of the population seems to occur north of 60°S (Miyashita *et al.*, 1995). Catches occurred throughout the Antarctic, but most whales (~73%) were taken in IWC Management Areas II and III (Kasamatsu *et al.*, 1996). Sighting data of this study suggest that the fin whale's spatial distribution varies across ocean basins. In this study, no formal analysis has been conducted but it is probable that there is an increasing trend of DIW (Fig. 8). Historically more blue whales were caught than fin whales in the earlier years of pelagic whaling, and thus fin whales are likely less depleted than blue whales now, given their much higher sighting rates. There have been a couple of genetic studies on population structure for fin whales in the management Areas III, IV, V and VI (e.g. Goto and Taguchi, 2019), but these studies did not find any genetic structure in the research area.

Sei whale

The sei whale was rarely sighted in the research area. A total of 36 schools (59 individuals) were sighted south of 60°S (Table 2), with no calves observed. Observed mean school size was 1.64 individuals. Sei whales occurred more frequently in Areas V and VIW than in Areas IIIE and IV in the northern strata (Fig. 5a). High density areas were observed in Area VW, particularly between 150°E and 160°E (Fig. 6a). Sei whales were tended to distribute more northerly between 40°S and 45°S compared to fin and blue whales (Fig. 7a). The DIW of this species was 0.017 for the whole research period.

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

Antarctic minke whale

The Antarctic minke whale 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 between 140°E and 160°E, in the Ross Sea and the Prydz Bay (Fig. 5b). Antarctic minke whales were widely and evenly distributed in the area south of 60°S (Figs. 6a and 7a). The DIW of this species for the whole research period was the highest of all recorded species (19.561). The indices increased from December to February and decreased in March (Fig. 9).

In the austral summer, the majority of Antarctic minke whales congregate in the Southern Ocean, with the greatest densities being close to and within the pack ice, and lower densities with increasing distance from the ice (Kasamatsu *et al.*, 2000; Hakamada and Matsuoka, 2014a; Herr *et al.*, 2019), 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 these 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 exists

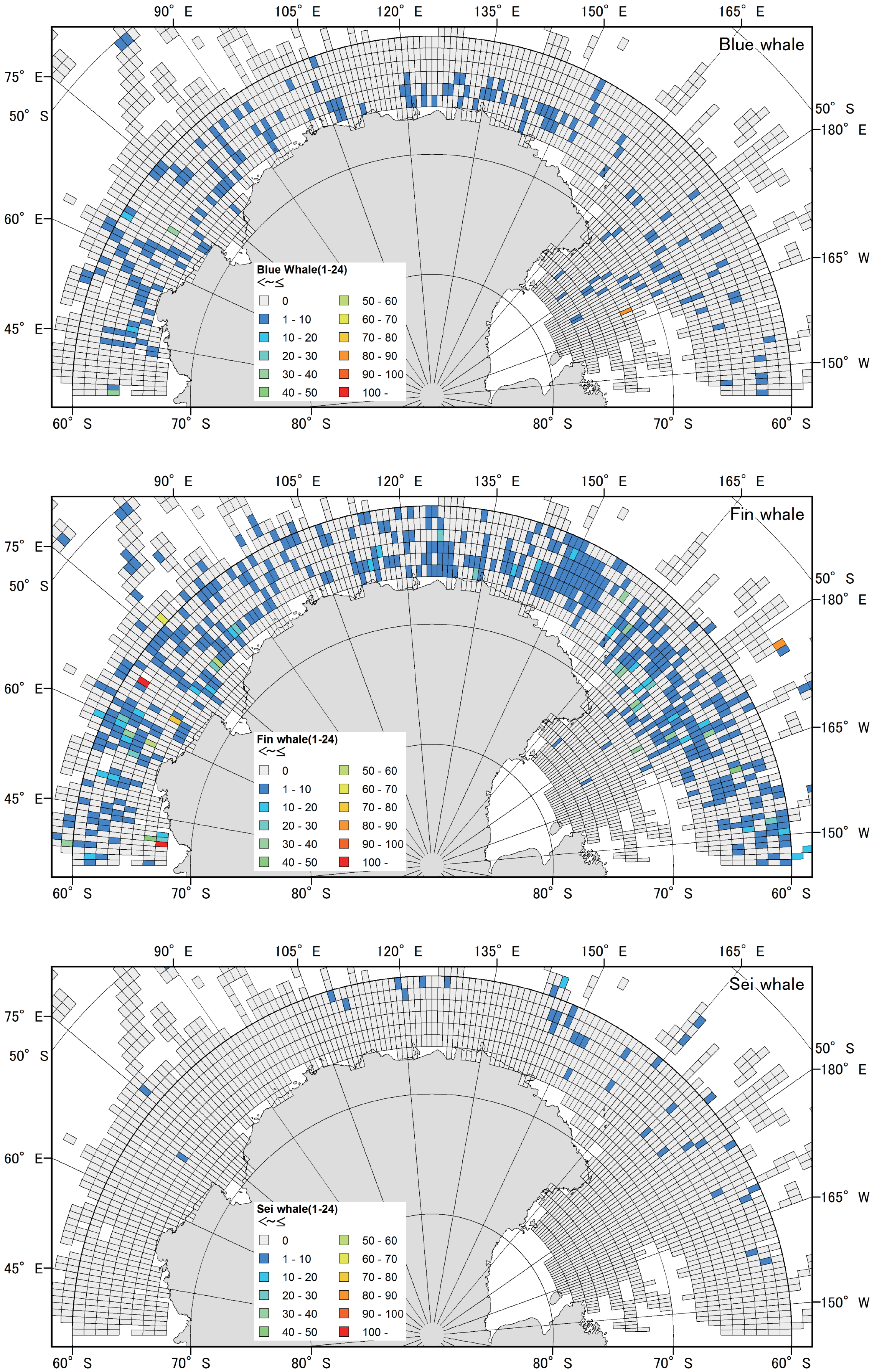

Fig. 5a. DIW of blue, fin and sei whales in the Indo-Pacific region of the Antarctic, based on one degree squares (whole research period).

within the pack ice, out of reach of ship-based sighting surveys (Murase *et al.*, 2005; 2014; Shimada and Kato, 2007; Williams *et al.*, 2014).

