Estimates of abundance and abundance trend of the sperm, southern bottlenose and killer whales in Areas IIIE-VIW, south of 60ºS, based on JARPA and JARPAII sighting data (1989/90-2008/09)

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ABSTRACT
This paper estimated abundance and annual abundance trends of sperm (*Physeter macrocephalus*), southern bottlenose (*Hyperoodon planifrons*) and killer whales (*Orcinus orca*) south of 60°S based on sighting data collected by JARPA and JARPA II (1989/90 - 2008/09). The estimates are calculated by standard line transect analysis methods using the program DISTANCE under the assumption that $g(0)=1$. Abundance and abundance trends of the species in the survey area was provided.

		Minimum		Maximum		Abundance trend		
Species	Area	Estimate	CV	Estimate	CV	Estimate	95%CILL	95%CIUL
Sperm	IIIE	1,181	0.197	2,309	0.199	0.021	-0.041	0.082
	IV	1,358	0.192	4,106	0.255	-0.024	-0.062	0.013
	V	597	0.509	2,185	0.254	-0.039	-0.082	0.005
	VIW	101	1.008	736	0.214	0.066	-0.090	0.223
S.bottle - nose	IIIE	866	0.569	7,364	0.383	-0.018	-0.225	0.190
	IV	1,082	0.266	11,828	0.266	0.104	0.030	0.179
	V	893	0.447	6,729	0.269	0.077	0.013	0.142
	VIW	908	0.396	2,681	0.233	0.009	-0.099	0.117
Killer	IIIE	524	1.036	6,300	1.157	0.084	-0.096	0.264
	IV	2,268	0.489	14,374	0.185	-0.021	-0.087	0.044
	V	7,185	0.356	18,867	0.277	-0.011	-0.048	0.026
	VIW	943	0.593	4,066	0.350	0.043	-0.120	0.206

This paper provides, for the first time, abundance trend for these three toothed whale species in a large sector of the Antarctic.

KEYWORDS: ABUNDANCE ESTIMATE, ANTARTIC, SPERM WHALE, SOUTHERN BOTTLENOSE WHALE, KILLER WHALE, SURVEY-VESSEL, TRENDS

INTRODUCTION

Since the start of modern commercial whaling in the Antarctic in 1904, substantial information has been gathered on the commercially valuable large baleen whales (Mackintosh, 1965), but the abundance and distribution of Antarctic Odontocetes other than the sperm whale (*Physeter macrocephalus*) have remained largely unassessed (Klinowska, 1991). The only toothed whale taken regularly was the sperm whale, and southern bottlenose (*Hyperoodon planifrons*) and killer whales (*Orcinus orca*) were pursued irregularly and in small numbers only (Mitchell, 1975; Kock and Shimadzu, 1994). Whaling of sperm whales in the Antarctic was banned in the 1979/80 season.

Kasamatsu and Joyce (1995) investigated the distribution pattern, abundance and $g(0)$ estimates of Odontocetes in Antarctic waters using data gathered during Japanese sighting surveys and during the International Decade of Cetacean Research (IDCR) organised by the International Whaling Commission

Scientific Committee (IWC SC) (Matsuoka *et al*., 2003). Data used by Kasamatsu and Joyce (1995) were from surveys conducted from 1976/77 to 1987/88.

IDCR and Southern Ocean Whale and Ecosystem Research (SOWER) surveys organised by the IWC SC had been conducted from 1978/79 to 2009/10 (Matsuoka *et al*., 2003). Based on sighting data collected during these surveys, the abundance for sperm, southern bottlenose, and killer whales was estimated in the first circumpolar (CPI) (1978/79-1983/84), second (CPII) (1985/86-1990/91) and uncompleted third (CPIII) (1992/93-1998/99) series in the area south of 60°S (Branch and Butterworth, 2001b).

Another source of sighting information comes from surveys conducted by the Japanese Whale Research Program under Special Program in the Antarctic (JARPA and JARPAII). Abundance estimates of sperm whales and beaked whales based on JARPA data were presented by Matsuoka *et al*. (1998; 2005). Distribution pattern of beaked whales were examined using 1987/88-92/93 JARPA sighting data (Ohsumi *et al*., 1994).

Information on the current status of toothed whales is important because they are placed in the highest trophic level in the Antarctic marine ecosystem (Kasamatsu and Joyce, 1995). This paper examined abundance and abundance trends of sperm, southern bottlenose, and killer whales based on JARPA and JARPAII sighting obtained in the period data for 1989/90-2008/09.

MATERIALS AND METHODS

Sighting survey procedure during JARPA II

Survey area and geographical stratification

The main region for full scale research was Antarctic Areas IIIE, IV and V (35°E - 175°E) and Area V and VIW (130°E - 145°W) south of 60°S; each of these Areas was divided into smaller strata. Distributions of primary sightings of minke whales and of efforts in Areas IIIE, IV, V and VIW for each year are shown in Figures 1a-1d.

Monthly coverage

JARPA II research period ranged from the end of December to March in each year; regular research in Areas IV and V was concentrated in January and February in most years, which coincided with the peak period for migration of minke whales to their Antarctic feeding grounds (Kasamatsu *et al*., 1996).

Trackline design

The trackline was designed to cover the whole research area and was followed consistently throughout the JARPA surveys (Figures 1a-1d). The starting points of the trackline were selected at random from 1 n.mile intervals on lines of longitude. Trackline way points (where the trackline changes direction) were systematically allocated on the ice edge and on the locus of points 45 n.miles from that edge in southern strata, and on this locus and the 60°S latitude line in the northern strata. There were two modifications in trackline design in JARPA II surveys considering the recommendations at the JARPA review meeting (IWC, 2008) to improve abundance estimation. One was that the saw-tooth type trackline for the southern strata was chosen to allow for wide area coverage in JARPA but was not chosen in JARPA II. Another is that northern and southern strata were surveyed in the same period (Nishiwaki *et al*., 2014) to avoid temporal gaps that occurred in the survey period of southern and northern strata during JARPA II period.

Sampling and Sighting Vessels (SSVs) and Sighting Vessels (SVs)

JARPA and JARPA II were comprised of a combination of sighting and sampling surveys. Researchers searched for schools until a school was detected, and then proceeded to confirm its species and school size. The procedure they use is identical to that of a SV in closing mode (Nishiwaki *et al*., 2006), except that once this confirmation has been achieved SSVs attempt to catch minke whales targeted within the school in terms of specified procedures (Nishiwaki *et al*., 2006). In the JARPAII period, SSVs covered south of 62°S whereas SVs covered south of 60°S. Therefore sighting data obtained by SSVs was not used for abundance estimation in the period of JARPA II.

Closing and passing mode

Fundamentally, the survey protocols of JARPA and JARPA II follow those of IDCR (Nishiwaki *et al*., 2006, 2014). A SV surveyed in passing mode (SVP) for the first 8 hours of the day and in closing mode (SVC) during the rest of the day. Therefore, the allocation of effort between passing mode and closing mode was systematic. In this analysis, the sighting data for SSV, SVC and SVP was grouped since it had a smaller number of sightings available for the species examined than Antarctic minke whales.

Sighting surveys in 2009/10 and 2010/11
Due to violent action by an anti-whaling non governmental organisation in the research area, the SVs and SSVs could not carry out the research on the planed track line in Area III East (35°E - 70°E), a part of Area IV (90°E - 130°E) and a part of Area V West (130°E - 132°E) in 2009/10 (Nishiwaki *et al*., 2010). Due to violent action by an anti-whaling non governmental organisation in the research area, a sighting survey by SV was not conducted in 2010/11 (IWC, 2012). Therefore, abundance estimates in those years could not be estimated.

