Distribution and the number of western North Pacific common minke, Bryde's, sei and sperm whales distributed in JARPN II Offshore component survey area

Takashi Hakamada[1], Koji Matsuoka[1] and Tomio Miyashita[2]

[1] *The Institute of Cetacean Research, 4-5, Toyomi-cho, Chuo-Ku, Tokyo, 104-0055, Japan.*
[2] *National Research Institute of Far Seas Fisheries (Yokohama), 2-12-4, Fukuura, Kanagawa, Yokohama, 236-8648, Japan.*
Contact e-mail: hakamada@cetacenan.jp

ABSTRACT

In order to examine an impact of large whales, such as common minke (*Balaenoptera acutorostrata*), Bryde's (*Balaenoptera edeni*), sei (*Balaenoptera borealis*) and sperm whales (*Physeter macrocephalus*), on Japanese fisheries through estimating the amount of prey consumed by these whales or using ecosystem models , it was required to estimate the number of these whales in the JARPN II survey area. Considering the migration pattern of these whales in the area suggested by our sighting survey data, the number of the whales needed to be estimated separately for the early and late seasons for each of the whale species. The estimates were 7,338 in the early and 2,976 in the late season for the common minke, 7,744 in the early and 5,406 in the late season for the sei whales, 1,677 in the early and 9,797 in the late season for the Bryde's whales, and 15,929 in the early and 20,292 in the late season for the sperm whales. It is important to note that these estimates should not be used for assessment because the estimated figures represent only a part of the population considered.

INTRODUCTION

Feeding ecology and ecosystem studies are one of the main objectives of JARPN II. An impact of whales on Japanese fisheries in the JARPNII survey area can be assessed from estimating the amount of prey consumed by the whales in the areas (Tamura *et al*, 2009) or applying ecosystem models developed for the area (Mori *et al*., 2009; Kawahara *et al*., 2009). For either way, it is required to estimate the number of whales distributed in the area. Stomach contents and distribution of the whales could differ between early (May – June) and late (July – September) feeding seasons and therefore the number of whales distributed in JARPN II survey area was estimated separately for the early and late seasons in this study.

MATERIALS AND METHODS

Dedicated sighting survey was conducted in JARPN II survey from 2002 to 2007. Timing of survey and surveying order of strata was changed substantially year by year in order to know how the number of distributed whales changed and how whales moved seasonally (for more details, see Kiwada *et al*., 2009). During 2002-2005, the survey area was planned to be covered for two years whereas during 2006-2007 the survey area was planned to be covered for a year. Table 1 shows survey period and survey days in each of the survey years. Table 2 shows survey period by latitudinal sector for each of the sub-areas. In 2006, the survey was conducted from south to north. In 2007, the survey was conducted from north to south. More details of the sighting survey procedure are explained in Kiwada *et al*., (2009). Stratification of the JARPN II survey area is shown in Fig. 1. Sub-areas 8 and 9 are stratified at 41°N latitudinal line. Distributions of trackline surveyed and primary sightings for the common minke, the sei, the Bryde's and the sperm whales are shown in Figs. 2, 3, 4 and 5, respectively.

Based on sighting data obtained during these surveys, the number of the whales distributed in the JARPN II survey area and their CVs was estimated from the following formulae;

$$N = \frac{AnE(s)}{2wl} \qquad (1)$$

$$CV(N) = \sqrt{\left\{CV\left(\frac{n}{l}\right)\right\}^2 + \{CV(w)\}^2 + \{CV(E(s))\}^2} \qquad (2),$$

where N was the number of the whales distributed, A was area size of the surveyed area, $E(s)$ was estimated mean school size, w was effective strip half width and l was searching distance. In case that data were pooled over multiple strata to estimate w and $E(s)$, CV of the estimated N was estimated from

$$\begin{aligned} CV\left(\sum_i^n N_i\right) &= CV\left(\frac{E(s)}{2w}\sum_i^n \frac{A_i n_i}{l_i}\right) \\ &= \sqrt{\left\{CV\left(\sum_i^n \frac{A_i n_i}{l_i}\right)\right\}^2 + \{CV(w)\}^2 + \{CV(E(s))\}^2} \qquad (3), \\ &= \sqrt{\frac{\sum_i^n A_i \operatorname{var}\left(\frac{n_i}{l_i}\right)}{\sum_i^n \frac{A_i n_i}{l_i}} + \{CV(w)\}^2 + \{CV(E(s))\}^2} \end{aligned}$$

where i was an index of strata. n was the number of strata whose data were pooled. In this calculation, it was assumed that

$$\operatorname{cov}\left(\frac{n_i}{l_i}, \frac{n_j}{l_j}\right) = 0 \qquad (i \neq j) \qquad (4).$$

The whale numbers were estimated using the program DISTANCE ver. 3.5 (Thomas *et al*., 1998) $g(0)$ was assumed to be 0.732 (Okamura *et al*, 2008) for Top barrel and Upper bridge for the minke whales, 0.64 (Whitehead, 2002) for sperm whales, and 1 for Bryde's and sei whales.

RESULTS AND DISCUSSIONS

Distribution and movement of whales

As shown in Table 3, the numbers of the whales distributed in the survey area fluctuate among years probably due to the difference in migration pattern among years. As discussed later, the common minke and sei whales mainly distribute in southern part of the survey area (south of 41ºN) in early season (May – June) and migrate to north of 41ºN in late season (July – September). In 2006, the southern part of the area was surveyed in early season and the northern part of the area was surveyed in later season. Therefore, our survey vessels likely followed migrating common minke and sei whales. This survey process should have caused the highest estimate observed for the common minke and sei whales in 2006. In 2007, northern part of the area was surveyed when the whales had not migrated there yet and southern part was surveyed in late season after the whales migrated out to north. As mentioned later, Bryde's whales hardly migrate yet in the JARPN II survey area in the early season and migrate in the southern part of the survey area in the late season. In 2006, because the southern part of the area was surveyed in the early season, the estimated number was low. In 2007, because the southern part of the area was surveyed in the late season, the estimated number was high.

Fig. 6 shows monthly searching effort by latitude. Because there was not enough searching effort in April and October, we used data from May to September. Fig 7 shows Density Index (DI: the number of the sightings per 100 n.minles) by latitude during the 1994-2007 JARPN and JARPN II (Matsuoka *et al*., 2009). Fig 7 suggested that the minke and sei whales were distributed south of 41ºN in May and June and north of 41ºN in July and August, and that Bryde's whales were distributed in south of 38ºN in June and south of 41ºN in July and August. For the sperm whales, there distributions did not change from May to September. In summary, distributions of the minke, sei and Bryde's whales change substantially from June to July compared to other month.