There have been a couple of genetic studies reporting some population structure in Antarctic minke whales which indicated at least two stocks in the research areas: P-stock originating from breeding grounds in the western South Pacific and I-stock originating in the Indian Ocean. The study also suggested that the two stocks overlap geographically in a wide area of the Antarctic located at 130°E–165°E, which changes by year and sex depending on the krill availability (Pastene and Goto, 2016).

Dwarf minke whale

Distribution of dwarf minke whale was limited within the research area. There were two separate areas of distribution between 120°E and 147°E, and between 165°E and 170°W in the northern stratum (mainly between 48°S and 63°S), south of Australia and New Zealand (Figs. 5b, 6a and 7a). The dwarf minke whale has a white band on the flipper that distinguishes it from the Antarctic minke whale, but it was only recently identified as separate from Antarctic minke whales (Best, 1985; Rice, 1998; Pastene *et al.*, 2010). Based on previous 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) (Branch and Butterworth, 2001). Based on this, no formal analysis has been conducted but it is probable that less than 0.2% of the minke whales south of 60°S are dwarf minke whales. In this study, only 0.129 % (85 out of 66,031) of the identified sightings were dwarf minke whales south of 60°S. Kato *et al.* (in press) further examined this aspect by a more extended data set.

Humpback whale

The humpback whale held 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. Humpbacks were widely distributed in the research area in both northern and southern strata. They were rarely found within Prydz Bay and no sightings occurred south of 73°S in the Ross Sea. This is a very curious difference in their distribution compared to blue whales and Antarctic minke whales. The current distribution map of this species suggests that humpback whales are encountered more frequently in the sector 80°E–110°E from the ice-edge to 60°S because of its high productivity (Figs. 5b and 6a). A high density area was observed in the north between 58°S and 65°S (Fig. 7a). In the 80°E–110°E sector, large scale distribution changes and a “Shift in baleen whale dominance” from Antarctic minke to humpback whales was observed between 85°E and 110°E (Matsuoka *et al.*, 2011; Matsuoka and Hakamada, 2014; Murase *et al.*, 2014; Hakamada and Matsuoka, 2014b). The DIW of this species was 5.315 for the whole survey period. Indices increased from December to February and decreased in March (Fig. 9).

There have been a couple of genetic studies reporting some population structure of humpback whales in the Antarctic (Pastene *et al.*, 2019), which suggested the core distribution areas for each of the ‘D: western Australia stock’ and ‘E1: eastern Australia stock’ and possible mixing areas around 130°E.

IDCR/SOWER circumpolar cruises encountered humpback whales more frequently in the sectors 20°E–40°E, 80°E–100°E and 150°E–180° (Branch, 2011). It has been suggested that such changes are related to changing oceanographic and krill environment conditions such as the effect of regime shift in global sea-surface temperatures in relation to El Nino-southern oscillation events (Watanabe *et al.*, 2014; Naganobu *et al.*, 2014). This suggestion should be further investigated in the future.

Southern right whale

A total of 235 schools (298 individuals), including six calves, were sighted (Table 2). Distribution area of this species was limited at certain longitudes of the sector 80°E–135°E, south of Western

