Improvements of the JARPA abundance estimation of Antarctic minke whales based on JARPA Review Meeting recommendations

Takashi Hakamada, Koji Matsuoka, Shigetoshi Nishiwaki

The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan
Contact e-mail: hakamada@cetacean.jp

ABSTRACT
Several recommendations were offered during the JARPA Review Meeting (JRM) to improve the abundance estimations of Antarctic minke whale based on JARPA sighting data. The JRM established an Advisory Group to facilitate the undertaking of these recommendations. This paper deals with four recommendations assigned as high priority by the Advisory Group: a) re-estimation of detection function by pooling sighting data; b) investigation of 'shoulder' of detection function; c) extrapolation of density to un-surveyed area, and d) abundance estimates accounting for the order that the strata were surveyed. By pooling sighting data (i.e. increasing simple size) the shape of detection functions, including 'shoulder', were improved in most of the cases (a and b above). By extrapolating density into un-surveyed area, abundance estimates did not change substantially except in the case of stratum Prydz Bay 2003/04 (c). Using linear model, reasonable estimate of date of peak migration could not be obtained possibly due to the fact that JARPA sighting data in Areas IV and V are collected in short-term from January to February, in which abundance is rather stable because of the peak migration. Other recommendations offered by the JRM will be considered in the near future.

KEY WORDS: ANTARCTIC MINKE WHALE, ABUNDANCE ESTIMATE, JARPA REVIEW MEETING.

INTRODUCTION

The abundances of the minke whales were estimated considering the recommendations at previous IWC/SC meetings (Hakamada *et al*., 2006). At the JRM, an Advisory Group (Kitakado (convener), Butterworth, Hedley, Matsuoka and Hakamada) was established to facilitate the undertaking of the recommendations and suggestions on abundance estimate given at the meeting listed in Table 1 (IWC, 2007). The Group recognized that the immediate priority is getting the JARPA estimates to the same level of acceptability as the current $g(0)$=1 IDCR estimates. Because there were many recommendations, it was agreed that there was not enough time to cover all the recommendations before IWC/SC meeting at Anchorage. As far as priorities before the SC meeting are concerned, the Group should give more attention to addressing (at least initially) suggestions of possible bias, rather than focus on variance. Therefore, the Group identified high priority for following items.

1. Re-estimation of detection function by pooling (Re-estimate in the cases where the number of detection is small)
2. Investigate 'shoulder' of detection function (response to 3 in Table 1)
3. Extrapolation of density in unsurveyed area (response to 7 and 8 in Table 1)
4. Abundance estimates accounting for change in order that the strata were surveyed (response to 9 in Table 1).

This paper reports some results on work for these recommendations.

MATERIALS AND METHODS

Re-estimation of detection function

Recommendations 1 and 2 were dealt with in this section. In cases where the number of sightings is less than 15, data will be pooled over northern strata (combined strata of North-West and North-East)/ southern strata (combined strata of South-West, South-East and Prydz Bay for Area IV and combined strata of South-West and South-East for Area V) as a part of task 1. In case that there were less than 15 detections in northern strata, data were aggregated over whole of Area IV or V. Estimated detection functions are shown in Figs 1-6.

For SSVs, the detection function has a clear shoulder in most of the cases. In discussion amongst by the Advisory Group, it was suggested that the strata NE in 1991/92, NE in 1990/91, SE in 1992/93 and SE in 1996/97 don't have clear shoulders, because the intercepts of the fitted curves with the vertical axis are highly influenced by the large number of sightings in the first 0.1 nm compared to neighbouring bins, with the fitted curves becoming flat only within this first bin. We compared estimates of effective half search width in those strata with the average of same strata excluding these estimates, respectively (Table 2).

For SV, though some of the detection function shows good fit but other detection functions don't have a clear shoulder, perhaps due to smaller samples size than in the case of SSVs. The Advisory Group recognized that further investigation is necessary. In order to reconsider the detection functions for SV, the Group suggested investigating followings.