Estimation of the numbers of whales distributed

Table 3 shows the number of the whales distributed in the research area during the survey period for each of the survey years. The estimates for the common minke whales and sei whales were high in 2006 and low in 2007 for the reason mentioned above. Contrary, the estimates for the Bryde's whales were low in 2006 and high in 2007. For sperm whales, the estimates did not fluctuate substantially year by year. However, as mentioned earlier, these high estimates might have included positive biases because our survey vessels followed migrating animals, while the low estimates might have included negative biases due to mismatching between timing of survey and distribution of whales.

Considering above changes in distribution and migration of whales, data set were selected so as to include sighting data in the peak migration area in the early (May and June) and late (from July and August) seasons, respectively, but not to combine the both data set to avoid double counting due to migration. The area of low coverage was not selected. The selected data set were obtained and listed in Table 4. The estimated number of whales distributed in JARPN II survey area in the early and late season can be obtained using the data listed in Table 4. Table 5 shows the estimated number of whales distributed in the JARPN II survey area in the early and late season. The estimates were 6,609 in the early and 2,879 in the late seasons for the common minke, 7,646 in the early and 5,370 in the late seasons for the sei whales, 1,559 in the early and 9,344 in the late seasons for the Bryde's whales and 14,987 in the early and 19,185 in the late seasons for the sperm whales. Fig. 8 shows distributions of primary sightings used for the estimation of the common minke, sei, Bryde's and sperm whales in the early and late seasons, respectively. For the common minke and sei whales, the main distribution area moves to north of JARPN II survey area. This figure likely well reflects the distribution pattern suggested by Fig. 7. Fig. 9 shows the detection probability functions for the common minke, sei, Bryde's and sperm whales. The detection probability functions seemed to fit the relative frequency of the distribution of perpendicular distance of the detections.

Coverage of the survey area for each of the sub-areas 7, 8 and 9 was 85.3%, 100% and 100%, respectively. The estimated numbers divided by these coverage are shown in Table 6.

DISUSSIONS

For the common minke whales, the estimated numbers distributed in the survey area in the late season was less than that in the early season. This can be considered that the minke whales migrate to further north of the JARPN II survey area. In fact, the common minke whales mainly distribute in the Sea of Okhotsk and in the waters east of the Kamchatka Peninsula and the Kuril Islands in August and September (Buckland *et al*, 1992; Miyashita, 2009). Similarly, in the case of the sei whales, the estimated number in the late season was much less than that in the early season. This can be interpreted as that the sei whales may migrate north or east of the survey area. Contrary, for the Bryde's whales, the estimated number in the early season was less than that in the late season. This can be interpreted as that the Bryde's whales distribute mainly in the south of the JARPN II survey area and migrate to southern part of the survey area (south of 41^{o}N) in summer (June – September). For the sperm whales, there was no indication that the distribution pattern in the survey area change substantially during the survey period.

As discussed above paragraph, the distributed whales in the JARPN II survey area were a part of the whole stock and therefore, the estimated numbers of the distributed whales in this study should not use as the representation of the population size of the stock. In order to obtain abundance estimates appropriate for assessment of whale stocks, we also need to consider the information outside of the JARPN II survey area. We will not discuss this matter further in this paper but in the other paper (i.e., re-assessment of effect of research take on the whales stocks).

In this paper, $g(0)<0$ was assumed for the common minke and sperm whales and the estimated density in the sub-area 7 in Table 5 was extrapolated to the unsurveyed stratum in the sub-area 7 (i.e. 7N in Fig. 1). For the estimate of prey consumption of the whales and the use for ecosystem models, the estimates corrected by g(0) and the estimated density extrapolated to unsurveyed area are appropriate rather than the estimates assuming g(0)=1 as well as no whales in the 7N stratum because the latter combination clearly underestimates the number of the whales.

In order to avoid the effect caused by disagreement between the survey timing and whales' migration pattern, the number of the dedicated sighting vessels has been increased from 1 to 2 since 2008, and thus northern and southern halves of the research area are now surveyed simultaneously by two vessels. Better estimates of the whales can be anticipated.

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Table 1. Period and days of the sighting survey by dedicated sighting vessel (KS2).

Season	Offshore Component		
	Research Area	Dedicated Sighting Vessel	
		Research Vessel	Research Period (Days)
2002	7,8,9	KS2	2002.6.5-9.8 (96)
2003	7,8,9	KS2	2003.5.14-9.5 (115)
2004	7,8,9	KS2	2004.5.14-9.5 (115)
2005	7,8,9	KS2	2005.5.15-8.24 (102)
2006	7,8,9	KS2	2006.5.16-8.29 (106)
2007	7,8,9	KS2	2007.5.13-7.30 (79)

KS2: *Kyoshin-Maru No.2*

Table 2. Survey period and latitudinal band within each stratum for sighting survey by year.

	Sub-area 7		Sub-area 8		Sub-area 9	
year	period	latitudinal band	period	latitudinal band	period	latitudinal band
2002	8/11-8/20	38-41^{o}N	6/8-6/18 7/25-7/30	35-40^{o}N north of 40^{o}N	6/18-7/2 7/3-7/25	35-40^{o}N 40-45^{o}N
2003	5/14-5/21 5/21-5/25 5/28-6/11	37-41^{o}N(west of 144^{o}E) north of 41^{o}N 38-41^{o}N(east of 144^{o}E)	7/2-7/6	north of 41^{o}N	7/15-9/5	north of 43^{o}N
2004	5/14-6/8	35-41^{o}N	6/10-6/30	north of 38^{o}N	6/30-7/31 8/3-8/23	38-41^{o}N 41-45^{o}N
2005	no survey	no survey	6/27-7/5 5/17-5/25 7/12-7/16	35-38^{o}N 38-41^{o}N north of 41^{o}N	6/12-6/27 5/26-6/11 7/16-8/22	35-38^{o}N 38-41^{o}N 41-45^{o}N
2006	5/17-5/19 6/24-7/6	35-38^{o}N 38-41^{o}N	5/19-5/25 6/18-6/24 7/11-7/17	35-38^{o}N 38-41^{o}N north of 41^{o}N	5/27-6/5 6/7-6/18 7/17-8/4 8/5-8/26	35-38^{o}N 38-41^{o}N 41-45^{o}N north of 45^{o}N
2007	7/25-7/30 6/22-6/27	35-38^{o}N 38-41^{o}N	7/20-7/24 6/27-7/2 6/10-6/15	35-38^{o}N 38-41^{o}N north of 41^{o}N	7/10-7/20 7/2-7/10 5/29-6/10 5/16-5/29	35-38^{o}N 38-41^{o}N 41-45^{o}N north of 45^{o}N