Analytical procedure

*Correction of the estimated angle and distanc*e
To be able to correct for biases in angle and distance observations, experiments using a radar reflecting buoy were conducted by each vessel during each cruise (the experimental methodology is described in Nishiwaki *et al*., 2006). Based on the data obtained, biases were estimated for each platform for each cruise. Linear regression models were used to examine possible differences between observed and true (obtained from radar) distances. In order to correct for such biases, the estimated distance was divided by the estimated slope of a regression through the origin if this slope differed significantly from 1 at the 5% level. The estimated factors in 1989/90 -2008/09 seasons are shown in Table 1. A similar approach was used for angles. More details of the methodology may be found in Branch and Butterworth (2001a).

Truncation distance
The conventional truncation distance for perpendicular distances of sightings that is used for Antarctic minke whales is 1.5 n.miles (Branch and Butterworth, 2001a; Hakamada *et al*., in press). However, because of their larger bodies and blow sizes, sperm whales can be seen much further from vessels than Antarctic minke whales. The rule of thumb advocated in Buckland *et al*. (2001), of truncating to exclude about 5% of the data, is therefore applied as in Branch and Butterworth (2001b). Accordingly the perpendicular distance distributions were truncated at 3.0 n. miles for sperm whales, and 2.0 n. miles for southern bottlenose and killer whales.

Smearing parameters
Smearing parameters were calculated for each cruise to make allowance for errors in estimates of distances and angles. The method used is the same in Branch and Butterworth (2001b). The sightings data is smeared before their truncation to give n, and then used in the estimation of the effective search half-width (esw) and the mean school size ($E(s)$) for input into equation (1). Radial distance and angle data were smeared in the conventional manner by using Method II of Buckland and Anganuzzi (1988) and then grouped into intervals of 0.3 n. miles (sperm whale) and 0.2 n. miles (southern bottlenose and killer whales) for estimating esw values. For Antarctic minke whales, smearing parameters are conventionally estimated separately for each stratum from the data. (Branch and Butterworth 2001a; Hakamada *et al*., in press) However, due to the lower number of sightings of these whales, pooling was necessary here to obtain robust estimates from the Buckland and Anganuzzi method. The smearing parameter values reported in Table 2 were thus obtained for each species during JARPA and JARPA II cruises.

Abundance estimation
The methodology for abundance estimation used in this study is described by Branch and Butterworth (2001a, 2001b), and has been termed the "standard methodology" in the IWC-SC. The program DISTANCE ver6.0 (Thomas *et al*., 2010) was used to provide abundance estimates. The following equation was used for abundance estimation in each stratum:

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

where
P is the abundance in numbers as estimated,
A is the open ocean area of the stratum,
E(s) is the estimated mean school size,
n is the number of primary sightings of schools,
w is the effective search half-width (esw) for schools and
L is the primary search effort.

In order to estimate esw for each species, hazard-rate model was used. Only primary sightings made during closing mode for schools with a confirmed size are used to estimate mean school size for each species. Regression method in Buckland *et al* (1993; 2001) was applied to estimate mean school size.

Abundance trend estimation
Regression model was applied to estimate abundance trend as follows;

$$\log(P_y) = a + by \qquad (2)$$

where
P_y is the abundance estimate in year *y*.
a is intercept,
b is abundance trend estimate.

RESULTS AND DISCUSSIONS

Primary search distance and
Search effort for each stratum, size of survey area and the numbers of primary sightings (after truncation and smearing) for sperm, southern bottlenose and killer whales were shown in Table 3. These statistics were used for abundance estimates for each Management Area.

Effective half search width and mean school size
Table 4 shows esw and mean school size estimate. Figure 2 shows the detection probability functions in relation to perpendicular distance from the trackline in nautical miles that were used for the analyses for each species. The figure suggests the model seemed fit the data. School size of sperm whales is nearly 1 whereas that of killer whales and its CV is larger than other whales examined in this paper. Most sperm whales detected were solitary schools during JARPA and JARPA II surveys.

Abundance estimate
Sperm whale
Table 5 shows abundance estimates for sperm whale in each Area. Abundance estimates for Area IIIE range from 1,181 (CV=0.197) in 1995/96 to 2,309 (CV=0.199) in 2001/02. Those for Area IV range from 1,358 (CV=0.192) in 2003/04 to 4,106 (CV = 0.255) in 1989/90.Those for Area V range from 597 (CV= 0.509) in 2006/07 to 2,185 (CV=0.254) in 1990/91. Those for Area VIW range from 101 (CV=1.008) in 1998/99 to 737 (CV=0.214) in 2004/05. Given the diving behavior of sperm whales, *g*(0) is considered to be much smaller than 1 for this species. Therefore the assumption of *g*(0)=1 would cause an underestimate of the abundance estimates. Kasamatsu and Joyce (1995) estimated *g*(0) for sperm whales, as 0.32 (CV=0.11). Correcting abundance estimates in Table 5 by this *g*(0) estimates are shown in Table 6. Further investigation of *g*(0) for this species would improve the abundance estimate.

Southern bottlenose whale
Table 5 shows abundance estimates for southern bottlenose whales in each Area. Abundance estimates for Area IIIE range from 866 (CV= 0.569) in 2005/06 to 7,364 (CV=0.383) in 1999/00.Those for. Area IV

range from 1,082 (CV=0.266) in 1991/92 to 11,828 (CV = 0.266) in 2005/06. Those for Area V range from 893 (CV= 0.447) in 1992/93 to 6,729 (CV=0.269) in 2002/03. Those for Area VIW range from 908 (CV=0.396) in 2000/01 to 2,681 (CV=0.233) in 2002/03. Given the diving behavior of southern bottlenose whales, *g*(0) is considered to be much smaller than 1 for this species. Therefore the assumption of *g*(0)=1 would cause an underestimate of the abundance estimates. Kasamatsu and Joyce (1995) estimated *g*(0) for beaked whales as 0.27 (CV=0.04). Correcting abundance estimates in Table 5 by this *g*(0) estimates are shown in Table 6. Further investigation of *g*(0) estimate would improve the abundance estimate.

Killer whale
Table 5 shows abundance estimates for killer whales in each Area. Abundance estimates for Area IIIE range from 524 (CV=1.036) in 2001/02 to 6,300 (CV=1.157) in 2005/06. Those for Area IV range from 2,268 (CV=0.489) in 2007/08 to 14,374 (CV = 0.185) in 2003/04. Those for Area V range from 7,185 (CV= 0.356) in 2006/07 to 18,867 (CV=0.277) in 2004/05. Those for Area VIW range from 943 (CV=0.593) in 1996/97 to 4,066 (CV=0.350) in 2002/03. Abundance estimates fluctuated among the years in each Area during the JARPA and JARPA II period more than those for other species examined (Table 5). One possible reason for this is the possible occurrence of different stocks which distribute and mix with each other in different proportions in different years (Kasamatsu, 1993; Kasamatsu and Joyce, 1995). Given the mean school size estimate is large for this species (Table 4), it can be considered that extent of bias in abundance estimate due to the assumption that *g*(0)=1 is small.

Abundance trend estimate
Sperm whale
Abundance trend estimate and their 95% confidence interval (95% CI) are shown in Table 7. The estimate for sperm whales are 2.1% (95% CI = -4.1- 8.2%), -2.4% (95% CI = -6.2 - 1.3%), -3.9% (95% CI = -8.2%-0.5%) and 6.6% (95% CI = -9.0 - 22.3%), in Areas IIIE, IV, V and VI, respectively. They were not statistically significant. Most of the sighting of this species during JARPA and JARPAII were solitary large male animals. This is the case for IDCR-SOWER (Branch and Butterworth, 2001b). This is because sperm whales are latitudinally segregated by size and sex, with females rarely found south of 40^{o}S, and male school size decreasing southwards (Best, 1979). Therefore, abundance estimates and trend estimates in this study should not necessary be considered as estimates for the whole population.