1) Simply increase the maximum number criterion that avoids pooling, so that one pools in more cases - the difficulty though this doesn't solve the problem where pooling has already occurred (and one wants if possible to avoid pooling Northern and Southern strata, as weather conditions and hence effective search half widths tend to differ between them). 2) In addition to 1), in cases where pooling doesn't solve the difficulty, replace the w estimate for the N stratum (or similarly for S/PB), by the average value of w for that stratum for all the cruises in that Area. 3). As 2) is rather *ad hoc.* a better (though it will mean more computations) way might be to analyse all the sightings for the N strata (similarly for S/PB) combined across years using the DISTANCE option for the hazard rate function which estimates a common shape parameter *b* for all the cruises, but a separate scale parameter *a* for each E/W stratum for each cruise.

For this study, analysis 3) was conducted. To conduct 3), MCDS (Multiple Covariates Distance Sampling) engine in DISTANCE ver. 5 was used. MCDS can incorporate covariates other than perpendicular distance to estimate scale parameter of detection function. Smearing was not conducted because MCDS does not support smearing. MCDS doesn't conduct variable selection automatically therefore we compared Akaike's Information Criteria (AIC) for the models examined. Hazard rate function was considered. Full model is described by

$$f(y) = 1 - \exp\left\{ -\left(y \big/ a\exp(EW + year) \right)^{-b} \right\}$$

where y is perpendicular distance and EW and $year$ are covariates for east/west and year, respectively.

Extrapolation to unsurveyed area

In this section, recommendation 3 was dealt with. Three types of extrapolation were considered:

a) unsurveyed longitudinal sector due to insufficient time;

b) stratum where coverage by the survey was small;

c) gap between two strata.

Unsurveyed longitudinal sector due to insufficient time

The western part of SW stratum in Area IV was not surveyed in 1993/94, 2001/02 and 2003/04. The western boundary of the stratum is 70^{o}E longitudinal line and its eastern boundary is 100^{o}E. The longitudinal band between 70^{o}E and 74^{o}E was not surveyed in 1993/94 and that between 70^{o}E and 78^{o}E was not surveyed in 2001/02 and 2003/04. Map of these unsurveyd area are shown in Fig 7. For extrapolation, the density in the unsurveyed longitudinal sectors was estimated using data in 1989/90 and 1991/92 when whole of the stratum was covered. The data for 1995/96, 1997/98 and 1999/2000 were not used for this extrapolation by the reason followings. In 1995/96, there was a gap between SW and PB strata. In 1997/98, sea ice condition was so extraordinary that sighting vessels could not survey in most part of PB. In 1999/2000, searching effort was insufficient due to bad weather condition in the longitudinal sector between 70^{o}E and 78^{o}E. First, we estimate ratio of density between 70-74^{o}E to that between 74-100^{o}E in 1989/90 and 1991/92 when whole of the stratum was surveyed. It is assumed that the estimated mean school size and effective half search width are unchanged within the stratum therefore encounter rate was estimated instead of density. Fig. 7 shows distribution of surveyed trackline by SSVs and unsurveyed area in 1993/94, 2001/02 and 2003/04. The ratio was estimated by

$$X_{y,74} = D_{y,70-74} \big/ D_{y,74-100} \qquad (y\text{=1989, 1991}) \qquad (1)$$

Then the average of $X_{y,\,74}$ over two years is estimated.

$$\hat{X}_{74} = \frac{1}{2}\left(X_{1989,74} + X_{1991,74} \right) \qquad (2)$$

Finally, we can estimate density in unsurveyed area for 1993/94 by

$$\hat{D}_{1993,70-74} = \hat{X}_{74} D_{1993,74-100} \qquad (3)$$

Similarly, we estimate density in unsurveyd area for 2001/02 and 2003/04 by

$$\hat{D}_{2001,70-78} = \hat{X}_{78} D_{2001,78-100} \qquad (4)$$

$$\hat{D}_{2003,70-78} = \hat{X}_{78} D_{2003,78-100} \qquad (5)$$

For the case of Eastern part of SW stratum in Area V in 2000/01, the method is similar to the case of NW in 1993/94, 2001/02 and 2003/04. We used the data in 2002/03 when the configuration of ice edge is similar to that in 2000/01 to estimated extrapolated density.