Table 3. The estimated number of the whales distributed in JARPN II survey area during the survey period for each year. $g(0)$ is assumed to be 0.732 (Okamura *et al*, 2008) for the minke whales, 0.64 (Whitehead, 2002) for sperm whales, and 1 for Bryde's and sei whales.

common minke whales

	2002&2003		2004&2005		2006		2007	
sub-area	P	CV	P	CV	P	CV	P	CV
SA7	1,330	0.431	1,147	0.301	3,104	0.881	415	0.591
SA8	0	0.000	173	0.560	480	0.526	248	0.872
SA9	4,261	0.283	514	0.699	2,471	0.392	227	1.022
total	5,591	0.254	1,834	0.280	6,055	0.546	890	0.471
$g(0)$=0.732	7,638	0.400	2,505	0.417	8,272	0.628	1,216	0.563

sei whales

	2002&2003		2004&2005		2006		2007	
sub-area	P	CV	P	CV	P	CV	P	CV
SA7	52	0.762	0	0.000	570	0.529	205	1.148
SA8	262	0.489	1,187	0.822	2,635	0.354	1,106	0.507
SA9	4,291	0.323	6,413	0.677	6,827	0.280	1,673	0.650
total	4,605	0.331	7,600	0.829	10,032	0.241	2,984	0.445

Bryde's whales

	2002&2003		2004&2005		2006		2007	
sub-area	P	CV	P	CV	P	CV	P	CV
SA7	0	0.000	39	0.896	686	1.593	2,637	0.456
SA8	982	0.393	535	1.296	0	0.000	2,918	0.466
SA9	1,019	0.671	338	0.732	178	1.161	3,790	0.582
total	2,001	0.402	911	0.853	865	1.406	9,344	0.316

sperm whales

	2002&2003		2004&2005		2006		2007	
sub-area	P	CV	P	CV	P	CV	P	CV
SA7	874	0.354	100	0.428	3,511	0.491	4,124	0.361
SA8	86	0.526	1,816	0.489	1,085	0.273	1,985	0.281
SA9	2,931	0.203	4,024	0.349	6,895	0.213	4,271	0.344
total	3,891	0.191	5,939	0.421	11,491	0.250	10,379	0.254
$g(0)$=0.64	6,079	0.407	9,280	0.554	17,954	0.438	16,218	0.440

Table 4. Sighting data used for the estimated number of whales distributed in early and late season.

period	SA 7	SA 8	SA 9
early (May-June)	2006 [*1]	South of 41°N in 2006 [*2] and North of 41°N in 2007	South of 41°N in 2006 [*2] and North of 41°N in 2007
late (July-August)	2007 [*3]	North of 41°N in 2006 and South of 41°N in 2007	North of 41°N in 2006 and South of 41°N in 2007

*1：SA7 was surveyed in several days in early July in 2006.

*2：For Bryde's whales, sighting data in the south of 41°N surveyed in 2005 was used.

*3：SA7 was surveyed in several days in late June in 2007.

Table 5. The estimated number of the whales distributed in JARPN II survey area in early and late season. $g(0)$ is assumed to be 0.732 with its CV=0.309 (Okamura *et al*, 2008) for the minke whales, 0.64 with its CV=0.36 (Whitehead, 2002) for sperm whales, and 1 for Bryde's and sei whales.

species	period	SA7		SA8N		SA8S		SA9N		SA9S		total	
		P	CV	P	CV	P	CV	P	CV	P	CV	P	CV
Common minke	early	4,240	0.934	339	0.925	430	0.782	0	0.309	1,600	0.577	6,609	0.691
	late	567	0.667	226	0.746	0	0.309	1,776	0.678	310	1.068	2,879	0.523
sei	early	570	0.529	61	1.240	2,280	0.342	0	0.000	4,735	0.371	7,646	0.272
	late	205	1.148	355	1.451	1,045	0.532	2,093	0.360	1,673	0.650	5,370	0.300
Bryde's	early	686	1.593	0	0.000	535	1.296	0	0.000	338	0.732	1,559	0.860
	late	2,637	0.456	0	0.000	2,918	0.466	0	0.000	3,790	0.582	9,344	0.316
sperm	early	5,487	0.609	501	0.424	616	0.618	5,452	0.521	2,930	0.501	14,987	0.439
	late	6,443	0.510	1,079	0.481	2,599	0.490	7,843	0.446	1,221	0.913	19,185	0.409

Table 6. The estimated numbers in Table 5 divided by coverage for sub-area 7 (85.4%). The estimated numbers in sub-areas 8N, 8S, 9N and 9S are same as those in Table 5.

species	period	SA7		SA8N		SA8S		SA9N		SA9S		total	
		P	CV	P	CV	P	CV	P	CV	P	CV	P	CV
Common minke	early	4,969	0.934	339	0.925	430	0.782	0	0.309	1,600	0.577	7,338	0.712
	late	665	0.667	226	0.746	0	0.309	1,776	0.678	310	1.068	2,976	0.517
sei	early	668	0.529	61	1.240	2,280	0.342	0	0.000	4,735	0.371	7,744	0.270
	late	241	1.148	355	1.45	1,045	0.532	2,093	0.360	1,673	0.650	5,406	0.300
Bryde's	early	804	1.593	0	0.000	535	1.296	0	0.000	338	0.732	1,677	0.893
	late	3,090	0.456	0	0.000	2,918	0.466	0	0.000	3,790	0.582	9,797	0.311
sperm	early	6,429	0.609	501	0.424	616	0.618	5,452	0.521	2,930	0.501	15,929	0.444
	late	7,550	0.510	1,079	0.481	2,599	0.490	7,843	0.446	1,221	0.913	20,292	0.411