Southern bottlenose whale
The estimate for southern bottlenose whales are -1.8% (95% CI = -22.5 -19.0%), 10.4% (95% CI =3.0 -17.9%), 7.7% (95% CI = 1.3 -14.2%) and 0.9% (95% CI = -9.7-11.7%) in Areas IIIE, IV, V and VI, respectively (Table 7). The increasing trend in Areas IV and V were statistically significant. Given that the number of historical catches of southern bottle nose whales was small, the population of this species could be near to carrying capacity assuming that carrying capacity is constant. If so, abundance would not be increasing substantially. Based on the composition of confirmed species identification, the majority (93%) of the *Ziphiidae* observed in Antarctic waters was southern bottlenose whales (Kasamatsu *et al.* 1988). Distribution pattern of southern bottlenose whales was consistent with that of unidentified beaked whales (Matsuoka *et al*., 1998). One possible reason for this is because proportion of southern bottlenose whales which were identified as *Ziphiidae* could be decreasing. Abundance estimation using sighting data for beaked whale and southern bottle nose whales combined can address this.

Killer whale
The estimate for killer whales are 8.4% (95% CI = -9.6-26.4%), -2.1% (95% CI = -8.7-4.4%), -1.1% (95% CI = -4.8%-2.6%) and 4.3% (95% CI = -12.0%-20.6%) in Areas IIIE, IV, V and VI, respectively (Table 7). These estimates were not statistically significant. If further sighting data for this species become available, precision of abundance estimate in Areas IIIE and VIW would be improved.

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Table 1. Estimated observer bias (expressed as multiplicative correction factors) in distance and angle estimation for JARPA surveys from 1989/90 to 2008/09. 'n.s' indicates no significant at 5% level.

Year	Vessel	Platform			
		Barrel		Upper bridge	
		Distance	Angle	Distance	Angle
1989/90	K01	n.s.	0.930	n.s.	0.872
	T18	n.s.	1.047	n.s.	n.s.
	T25	1.099	n.s.	1.075	n.s.
1990/91	K01	n.s.	1.051	0.953	1.064
	T18	n.s.	n.s.	n.s.	n.s.
	T25	0.882	n.s.	0.961	n.s.
1991/92	K01	0.930	n.s.	n.s.	0.950
	T18	n.s.	n.s.	0.960	n.s.
	T25	n.s.	n.s.	1.070	n.s.
1992/93	K01	n.s.	0.942	1.083	0.941
	T18	n.s.	n.s.	n.s.	n.s.
	T25	n.s.	1.056	n.s.	1.082
1993/94	K01	0.863	n.s.	n.s.	n.s.
	T18	n.s.	n.s.	n.s.	n.s.
	T25	n.s.	n.s.	n.s.	1.057
1994/95	K01	n.s.	n.s.	n.s.	0.933
	T18	n.s.	n.s.	0.934	n.s.
	T25	0.940	n.s.	0.902	n.s.
1995/96	K01	n.s.	n.s.	n.s.	n.s.
	T18	n.s.	n.s.	1.110	0.956
	T25	0.889	n.s.	0.905	1.040
	KS2	n.s.	0.905	n.s.	0.898
1996/97	K01	0.822	n.s.	0.844	n.s.
	T18	0.711	n.s.	n.s.	n.s.
	T25	0.799	n.s.	0.773	1.036
	KS2	0.789	0.951	0.662	1.050
1997/98	K01	0.842	n.s.	0.746	n.s.
	T18	0.902	n.s.	0.788	n.s.
	T25	0.729	n.s.	0.914	n.s.
	KS2	0.876	n.s.	0.788	n.s.
1998/99	K01	0.902	n.s.	0.956	1.057
	T25	n.s.	1.053	n.s.	1.065
	YS1	0.923	n.s.	0.968	n.s.
	KS2	0.928	0.950	n.s.	n.s.
1999/2000	K01	n.s.	n.s.	1.050	n.s.
	T25	n.s.	1.081	n.s.	n.s.
	YS1	n.s.	n.s.	n.s.	n.s.
	KS2	n.s.	0.930	n.s.	n.s.
2000/2001	K01	n.s.	1.051	n.s.	n.s.
	T25	n.s.	n.s.	1.062	n.s.
	YS1	n.s.	n.s.	n.s.	n.s.
	KS2	n.s.	n.s.	n.s.	0.861
2001/2002	K01	0.957	0.921	0.957	n.s.
	T25	0.951	n.s.	0.960	n.s.
	YS1	n.s.	n.s.	n.s.	n.s.
	KS2	n.s.	n.s.	n.s.	n.s.
2002/2003	K01	1.073	n.s.	n.s.	n.s.
	YS1	1.051	1.037	1.058	0.938
	YS2	1.050	n.s.	n.s.	n.s.
	KS2	n.s.	n.s.	n.s.	1.088
2003/2004	K01	0.957	0.921	0.957	n.s.
	YS1	0.951	n.s.	0.960	n.s.
	YS2	n.s.	n.s.	n.s.	n.s.
	KS2	n.s.	n.s.	n.s.	n.s.
2004/2005	K01	1.113	1.096	1.044	n.s.
	YS1	1.029	0.939	1.024	0.919
	YS2	1.102	1.061	n.s.	n.s.
	KS2	1.084	0.966	1.064	n.s.
2005/06	KS2	1.043	0.914	n.s.	n.s.
	KK1	1.049	n.s.	n.s.	n.s.
2006/07	KS2	n.s.	n.s.	n.s.	n.s.
	KK1	n.s.	n.s.	n.s.	n.s.
2007/08	KS2	n.s.	0.961	n.s.	0.950
	KK1	n.s.	n.s.	0.839	n.s.
2008/09	KS2	n.s.	0.918	n.s.	n.s.
	KK1	1.055	0.963	n.s.	0.949

Table 2. Smearing parameters for each species. Units for angles are degrees, while for distances the values given are proportions.

Species	Angle	Distance
Sperm	9.461	0.216
S.bottlenose	11.330	0.201
Killer	10.280	0.248

Table 3. Statistics for strata for each Area during JARPA and JARPA II periods. The search effort (*L*), size of research area (*A*) and the number of primary sightings within the truncation distance after smearing for sperm, southern bottlenose and killer whales.

Area IV

Year	Stratum	*A*	*L*	Number of sightings		
		(n.miles^2)	(n.miles)	Sperm	S.Bottle	Killer
1989/90	NW	222,563	1987.6	77.0	2.0	6.8
	NE	219,245	1964.4	19.0	2.0	-
	SW	35,878	2518.3	37.7	6.0	9.0
	SE	41,143	1325.5	8.0	6.0	9.9
	PB	36,488	831.9	1.0	1.0	5.6
1991/92	NW	219,713	2482.7	63.2	3.0	6.0
	NE	216,299	2173.9	11.5	-	2.0
	SW	37,191	2237.5	81.5	8.0	10.4
	SE	39,732	2281.7	50.3	18.0	30.0
	PB	36,569	583	5.0	-	6.0
1993/94	NW	233,289	4160.7	88.3	27.0	10.3
	NE	148,982	3175.1	20.1	-	6.1
	SW	39,755	2377.7	72.0	32.9	9.0
	SE	41,353	2258.9	82.0	32.3	3.3
	PB	34,506	1077	-	-	8.1
1995/96	NW	149,107	3530.5	49.6	12.0	14.0
	NE	230,473	2979.7	8.1	31.0	13.6
	SW	89,826	2851.2	126.4	45.0	20.6
	SE	33,980	2039.9	27.9	8.6	19.3
	PB	25,970	1298.2	5.0	1.0	11.5
1997/98	NW	217,645	3367.2	90.1	64.4	12.6
	NE	219,602	3622.7	2.0	37.0	12.0
	SW	31,615	3432.5	46.3	24.0	13.6
	SE	34,374	3195.9	16.6	25.0	17.5
	PB	4,407	489.9	-	1.0	6.0
1999/00	NW	229,368	2825.3	74.5	39.8	10.0
	NE	226,272	3550.8	15.0	25.0	9.0
	SW	44,862	2336.7	15.9	5.0	23.8
	SE	34,175	2704.3	32.4	23.0	26.9
	PB	21,288	1244.7	1.0	2.0	17.8
2001/02	NW	222,450	3043.6	52.8	30.0	8.0
	NE	244,921	3271.6	38.9	24.0	9.1
	SW	32,199	2321.8	66.5	8.0	18.6
	SE	35,955	2885.2	29.5	5.0	18.7
	PB	28,472	1033.7	-	-	9.7
2003/04	NW	243,850	3236.6	31.4	22.0	10.5
	NE	218,072	3738.5	13.1	31.0	11.9
	SW	38,976	2275.2	20.6	10.8	35.4
	SE	38,952	3633.2	32.0	32.0	31.4
	PB	37,537	508.5	-	-	11.9
2005/06	NW	228,919	1131.4	11.8	14.0	1.0
	NE	213,660	1450.3	12.8	30.0	2.4
	SW	47,117	859.42	21.2	1.0	4.9
	SE	37,228	865.48	7.0	11.0	6.4
	PB	31,689	381.06	1.0	-	8.2
2007/08	NW	213,311	958.89	37.0	12.0	-
	NE	216,236	1332.4	5.0	9.0	0.5
	SW	39,787	847.54	24.2	4.0	5.5
	SE	36,277	819.76	-	6.0	2.0