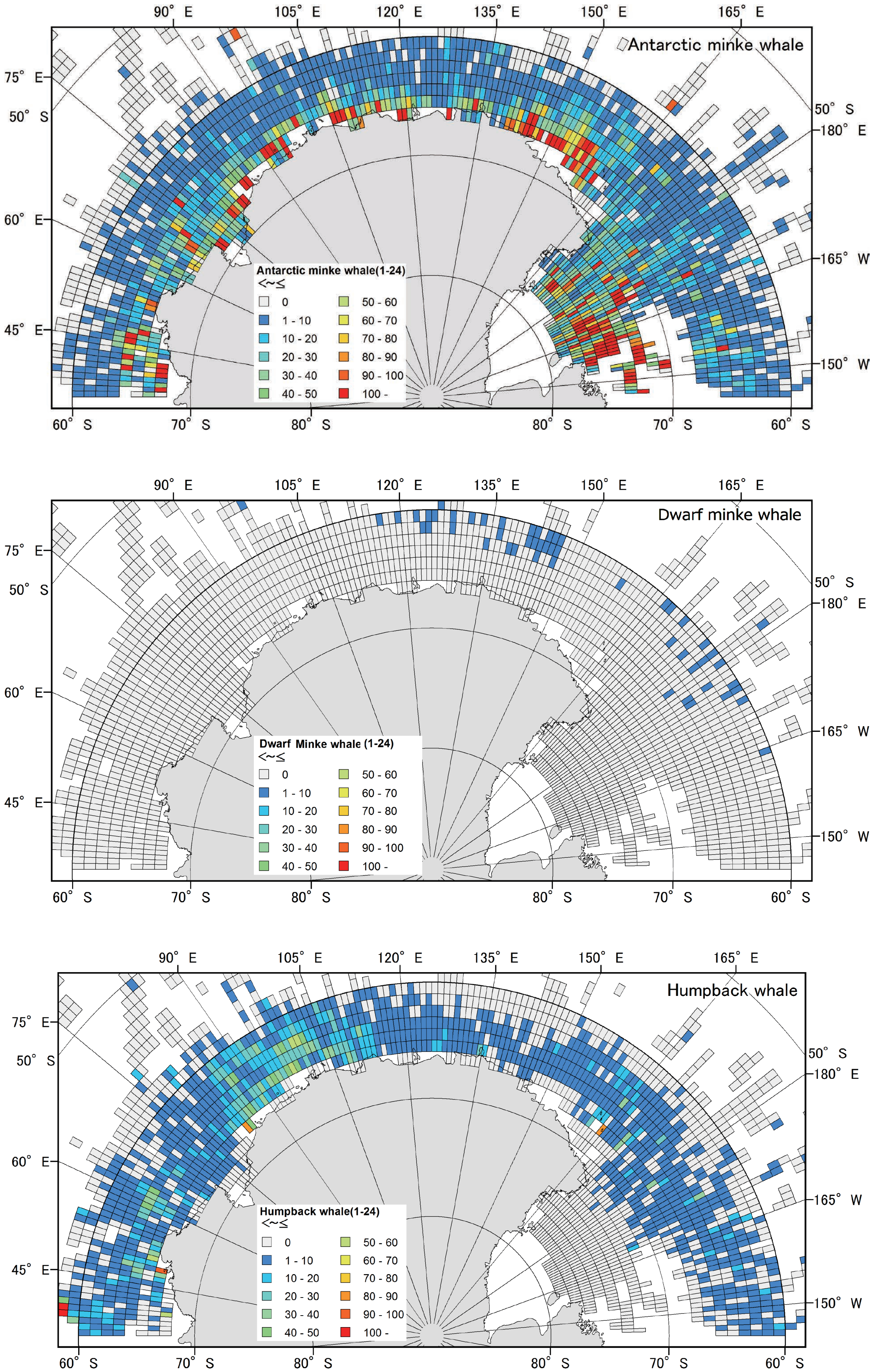

Fig. 5b. DIW of Antarctic minke, dwarf minke and humpback whales in the Indo-Pacific region of the Antarctic, based on one degree squares (whole research period).

Australia (Figs. 5c and 6a). Sighting rate of mother and calf pairs was 2.54% (6 out of 235 schools) which is highest number compared to other baleen whale species in the Antarctic. Southern right whales tended to be distributed more northerly between 40°S and 45°S and more southerly between 62°S and 65°S (Fig. 7a).

The DIW of this species was 0.084 for the whole survey period. Indices increased from December to March (Fig. 9). In summer, southern right whales migrate south, but generally not as far south as other baleen whale species. Southern right whales 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 these animals much further south, for example, around 60°S−65°S, south of Australia (Bannister *et al.*, 1999; 2008). 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), based on JARPAII data for the 2007/08 season (Matsuoka and Hakamada, 2014). This indicates that southern right whales migrate and make the Antarctic region an important feeding ground in the Austral summer.

Sperm whale

The sperm whale held 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). Of these sightings, most were single large males (96.5%) and, consequently, the observed mean school size was 1.03. Sperm whales were widely distributed in the research area with high density values being recorded between 35°E and 100°E and between 170°E and 170°W, in the mouth of the Ross Sea (Figs. 5c and 6b). These whales tended to be concentrated on the Antarctic continental slope, on the southern Kerguelen Plateau, and around the mouth of the Ross Sea, where the depth was usually between 1,000 and 4,000 m. This species was rarely found within Prydz Bay or in the Ross Sea (Fig. 5c). Latitudinally, sperm whales tended to be distributed between 40°S and 45°S and between 61°S and 73°S (Fig. 7b). There were no sightings south of 74°S in the Ross Sea. In this study, no formal analysis has been conducted but it is probable that the trend of DIW was stable (Fig. 8). The DIW of this species was 1.081 for the whole research period. The indices decreased from December to March (Fig. 9).

Southern bottlenose whales

The southern bottlenose whale was ranked 7th 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). These whales were widely distributed in the research area but were rarely sighted within Prydz Bay and in the Ross Sea. High density values of this whale were observed between 35°E and 70°E (Figs. 5c and 6b). Southern bottlenose whales were latitudinally distributed between 47°S and 70°S (Fig. 7b). Observed mean school size was 1.83 individuals. The DIW of this species was 0.862 for the whole survey period. Indices decreased from December to March (Fig. 9).

Unidentified beaked whales

Unidentified beaked whales held 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 but confirmed as beaked whales. These ‘unidentified beaked whales’ possibly included the southern bottlenose whale (*Hyperoodon planifrons*), Arnoux’s beaked whale (*Berardius arnuxii*), strap-toothed whale (*Mesoplodon layardii*), Grey’s beaked whale (*M. grayi*) and Cuvier’s beaked whale (*Ziphius cavirostris*). The distribution pattern of the unidentified beaked whales was consistent with that of southern bottlenose whales (Fig. 5d).