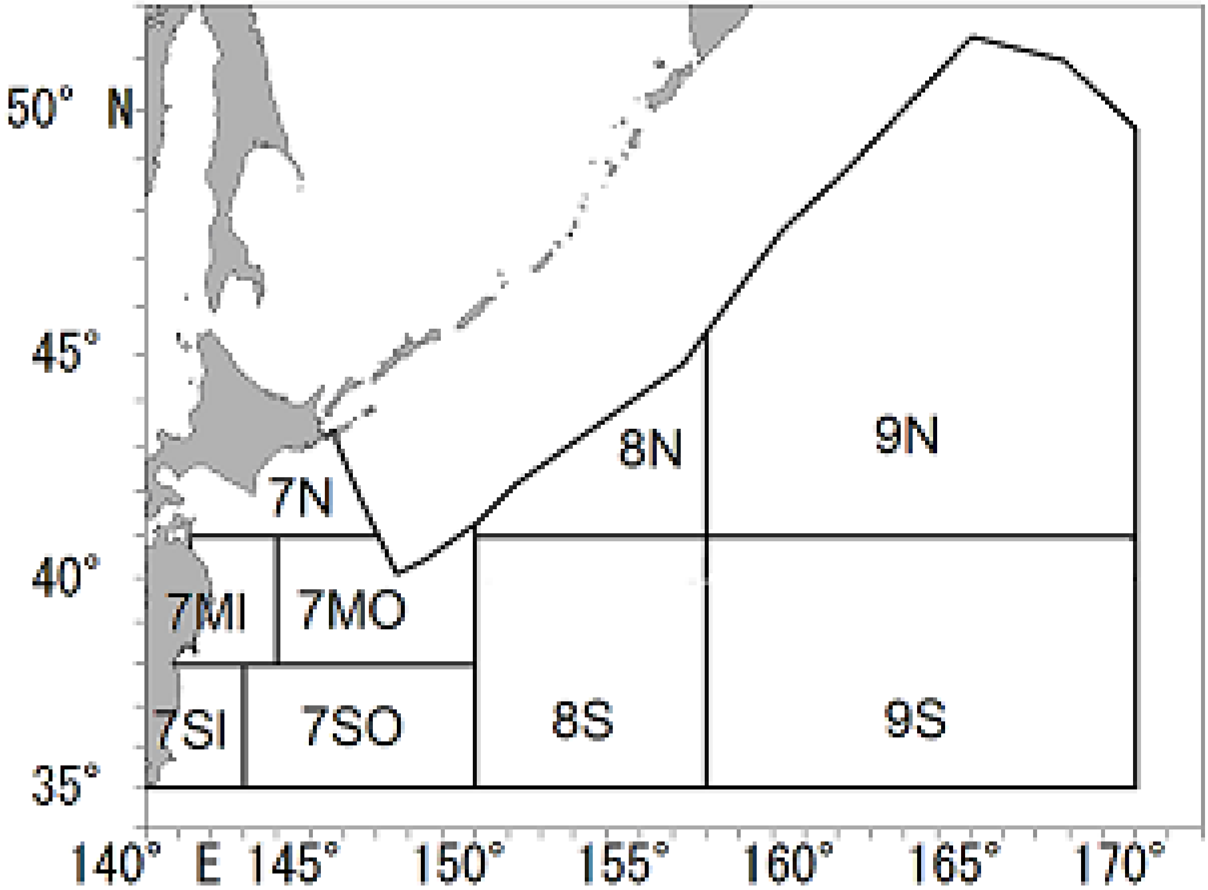

Fig. 1. JARPN II survey area and its stratification.

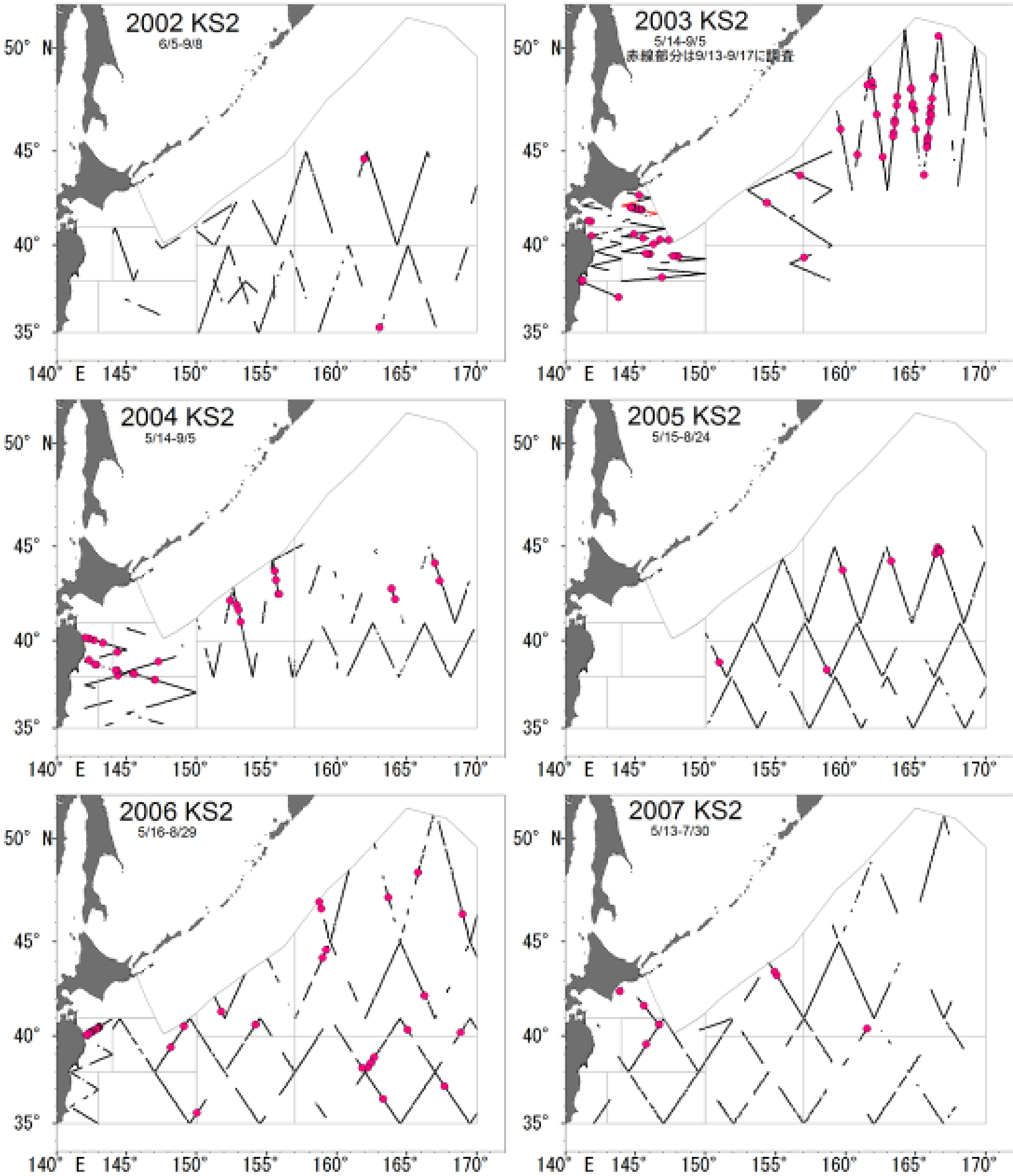

Fig. 2. Distribution of the effort and primary sightings of western North Pacific common minke whales by dedicated sighting vessel during JARPN II