Area V

Year	Stratum	*A*	*L*	Number of sightings		
		(n.miles^2)	(n.miles)	Sperm	S.Bottle	Killer
1990/91	NW	239,688	2726.8	4.9	5.0	2.0
	NE	348,822	2498.9	5.7	2.0	9.0
	SW	64,431	1635	33.1	3.0	2.0
	SE	188,136	1670	32.2	-	12.0
1992/93	NW	325,648	2294.2	4.0	2.0	1.0
	NE	348,822	1661.5	3.7	1.0	4.0
	SW	59,450	1907.4	14.1	3.0	23.9
	SE	210,194	2253.6	33.0	-	19.1
1994/95	NW	209,990	3229.4	4.8	14.0	6.0
	NE	348,822	2554.1	25.6	13.0	3.4
	SW	39,911	2469	58.1	26.0	6.8
	SE	173,180	1293	6.0	2.0	7.8
1996/97	NW	288,197	2784.6	7.0	12.0	7.0
	NE	337,779	3133.4	11.0	10.0	3.0
	SW	53,960	2995.3	62.4	19.0	14.8
	SE	187,983	2098.5	4.0	1.0	11.0
1998/99	NW	314,778	1830.6	21.0	5.0	3.0
	NE	327,490	1226.9	8.0	2.0	7.0
	SW	48,333	2206.5	11.0	5.0	19.8
	SE	25,709	1561	7.0	7.0	4.0
2000/01	NW	271,089	3595.5	9.0	23.0	4.8
	NE	348,535	3941.1	24.4	12.0	12.0
	SW	79,594	3152.9	7.0	17.0	19.8
	SE	148,828	2254.9	5.0	1.0	17.0
2002/03	NW	266,687	2735.7	1.9	18.0	7.0
	NE	345,003	5047	36.9	27.8	20.0
	SW	79,376	1458.3	8.0	11.0	10.4
	SE	69,872	1991.9	45.8	5.0	15.7
2004/05	NW	278,281	970	6.5	3.0	7.0
	NE	336,130	3230.8	23.7	20.0	5.7
	SW	51,373	856.7	-	1.0	14.3
	SE	212,181	8039.2	34.2	5.0	33.2
2006/07	NW	38,740	97.247	-	-	-
	NE	340,889	2107.7	9.6	18.5	3.0
	SW	9,260	136.24	1.0	-	1.0
	SE	139,575	2272.9	1.0	-	14.9
2008/09	NW	224,275	1144.7	-	6.0	1.0
	NE	324,889	1369.5	6.5	8.0	6.0
	SW	64,901	638.13	12.0	1.0	1.0
	SE	277,209	2757.8	6.0	1.0	2.6

Table 3 (Cont.).

Area IIIE

Year	Stratum	*A*	*L*	Number of sightings		
		(n.miles^2)	(n.miles)	Sperm	S.bottle	Killer
1995/96	IIIE	253,343	3442.5	45.2	13.0	6.0
1997/98	IIIE	250,985	4340.6	72.7	46.0	4.8
1999/00	IIIE	356,702	1578.4	22.6	21.4	3.0
2001/02	IIIE	355,124	2886.9	52.9	36.0	1.0
2003/04	IIIE	324,032	4869.1	92.7	38.8	7.6
2005/06	IIIES	51,635	675.0	27.8	1.0	-
	IIIEN	332,409	674.2	6.6	1.0	3.0
2007/08	IIIES	50,431	1126.2	54.9	8.9	2.0
	IIIEN	228,382	931.4	5.9	8.0	2.0

Area VIW

Year	Stratum	*A*	*L*	Number of sightings		
		(n.miles^2)	(n.miles)	Sperm	S.bottle	Killer
1996/97	VIW	205,835	3717.5	25.3	18.0	4.0
1998/99	VIW	316,727	1114.5	1.0	4.0	-
2000/01	VIW	290,908	4383.6	23.7	9.0	5.0
2002/03	VIW	319,627	5893.2	20.8	32.5	17.6
2004/05	VIW	292,218	3954.7	28.0	15.0	5.0
2006/07	IIIES	31,008	721.2	13.5	-	1.9
	IIIEN	220,818	756.4	3.3	6.0	2.0
2008/09	IIIES	76,255	990.1	3.5	-	1.0
	IIIEN	166,610	721.6	5.0	3.0	1.0

Table 4. Effective half-search width (*esw*) and estimated mean school size ($E(s)$) for each species.

Species	*esw*	CV	$E(s)$	CV
Sperm	1.460	0.013	1.037	0.006
S. bottlenose	0.553	0.025	1.681	0.026
Killer	1.018	0.021	8.674	0.090

Table 5. Abundance estimate and CV for sperm, southern bottlenose and killer whales in Areas IIIE, IV, V and VIW

Sperm whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	4,106	0.255
1991/92	-	-	3,296	0.131
1993/94	-	-	3,054	0.115
1995/96	1,181	0.197	2,579	0.150
1997/98	1,493	0.258	2,326	0.195
1999/00	1,815	0.208	2,745	0.202
2001/02	2,309	0.199	2,861	0.187
2003/04	2,191	0.211	1,358	0.192
2005/06	1,907	0.243	2,064	0.276
2007/08	1,384	0.261	3,613	0.325

year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	2,185	0.254	-	-
1992/93	1,726	0.208	-	-
1994/95	1,969	0.173	-	-
1996/97	1,204	0.163	497	0.215
1998/99	2,166	0.315	101	1.008
2000/01	1,184	0.212	559	0.286
2002/03	1,687	0.196	401	0.249
2004/05	1,856	0.214	736	0.214
2006/07	597	0.509	553	0.369
2008/09	1,192	0.216	504	0.344

Southern bottlenose whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	1,159	0.340
1991/92	-	-	1,082	0.266
1993/94	-	-	4,035	0.147
1995/96	1,454	0.273	6,818	0.118
1997/98	4,044	0.150	10,497	0.188
1999/00	7,364	0.383	7,974	0.186
2001/02	6,732	0.238	6,328	0.151
2003/04	3,928	0.219	6,072	0.185
2005/06	866	0.569	11,828	0.266
2007/08	3,591	0.263	6,967	0.208

Year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	1,272	0.298	-	-
1992/93	893	0.447	-	-
1994/95	5,129	0.251	-	-
1996/97	4,184	0.201	1,515	0.278
1998/99	2,460	0.377	1,728	0.407
2000/01	5,003	0.199	908	0.396
2002/03	6,729	0.269	2,681	0.233
2004/05	4,764	0.204	1,685	0.261
2006/07	4,549	0.299	2,663	0.404
2008/09	4,980	0.227	1,094	0.599

Killer whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	7,432	0.263
1991/92	-	-	7,717	0.219
1993/94	-	-	7,132	0.181
1995/96	1,881	0.360	11,786	0.248
1997/98	1,232	0.413	10,161	0.205
1999/00	1,239	0.501	10,678	0.219
2001/02	524	1.036	9,009	0.206
2003/04	2,268	0.415	14,374	0.185
2005/06	6,300	1.157	8,737	0.362
2007/08	2,470	0.872	2,268	0.489

Year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	12,195	0.250	-	-
1992/93	15,447	0.206	-	-
1994/95	9,606	0.268	-	-
1996/97	9,812	0.222	943	0.593
1998/99	12,303	0.254	-	-
2000/01	13,055	0.229	1,413	0.553
2002/03	13,821	0.188	4,066	0.350
2004/05	18,867	0.277	1,574	0.428
2006/07	7,185	0.356	2,827	0.807
2008/09	9,044	0.606	1,312	0.735

Table 6. Same as Table 5 but correcting abundance estimate *g*(0) estimate in Kasamatsu and Joyce (1995).CV estimates are taking CV of *g*(0) estimates into account.