Killer whale

Killer whales held the 2nd rank among the ten species sighted in the research area. A total of 1,472

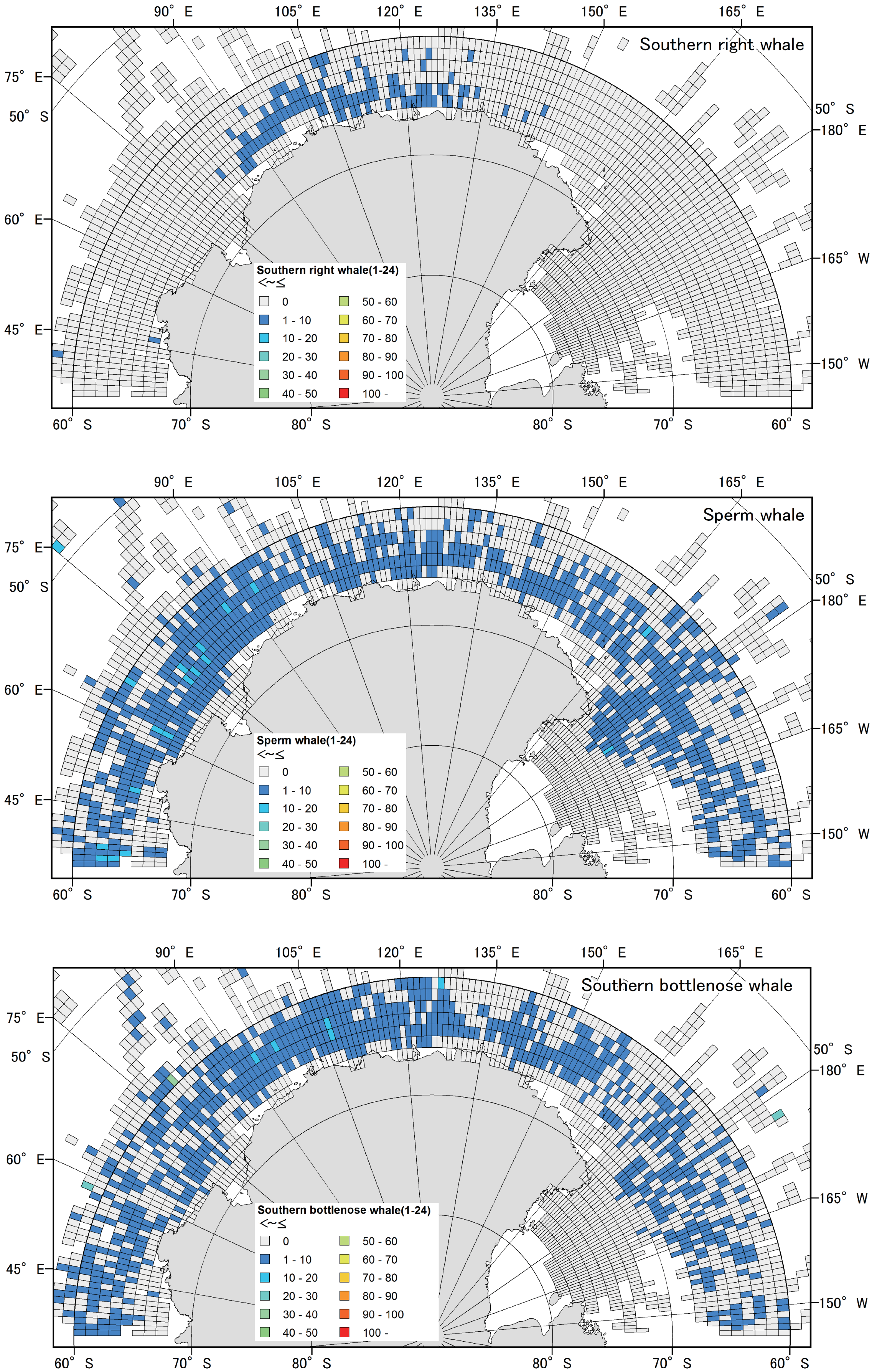

Fig. 5c. DIW of southern right, sperm and southern bottlenose whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