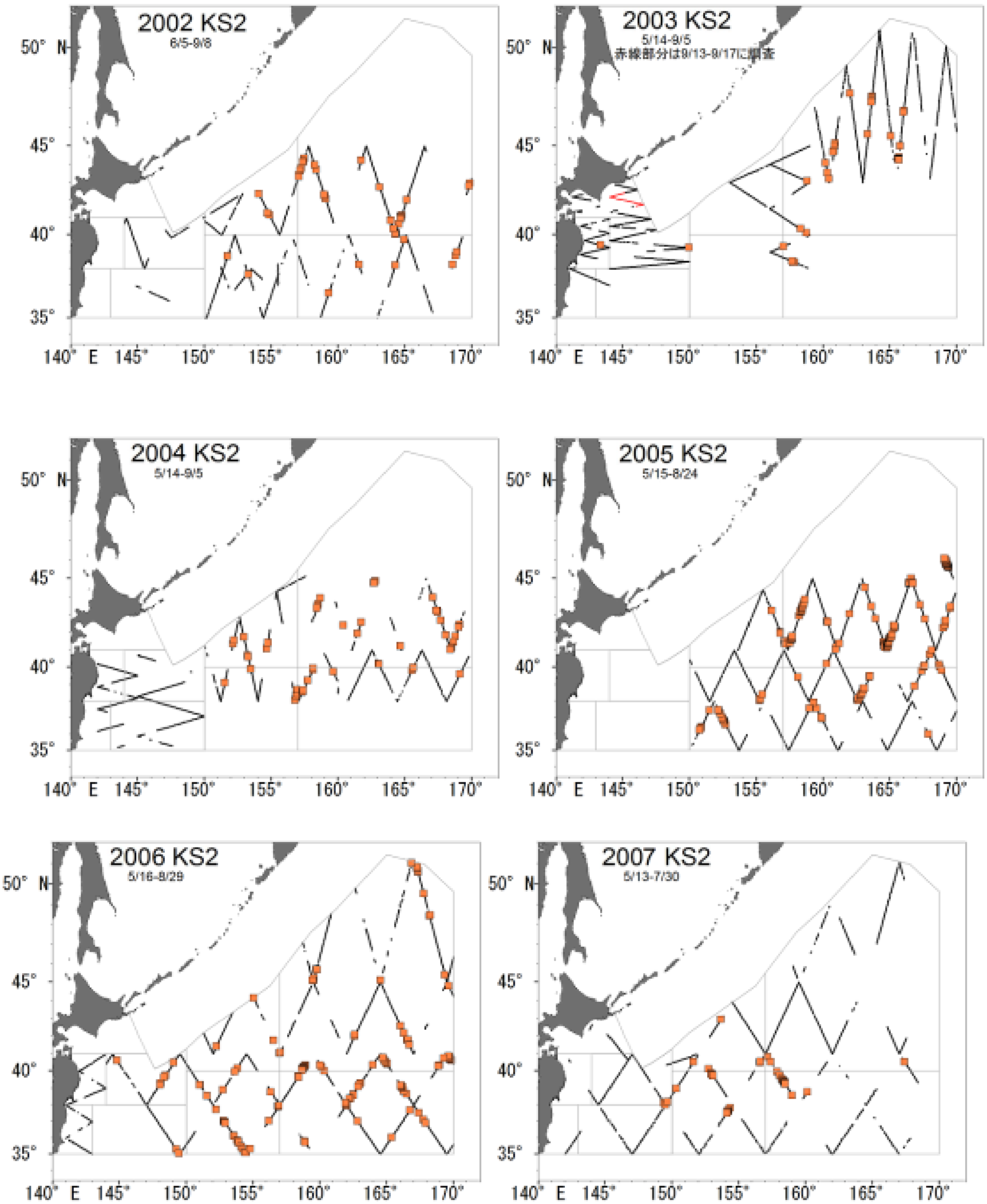

Fig. 3. Distribution of the effort and primary sightings of western North Pacific sei whales by dedicated sighting vessel during JARPN II