Sperm whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	12,833	0.278
1991/92	-	-	10,301	0.171
1993/94	-	-	9,544	0.159
1995/96	3,690	0.225	8,058	0.186
1997/98	4,665	0.280	7,267	0.224
1999/00	5,671	0.235	8,580	0.230
2001/02	7,215	0.228	8,941	0.217
2003/04	6,846	0.238	4,245	0.222
2005/06	5,958	0.267	6,449	0.297
2007/08	4,325	0.283	11,290	0.343

year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	6,829	0.277	-	-
1992/93	5,393	0.235	-	-
1994/95	6,154	0.205	-	-
1996/97	3,761	0.196	1,553	0.241
1998/99	6,770	0.333	315	1.014
2000/01	3,700	0.239	1,747	0.307
2002/03	5,273	0.225	1,254	0.272
2004/05	5,799	0.241	2,299	0.241
2006/07	1,865	0.521	1,728	0.385
2008/09	3,725	0.243	1,576	0.362

Southern bottlenose whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	4,291	0.342
1991/92	-	-	4,009	0.268
1993/94	-	-	14,946	0.152
1995/96	5,387	0.275	25,252	0.124
1997/98	14,977	0.155	38,879	0.192
1999/00	27,274	0.385	29,535	0.190
2001/02	24,935	0.242	23,438	0.157
2003/04	14,547	0.223	22,490	0.190
2005/06	3,207	0.570	43,808	0.269
2007/08	13,300	0.266	25,802	0.211

Year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	4,711	0.301	-	-
1992/93	3,307	0.449	-	-
1994/95	18,997	0.254	-	-
1996/97	15,495	0.205	5,612	0.281
1998/99	9,113	0.379	6,401	0.409
2000/01	18,528	0.203	3,363	0.398
2002/03	24,923	0.272	9,929	0.237
2004/05	17,643	0.208	6,241	0.264
2006/07	16,848	0.302	9,863	0.406
2008/09	18,444	0.230	4,052	0.600

Killer whale

Year	Area IIIE		Area IV	
	P	CV(*P*)	*P*	CV(*P*)
1989/90	-	-	7,742	0.272
1991/92	-	-	8,038	0.230
1993/94	-	-	7,429	0.194
1995/96	1,959	0.367	12,277	0.258
1997/98	1,283	0.419	10,584	0.217
1999/00	1,290	0.506	11,123	0.230
2001/02	546	1.038	9,385	0.218
2003/04	2,362	0.421	14,972	0.198
2005/06	6,563	1.159	9,101	0.369
2007/08	2,573	0.875	2,363	0.494

Year	Area V		Area VIW	
	P	CV(*P*)	*P*	CV(*P*)
1990/91	12,703	0.260	-	-
1992/93	16,091	0.218	-	-
1994/95	10,006	0.277	-	-
1996/97	10,221	0.233	983	0.597
1998/99	12,816	0.264	-	-
2000/01	13,599	0.240	1,472	0.557
2002/03	14,397	0.201	4,236	0.356
2004/05	19,654	0.286	1,639	0.433
2006/07	7,484	0.363	2,945	0.810
2008/09	9,421	0.610	1,366	0.739

Table 7. Abundance trend estimate and their 95% CI of sperm, southern bottlenose and killer whales in Areas IIIE, IV, V and VIW.

Sperm whale

Area	Estimate	SE	95%CI LL	95%CI UL
IIIE	0.021	0.024	-0.041	0.082
IV	-0.024	0.016	-0.062	0.013
V	-0.039	0.019	-0.082	0.005
VIW	0.066	0.061	-0.090	0.223

Southern bottlenose whale

Area	Estimate	SE	95%CI LL	95%CI UL
IIIE	-0.018	0.081	-0.225	0.190
IV	0.104	0.032	0.030	0.179
V	0.077	0.028	0.013	0.142
VIW	0.009	0.042	-0.099	0.117

Killer whale

Area	Estimate	SE	95%CI LL	95%CI UL
IIIE	0.084	0.070	-0.096	0.264
IV	-0.021	0.028	-0.087	0.044
V	-0.011	0.016	-0.048	0.026
VIW	0.043	0.059	-0.120	0.206