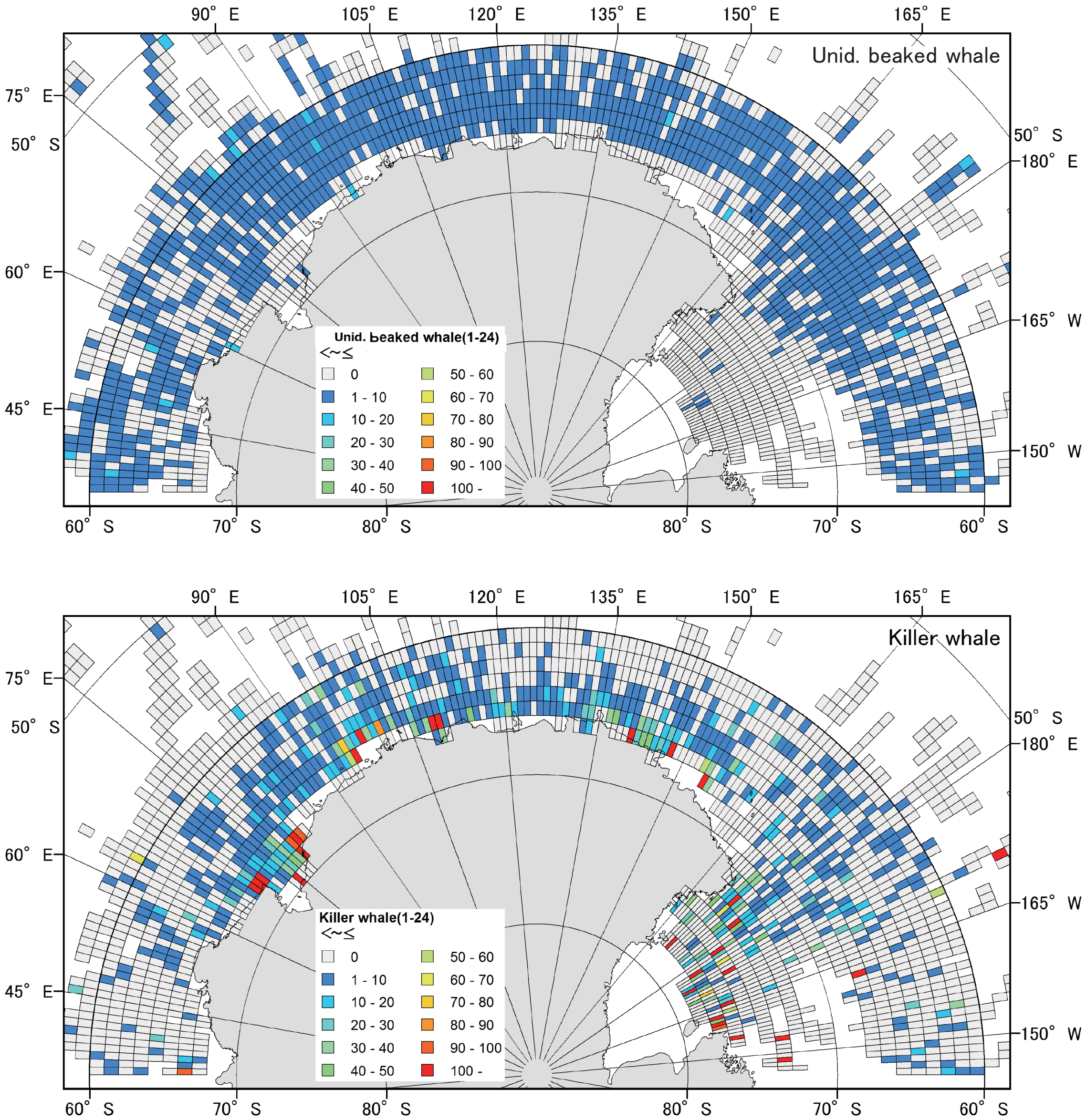

Fig. 5d. DIW of unidentified beaked and killer whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

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 study period (Table 2). These whales were widely distributed in the research area longitudinally and latitudinally (Figs. 6b and 7b), and were more frequently sighted in the southern stratum. High density areas were observed near the ice-edge or within Prydz Bay and in the Ross Sea where the pack-ice had melted on the continental shelf slope in February (Figs. 5d, 6b, 7b and 9). Killer whale abundance in the Antarctic was estimated by Branch and Butterworth (2001), and appears to be far higher than in any other ocean in the world. In this study, no formal analysis has been conducted but it is probable that the trend of DIW was stable (Fig. 8). The large school size of killer whales considered to be fish eaters were often sighted in the Prydz Bay and the Ross Sea. Further analyses will be required to definitively identify the killer whale type (fish eater or marine mammal eater etc.) as part of ongoing Antarctic ecosystem research.