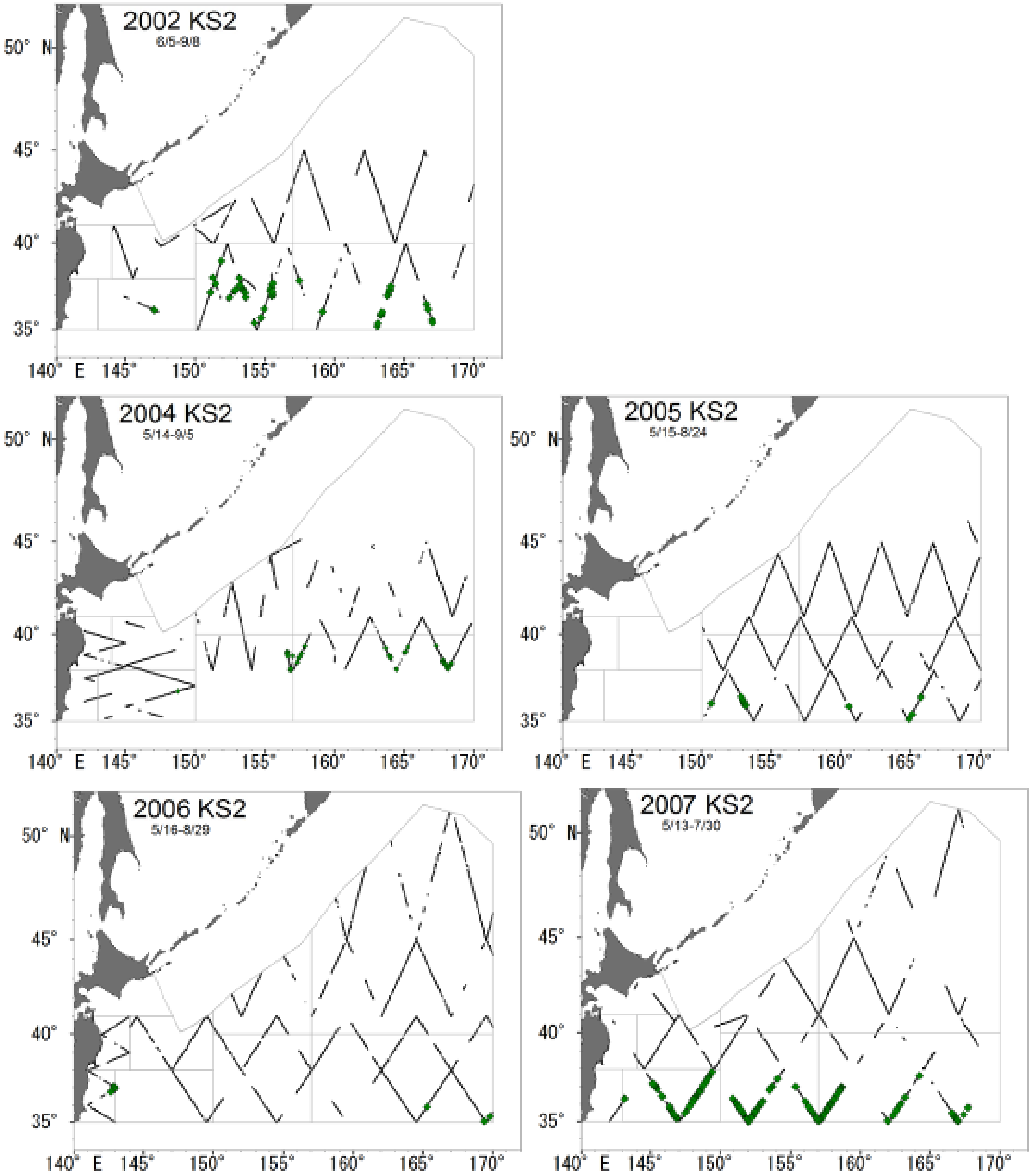

Fig. 4. Distribution of the effort and primary sightings of western North Pacific Bryde's whales by dedicated sighting vessel during JARPN II. In 2003, there was no primary sighting.

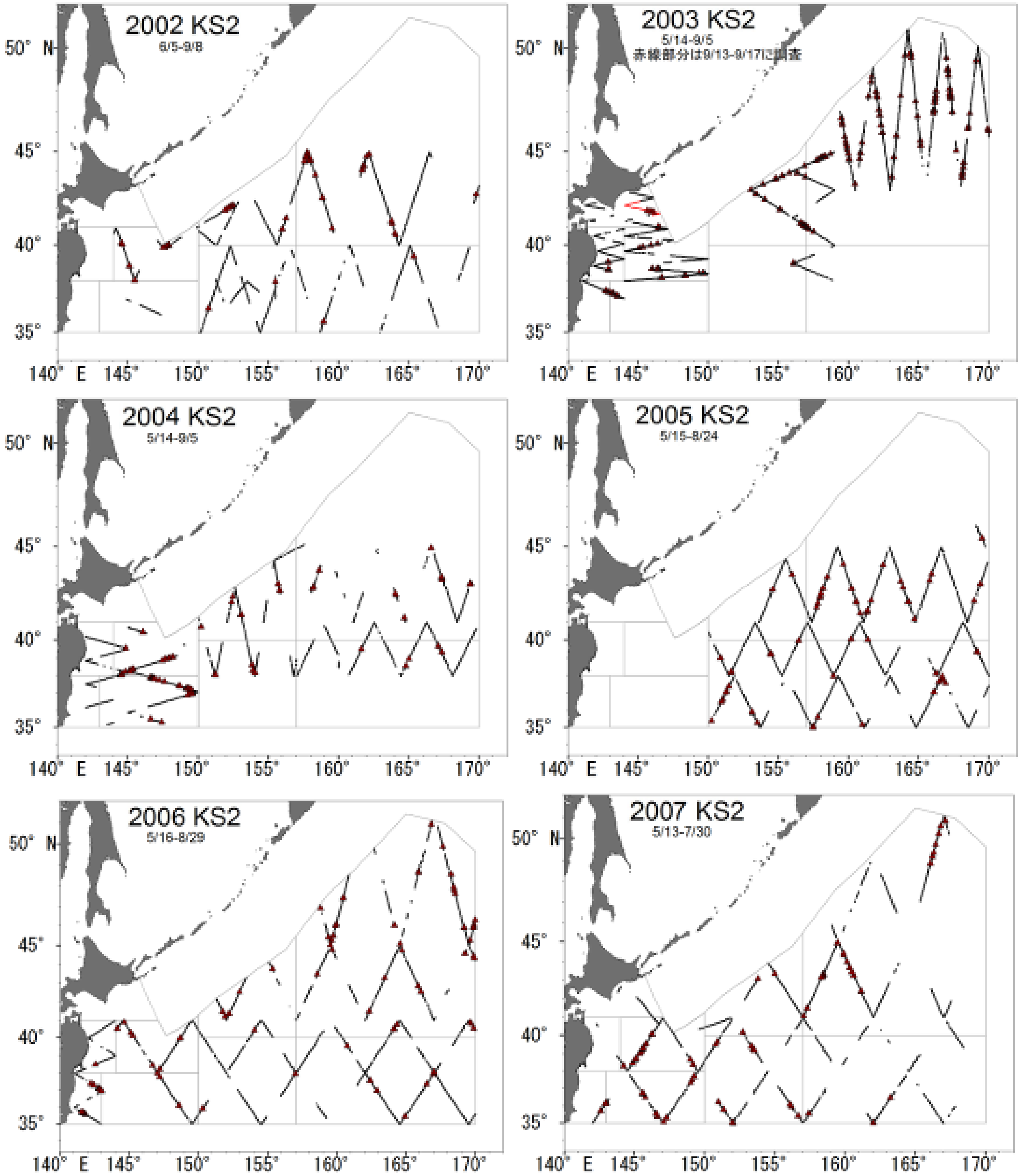

Fig. 5. Distribution of the effort and primary sightings of western North Pacific sperm whales by dedicated sighting vessel during JARPN II