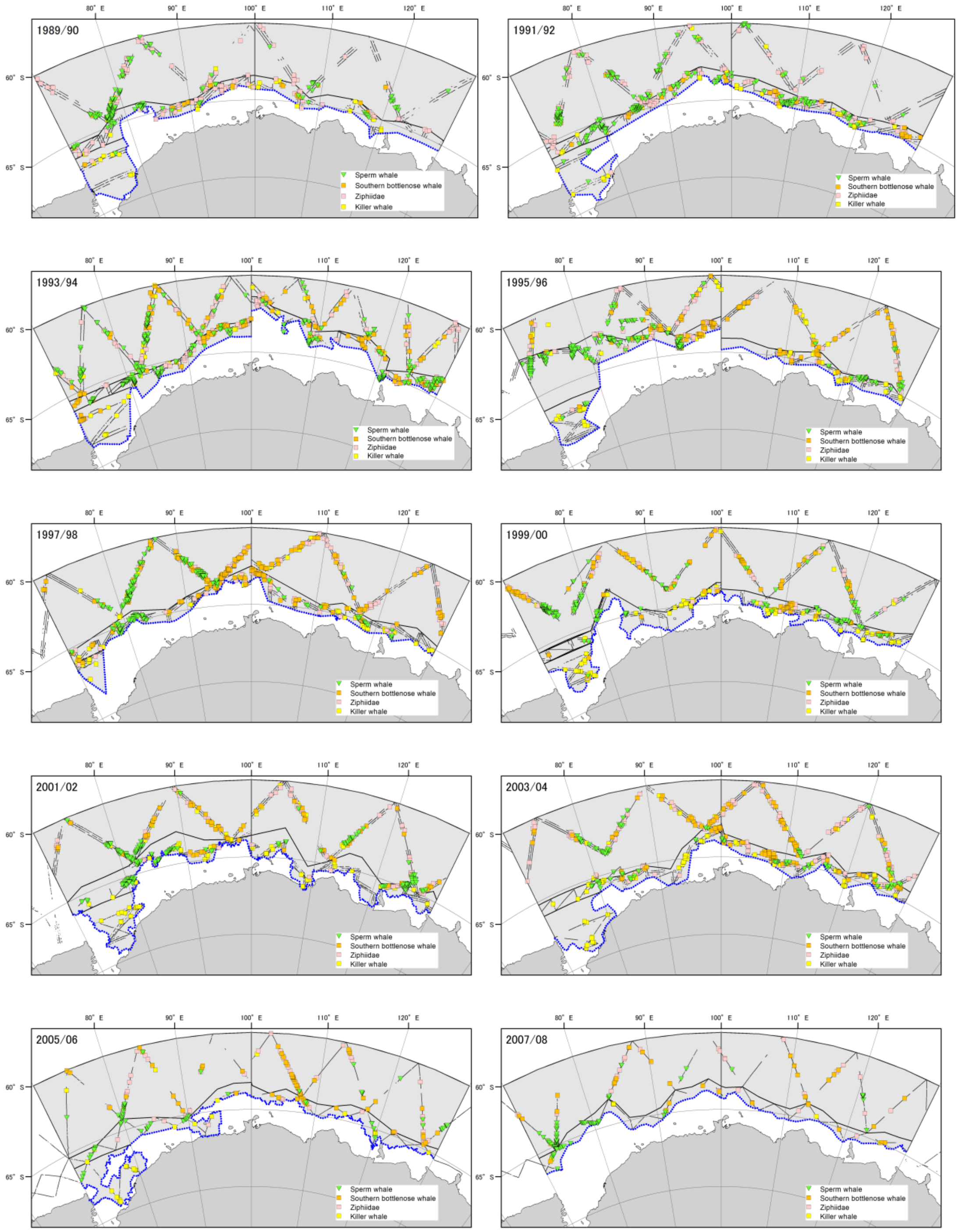


Figure 1a. Primary search effort (thin lines) and associated primary sightings of sperm (green triangle), southern bottlenose (orange square) and killer whales (yellow square) in Area IV (70^{o}E-130^{o}E) together with the ice edge (dotted blue line) from 1989/90 to 2007/08 JARPA and JARPA II surveys.

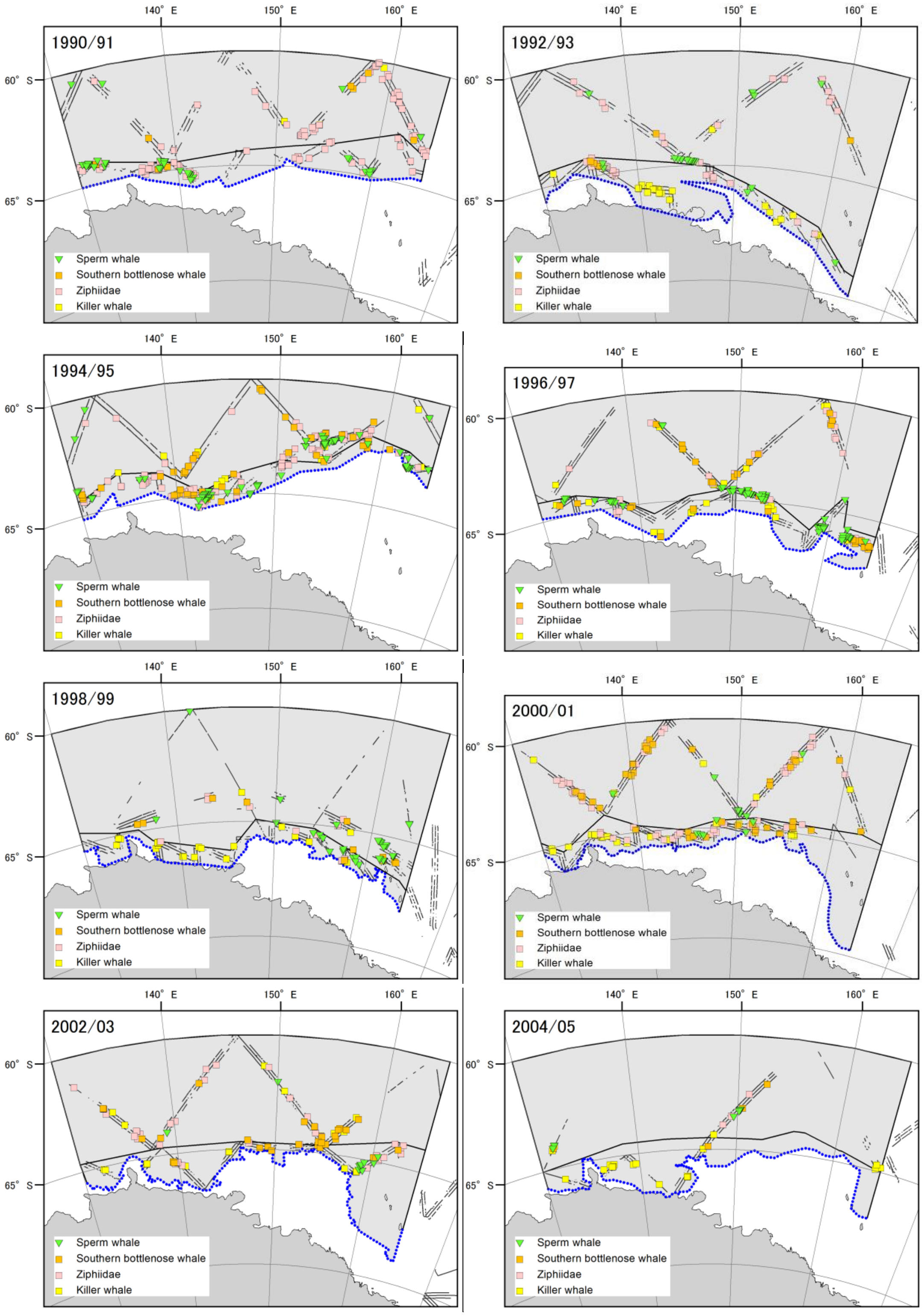


Figure 1b. Primary search effort (thin lines) and associated primary sightings of sperm (green triangle), southern bottlenose (orange square) and killer whales (yellow square) in Area VW (130°E-165°E) together with the ice edge (dotted blue line) from 1990/91 to 2008/09 JARPA surveys.

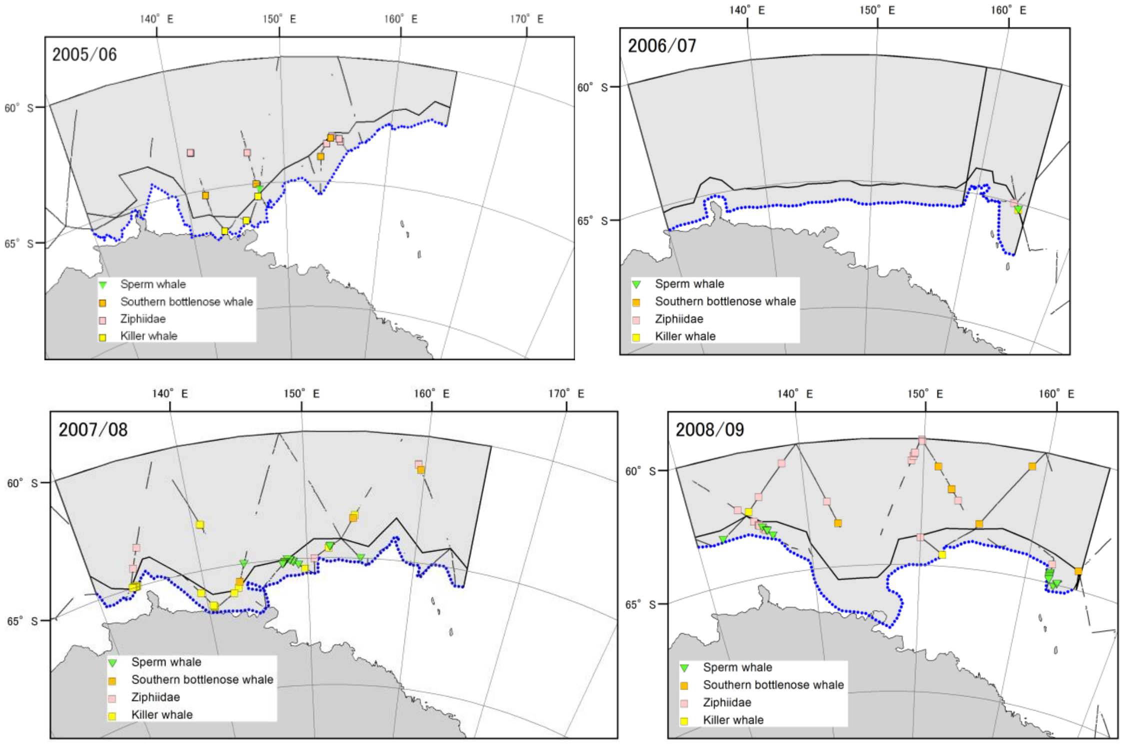


Figure 1b (Cont.).