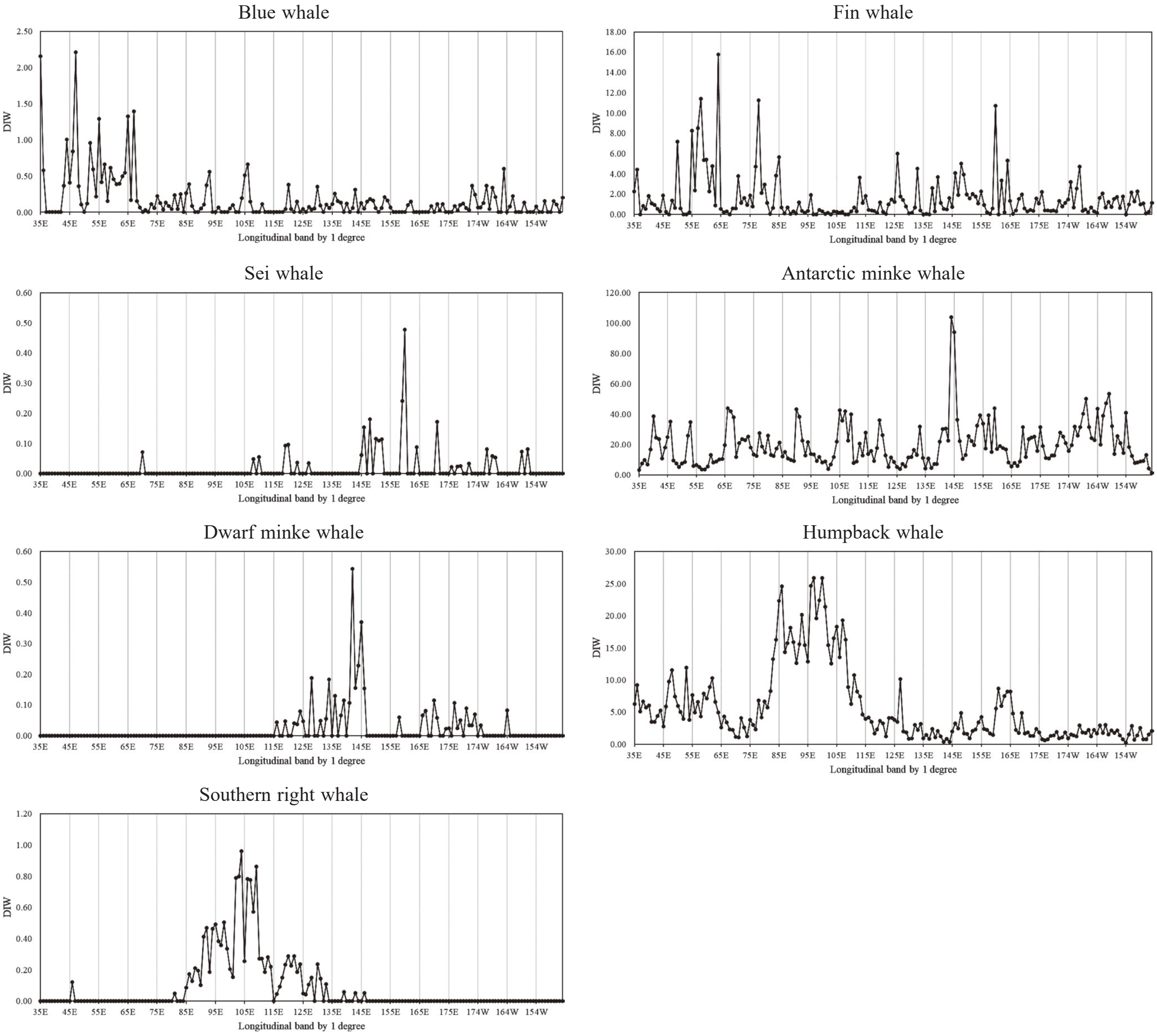

Fig. 6a. The longitudinal band of DIW for blue, fin, sei, Antarctic minke, dwarf minke, humpback and southern right whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

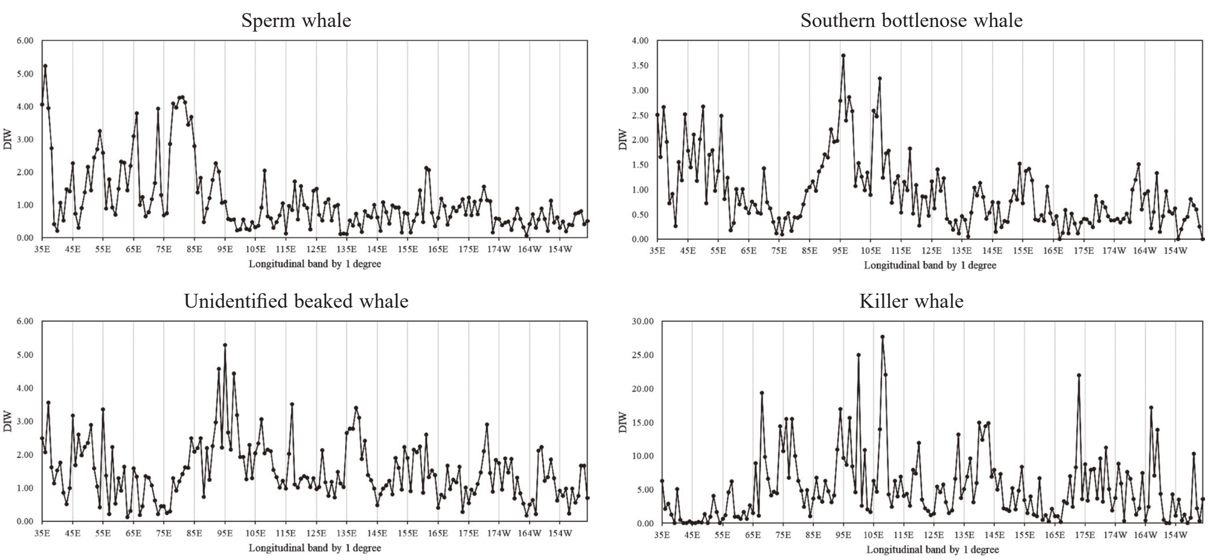

Fig. 6b. The longitudinal band of DIW for sperm, southern bottlenose, unidentified beaked and killer whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