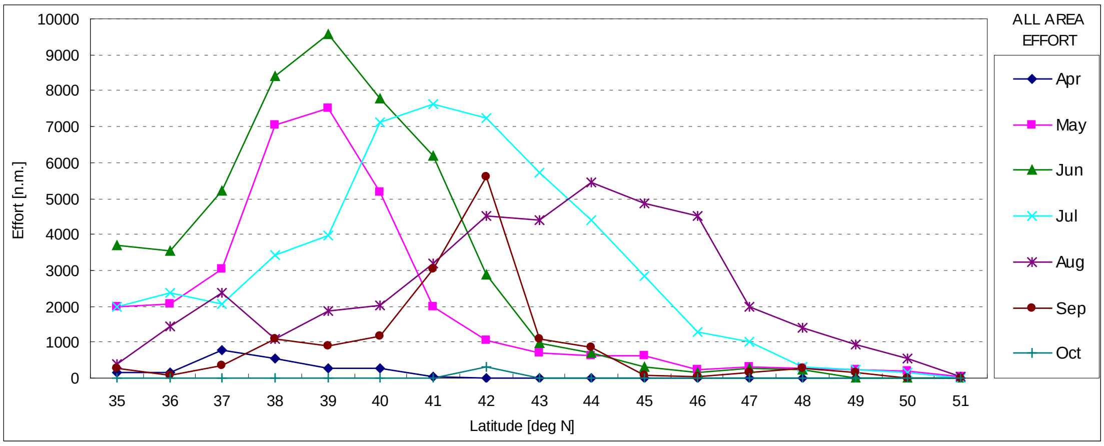

Fig. 6. Effort by latitude from April to October during 1994-2007.

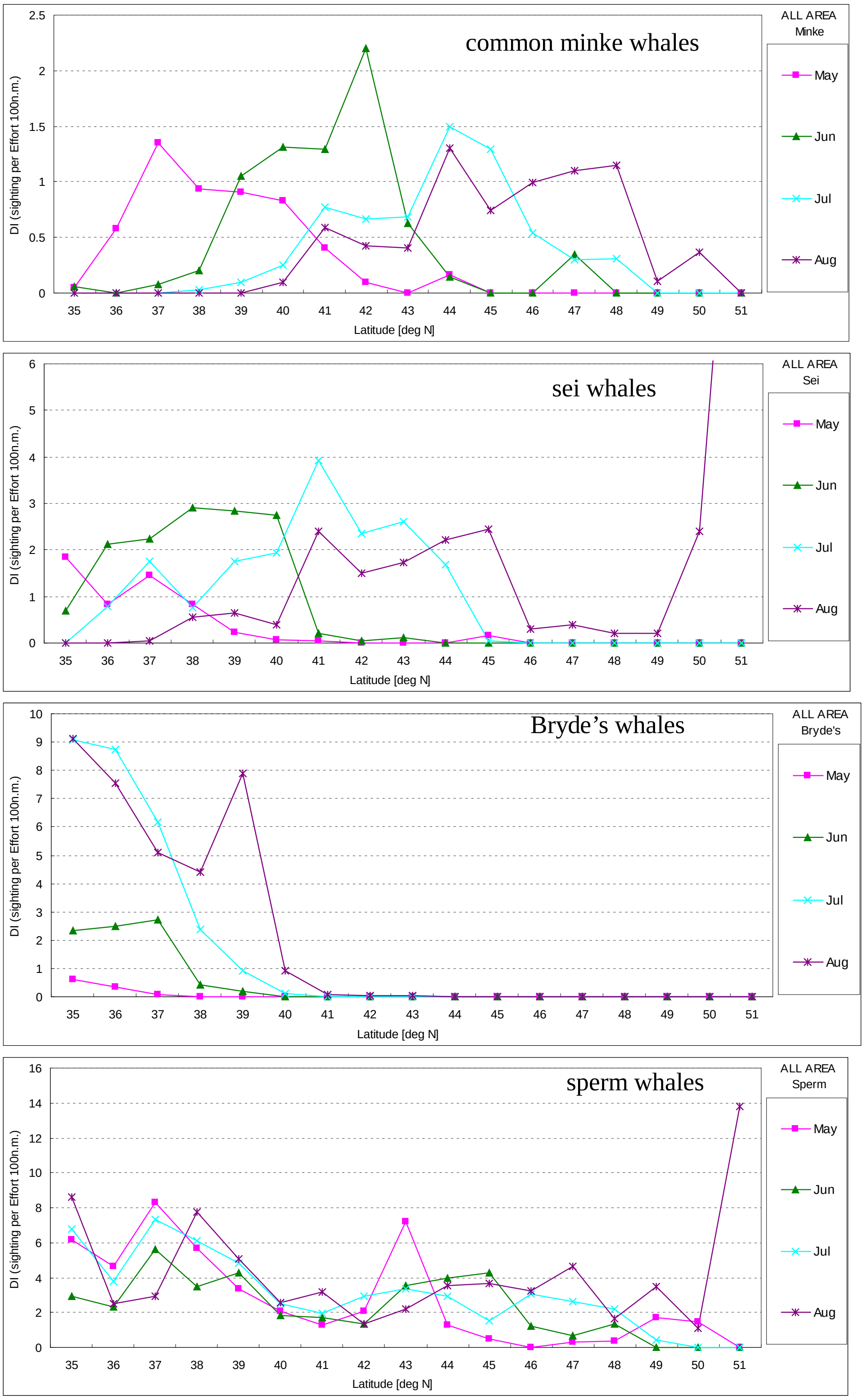

Fig. 7. DI (whale/100n.mile) by latitude from May to September during 1994-2007 for the common minke, sei, Bryde's and sperm whales.