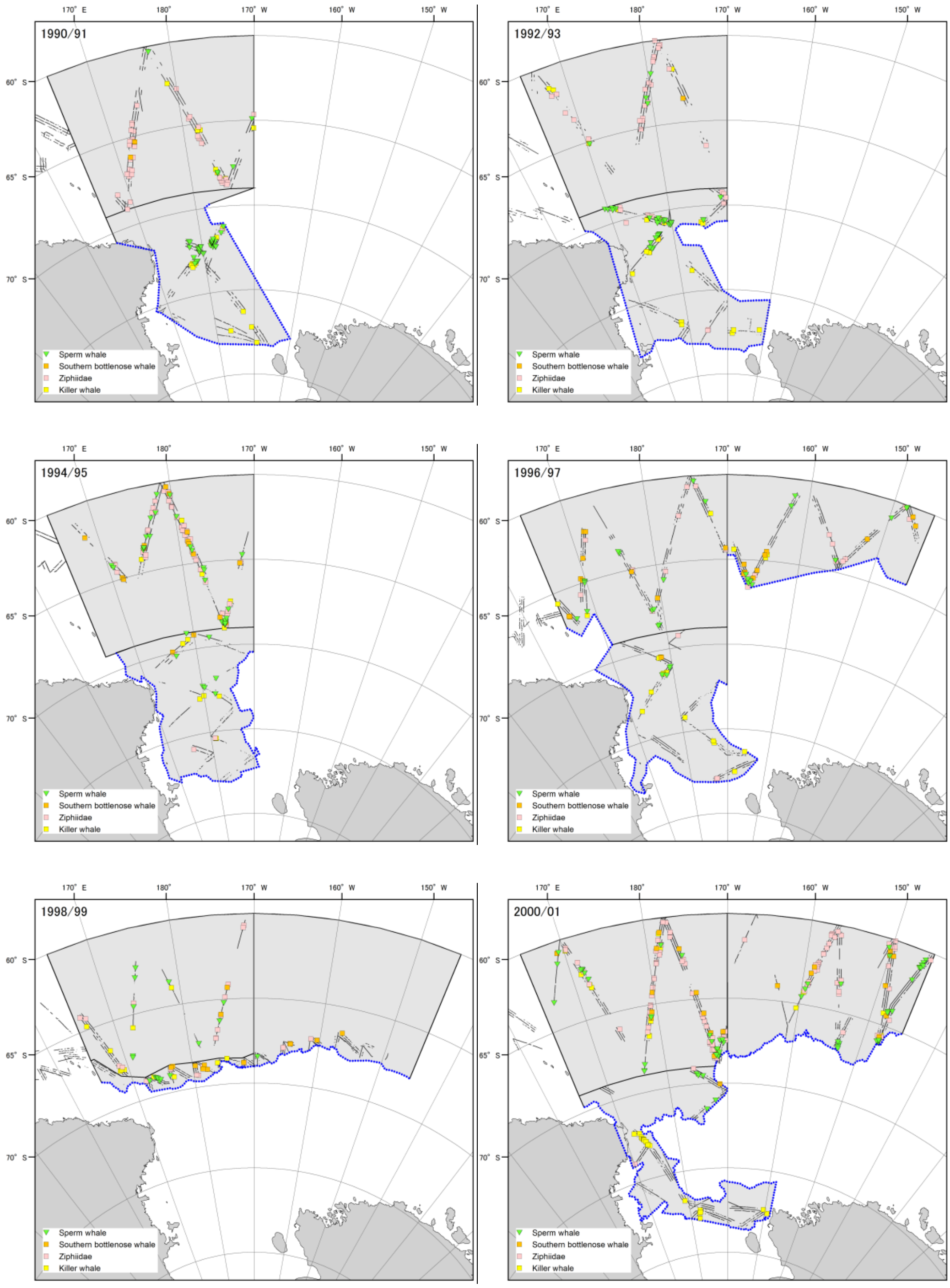
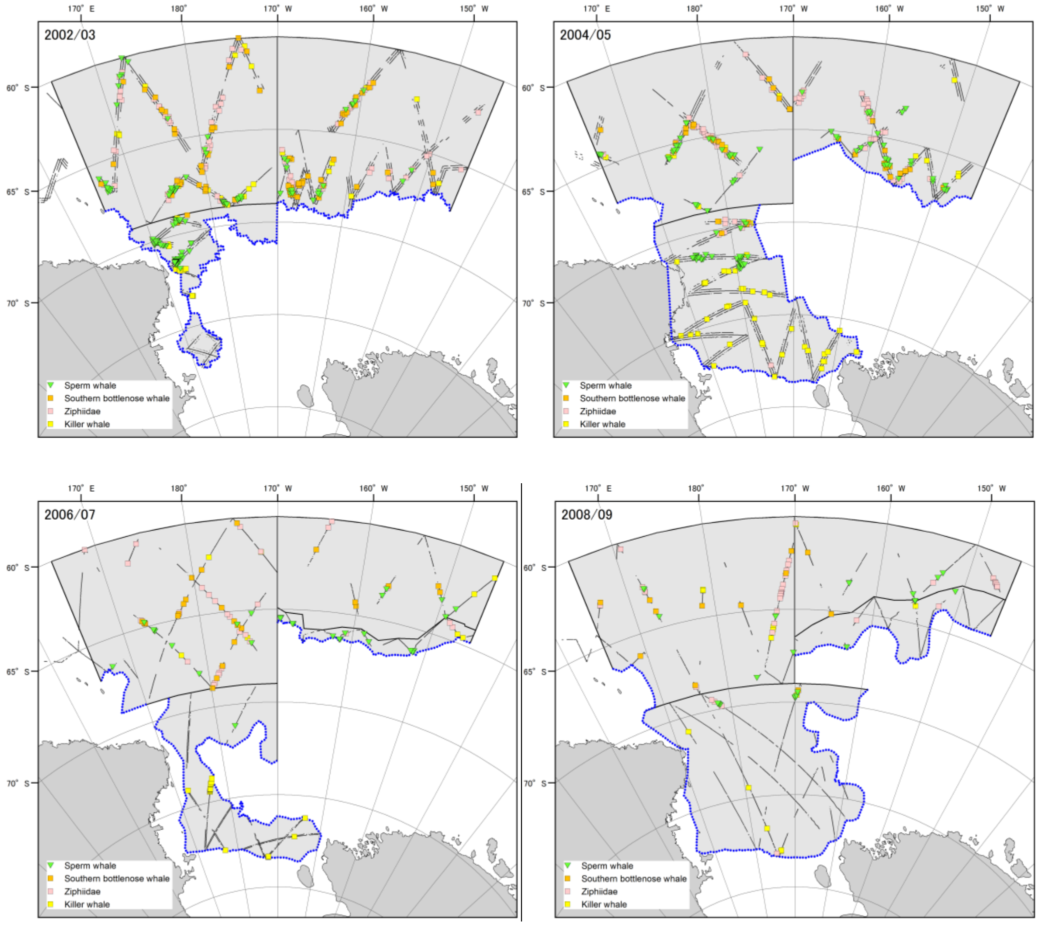


Figure 1c. Primary search effort (thin lines) and associated primary sightings of sperm (green triangle), southern bottlenose (orange square) and killer whales (yellow square) in Area VW (165^{o}E-145^{o}W) together with the ice edge (dotted blue line) from 1990/91 to 2008/09 JARPA and JARPA II surveys.