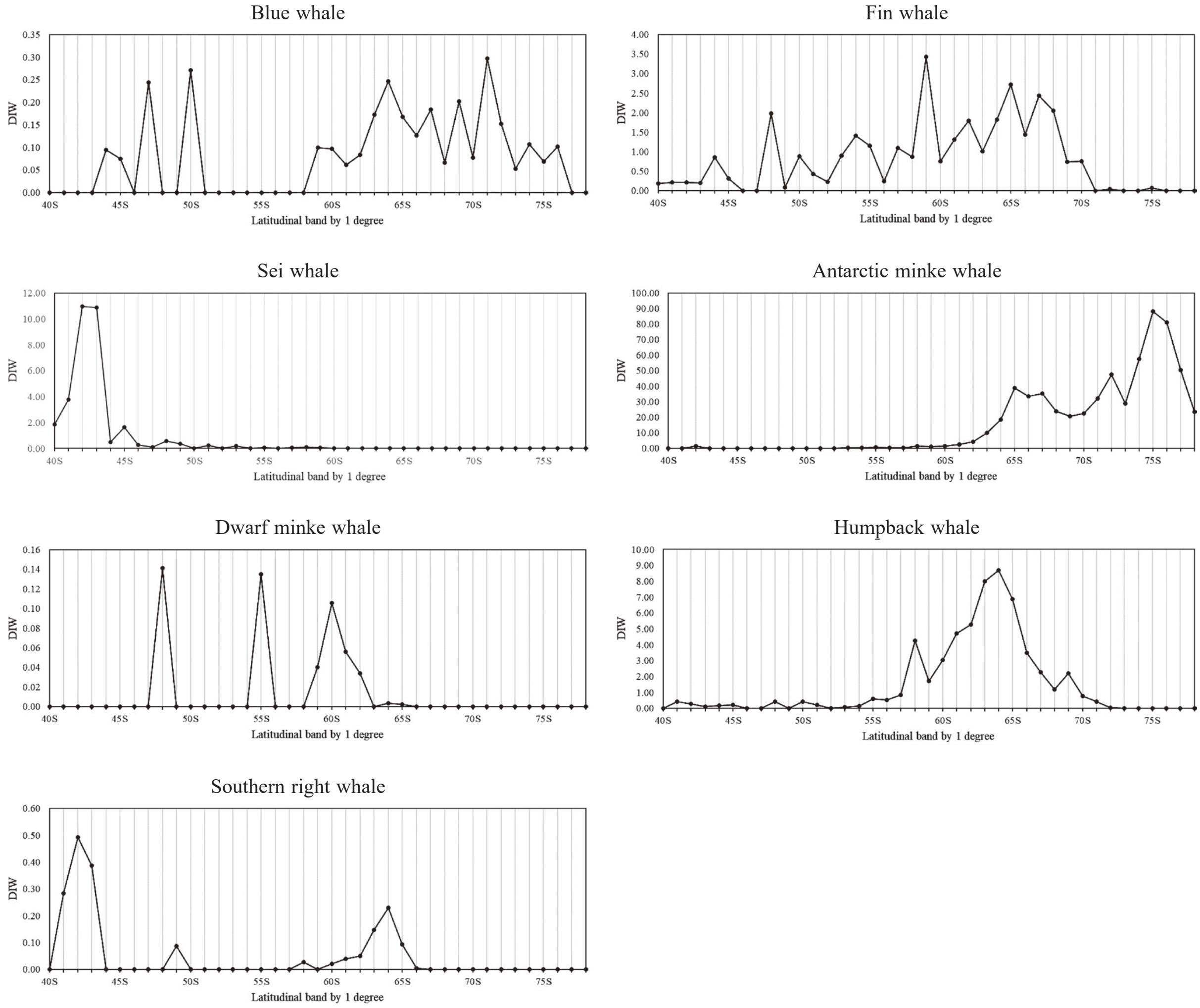

Fig. 7a. The latitudinal band of DIW for blue, fin, sei, Antarctic minke, dwarf minke, humpback and southern right whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

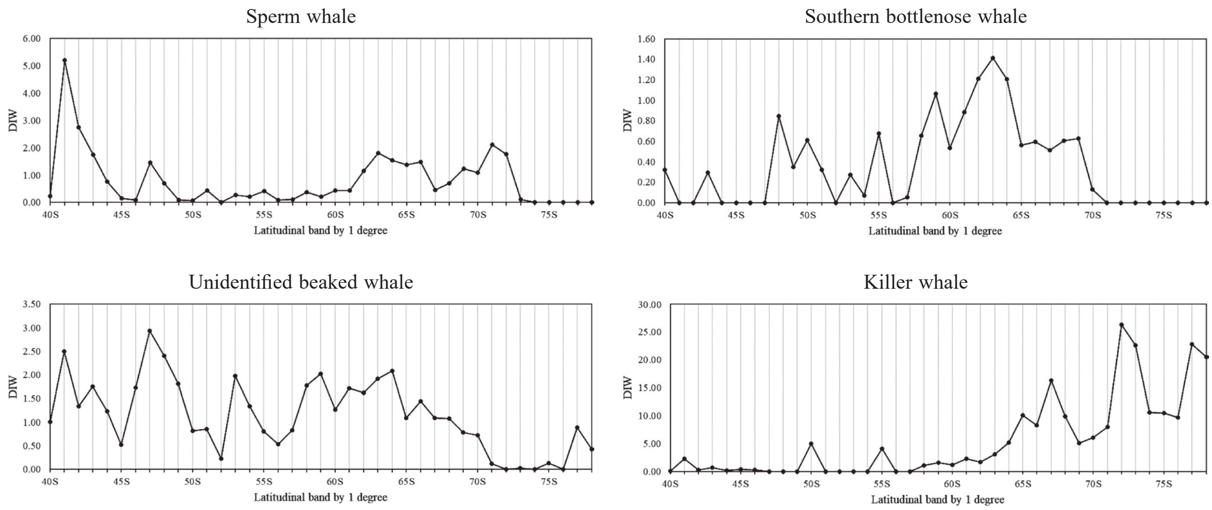

Fig. 7b. The latitudinal band of DIW for sperm, southern bottlenose, unidentified beaked and killer whales in the Indo-Pacific region of the Antarctic, based on Lat.1° × Long.1° squares (whole research period).

Fig. 8. Plot with time trends in DIW for each species and unidentified beaked whales in the Indo-Pacific region of the Antarctic (south of 60°S) during 1987/88 to 2008/09 seasons.