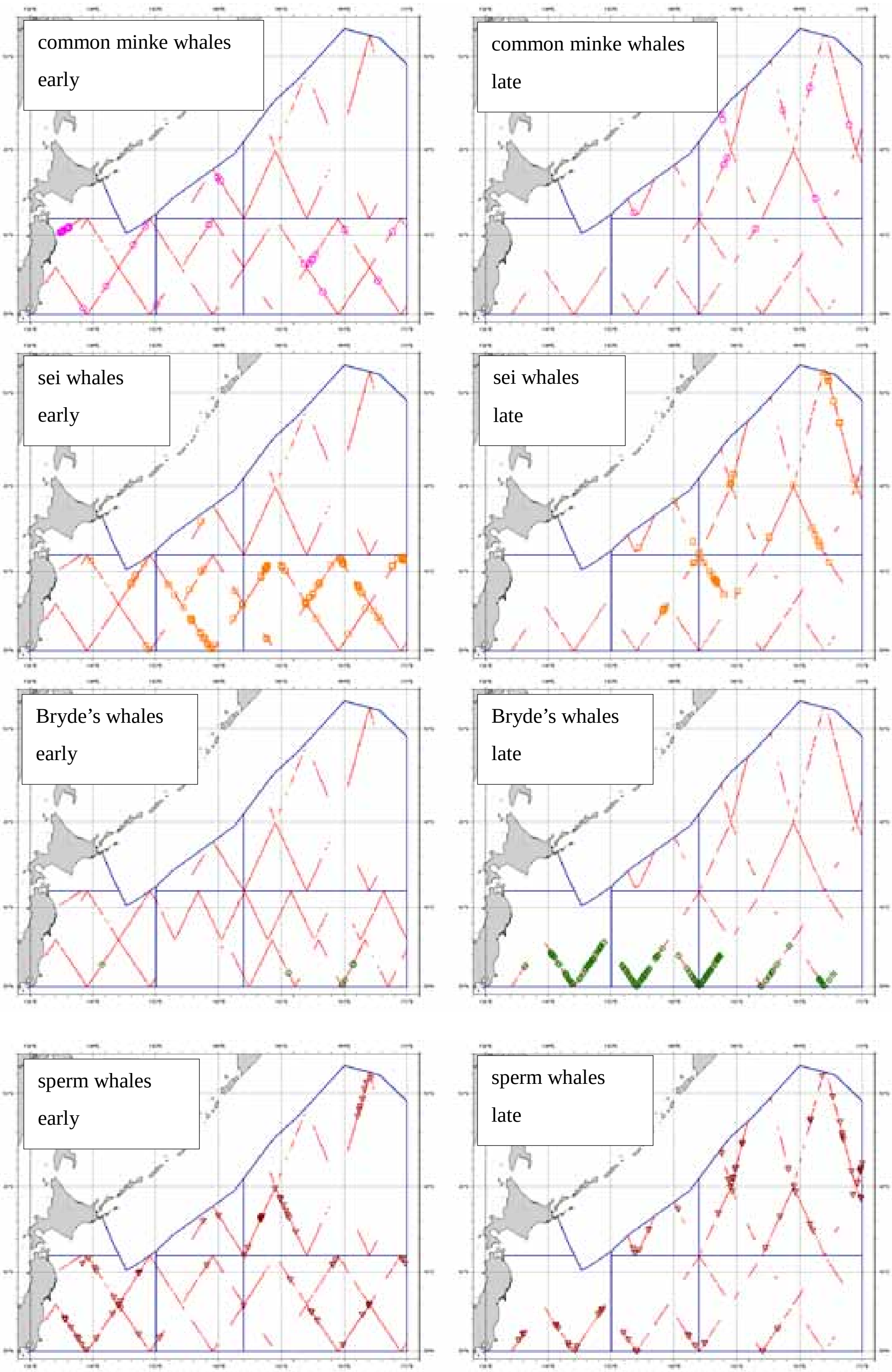

Fig. 8. Distribution of primary sightings of the common minke, sei, Bryde's and sperm whales in early and late seasons. Left panels are figures in early season and right ones are in late season.

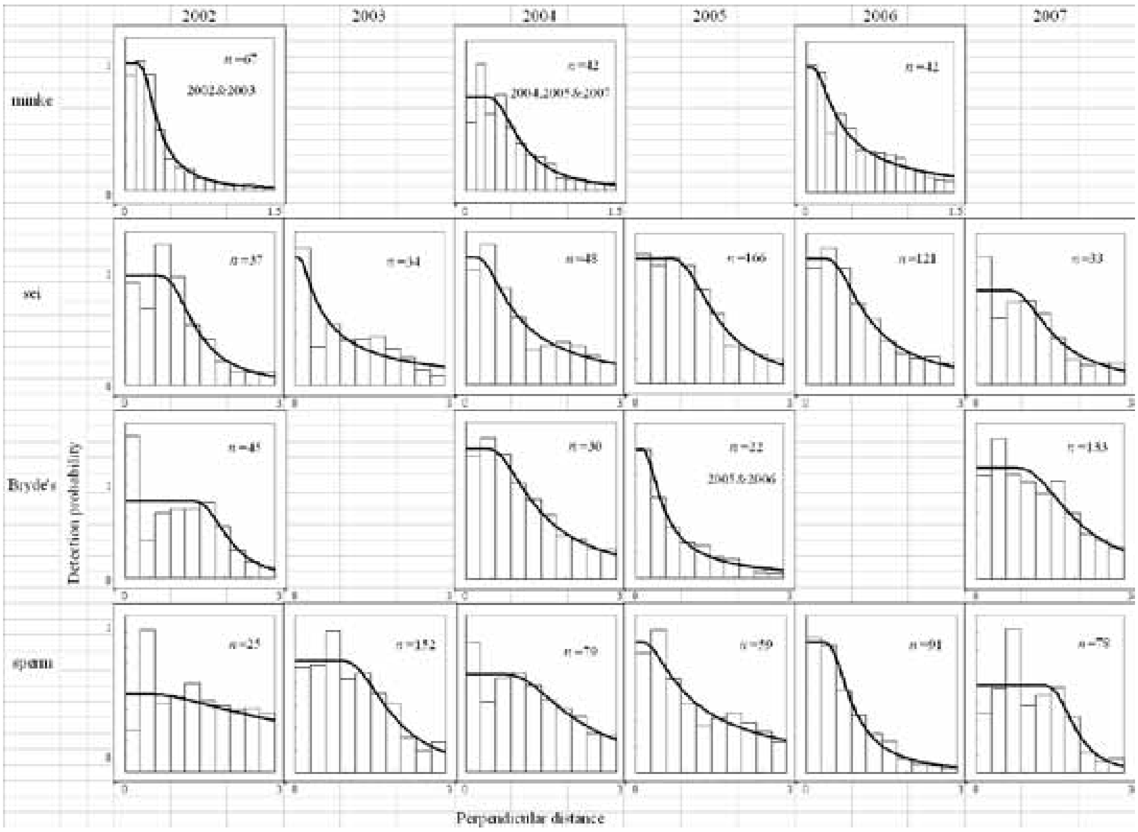

Fig. 9. Plot of detection probability functions for the common minke, sei, Bryde's and sperm whales. *n* is the number of the primary sightings to estimate the detection probability functions.