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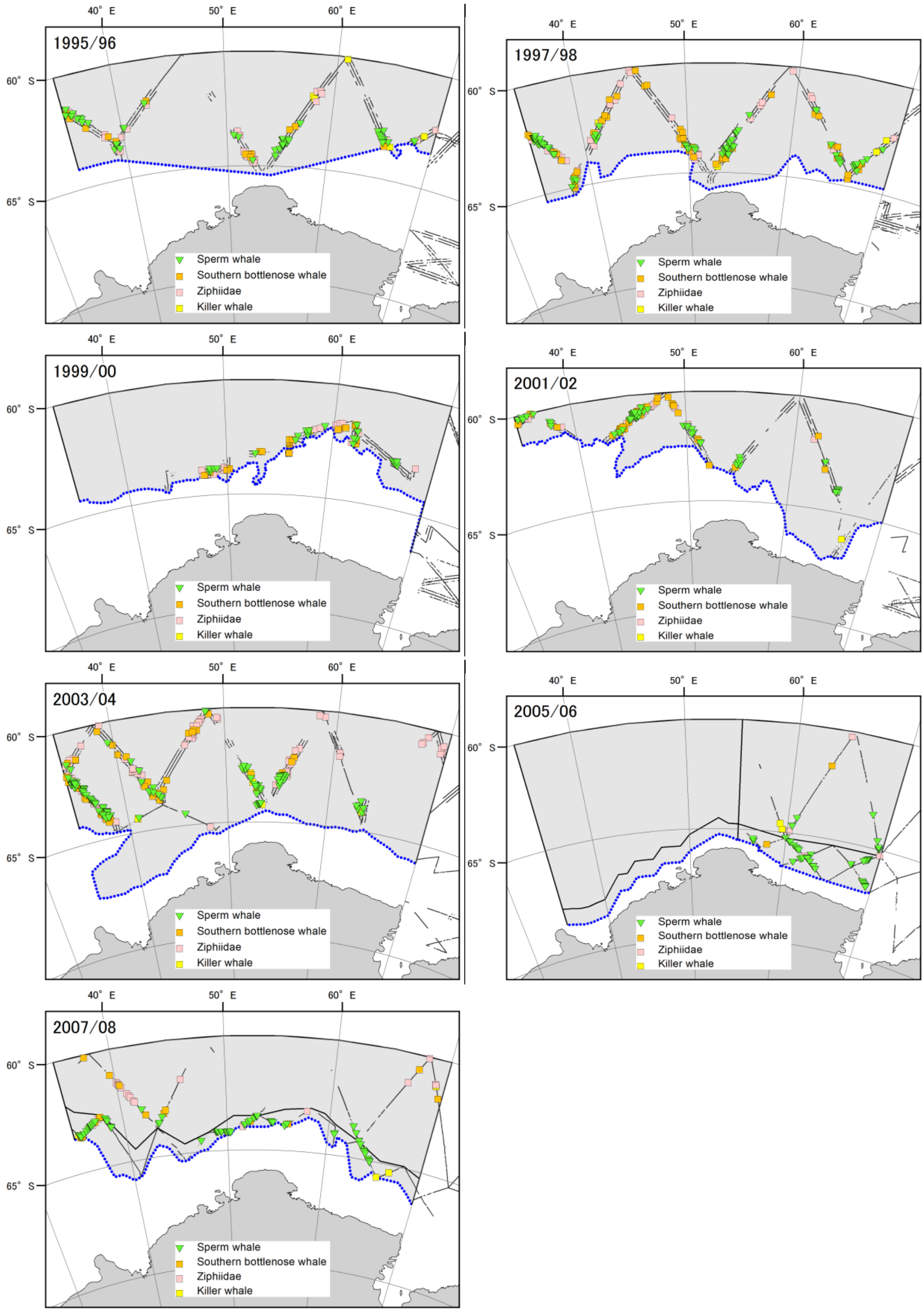

Figure 1d. Primary search effort (thin lines) and associated primary sightings of sperm (green triangle), southern bottlenose (orange square) and killer whales (yellow square) in Area VW (35°E-70°E) together with the ice edge (dotted blue line) from 1995/96 to 2007/08 JARPA and JARPA II surveys.

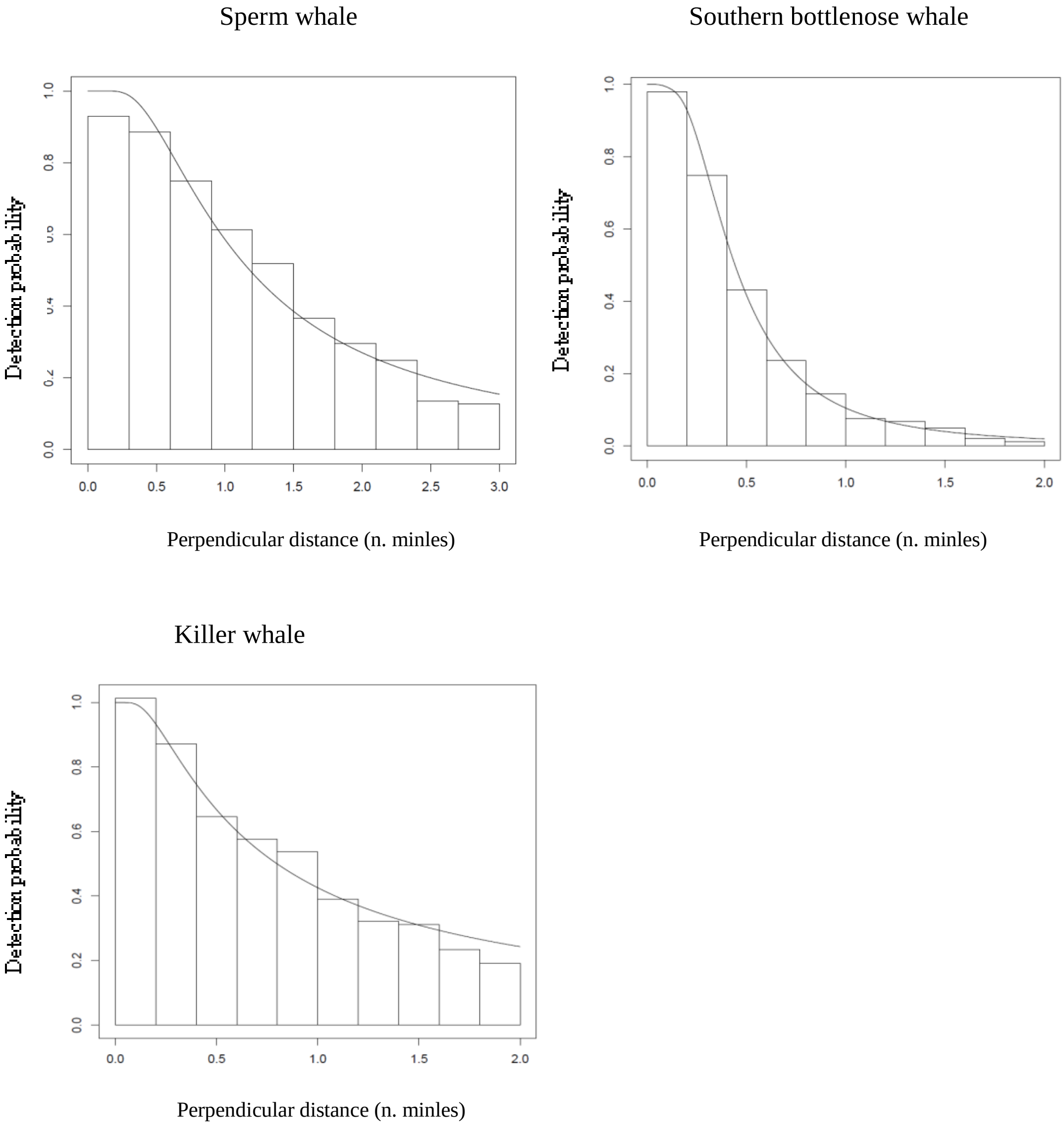

Figure 2. Estimated detection functions for sperm, southern bottlenose and killer whales for 1989/90-2008/09 JARPA and JARPA II data.