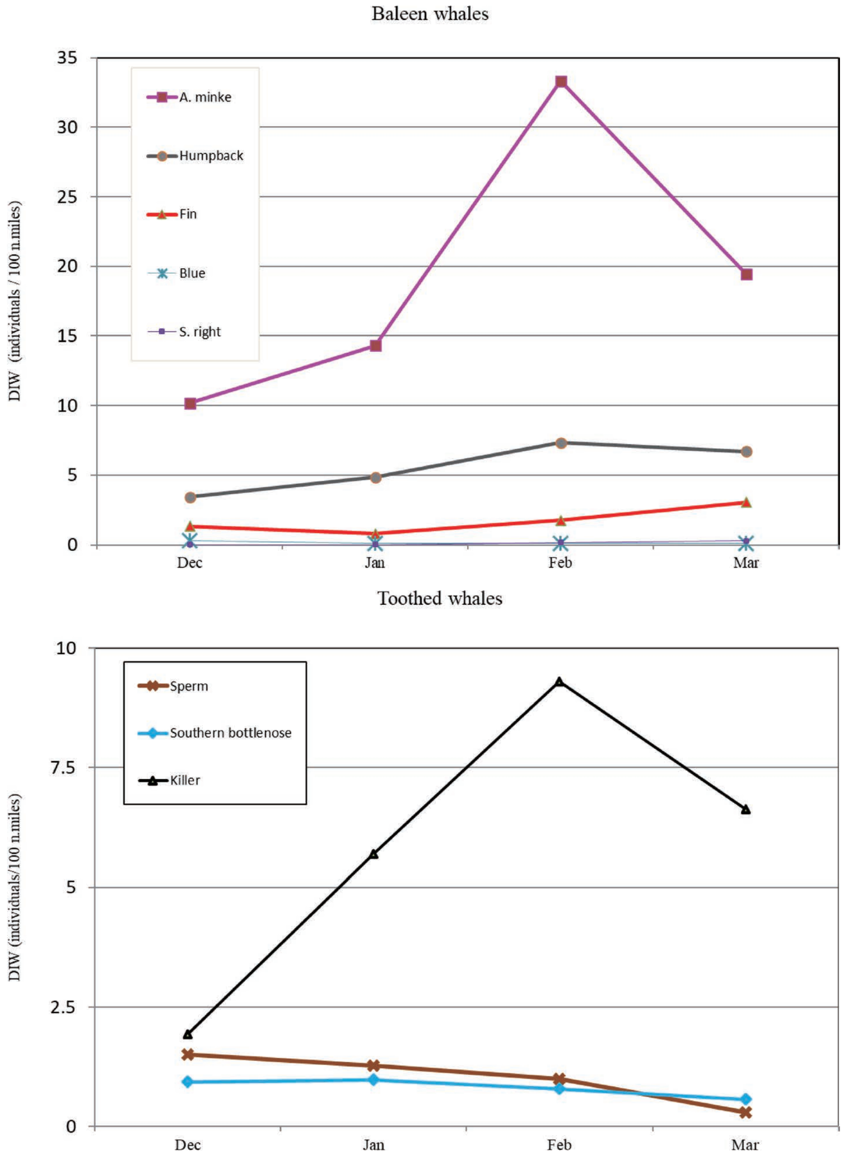

Fig. 9. Yearly trend in DIW for baleen (top) and toothed (bottom) whales in the the Indo-Pacific region of the Antarctic (south of 60°S) during 1987/88 to 2008/09 seasons.

Conclusions

Importance of monitoring whale populations

Most large whales were heavily exploited during the past century and most of the stocks in the Southern Hemisphere were substantially depleted. In the Antarctic Ocean, catches of southern right, humpback, blue, fin and sei whales were prohibited in 1932, 1963, 1964, 1976 and 1978, respectively. Eighty years have passed since the southern right whale has been protected, and more than 50 years have passed since the humpback whale and blue whale have been protected. In the coastal waters of South America, South Africa and along the east and west coasts of Australia, significant recovery of southern right whales and humpback whales in these breeding areas has been recently reported. On the other hand, the information on the present status of pelagic species, such as blue, fin and sei whales was limited. The IWC/IDCR-SOWER cruises have covered the same area every year for 6 years however this is insufficient for monitoring the ecosystem. On the other hand, JARPA and JARPAII have been monitoring baleen whale species populations by large-scale and long-term line transect surveys for over 30 years in Areas IV and V. However, the survey years is still not enough to detect precise yearly trends for whale populations. For this reason, the JASS-A (Japanese Abundance and Stock structure Surveys in the Antarctic) was started from the 2019/2020 season as a successor to the Japanese Antarctic survey programs such as JARPAII and NEWREP-A (New Scientific Whale Research Program in the Antarctic Ocean), in order to continue to provide additional information about the recovery of whale stocks (Government of Japan, 2019).

Relationship between distribution and oceanographic conditions

There was a common pattern for several whale species to concentrate mainly in the sector 80°E–110°E, south of 60°S. This area is characterised 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 seems to be caused by large-scale upwelling with nutritious bottom waters, resulting from the bottom shape of the southern Kerguelen Plateau (Watanabe *et al.*, 2014; Naganobu *et al.*, 2014). The BROKE Australian Antarctic survey previously indicated the possibility 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). Humpback, southern right, large male sperm and southern bottlenose whales used this longitudinal section between 80°E and 100°E as their key feeding area from December to March. It is necessary to further investigate the relationship between whale distribution and oceanographic condition shifts such as the effect of regime shift in 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).

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Photo 1. Two surfacing Antarctic blue whales during biopsy experiment in the Antarctic.

Photo 2. Five fin whales surfacing in the Antarctic.

Photo 3. Surfacing sei whale.

Photo 4. Seven Antarctic minke whales surfacing near pack-ice.

Photo 5. Surfaced humpback whale in the Antarctic.

Photo 6. Surfacing southern right whale during biopsy experiment in the Antarctic.

Photo 7. Surfacing sperm whales near pack-ice in the Antarctic.

Photo 8. Surfacing southern bottlenose whales in the Antarctic.

Photo 9. Killer whales in the Antarctic.