Stratum where coverage by the survey was small

In 2003/04, SSVs surveyed PB stratum with low coverage. Map of this stratum is shown in Fig. 8. For extrapolation, ratio of density Y_y in PB to that in the SW stratum in year y was estimated for other years except 1997/98 when the PB stratum could not be surveyed due to sea ice.

$$Y_y = D_{y,PB} \big/ D_{y,SW} \qquad (y\text{=1989, 1991, 1993, 1995, 1999, 2001}) \qquad (6)$$

where $D_{y,PB}$ and $D_{y,SW}$ are density in stratum PB and SW in year y, respectively. For $D_{1993,SW}$, $D_{2001,SW}$, and $D_{2003,SW}$, the updated estimates described in previous section were used. Density in PB for 2003/04 was estimated by

$$D_{2003,PB} = \hat{Y} D_{2003,SW} \qquad (7)$$

where $\hat{Y}$ is average of Y_y over the years indicated.

For the case of NW stratum in Area V for 2004/05, the method is similar to the case of PB for 2003/04. We estimated this average ratio of D_{NW}/D_{NE} for 1990/91, 1994/95 and 1996/97 and multiplied the density in the NE stratum for 2004/05 by this ratio.

Gap between two strata

For a gap between PB and SW strata in 1995/96, the average density of two strata was applied. For a sensitivity test, the density estimate in SW stratum was applied instead for the gap. The gap between NW and SW for 1999/2000, 2001/02 and 2003/04 are also examples of c). Map of these gaps are illustrated in Fig. 9. In these gaps, the average density of two strata was again applied. For a sensitivity test, the density estimate in NW stratum was used for the gap.

Abundance estimates accounting for change in order that the strata were surveyed

In order to deal with recommendation 9 in Table 1, a GLM is applied to estimate abundance accounting for change in order that the strata were surveyed. We use a log linear model described by:

$$\log(P_{obs}(y,a)) = \log(P_{true}(0,a)) + \alpha y + M + Q(T) + \varepsilon \qquad (8)$$

where y is year, a is stratum, $P_{obs}(y,a)$ is observed abundance estimate, $P_{true}(y,a)$ is unbiased abundance (i.e. free from survey mode and order effects) to be estimated in year y and in Area a. M is the mode factor (distinguishing SV/SSV and closing/passing), T the covariate related to survey timing (i.e. middle day of the survey period, order of the survey or month), $Q(T)$ is a quadratic form of T with negative coefficient for the term of second order with respect to T. ε the survey sampling error with variance equal to $[CVP_{obs}(y,a)]^2$.

RESULTS

Re-estimation of detection functions

Table 2 shows comparison estimated esw's and averaged ones among the other years. In the case of NE for 1990/91, estimated esw and averaged one is different and this may suggest underestimate of esw. But this may over correction because this substitution introduces an overall bias because one is not also adjusting for potential biases for cases with the reverse features.

Table 3 shows AIC in each model for all cases. In most of the cases, esw was not different among the model. This suggests that such examination would not affect on abundance estimate substantially. Except one case, covariate of EW was not selected by AIC. Therefore it was suggested that covariate EW would not affect estimate of esw significantly. Fig. 10 shows plots of detection functions for each pooled data explained above. In case that the model including covariates of EW or year was selected, the effects of these covariates were averaged. Comparing Figs 3-6, shape of detection functions in this figure were improved.

Extrapolation of unsurveyed area

unsurveyed longitudinal sector due to insufficient time

As for Western part of SW stratum in Area IV in 1993/94, 2001/02 and 2003/04, Table 4 shows correction factor estimated from data in 1989/90 and 1991/92. These results suggests density in unsurveyd longitudinal sectors (i.e. 70-74^{o}E and 70-78^{o}E) were higher than rest of SW stratum, though it is not clear if it is significant. Extrapolated abundances in SW stratum were 4,285, 2,609 and 10,682 in 1993/94, 2001/02 and 2003/04, respectively. There estimates were higher than previous estimates in Hakamada *et al*. (2006).

As for Eastern part of SW stratum in Area V in 2000/01, Table 6 shows estimates of correction factor and extrapolated abundance estimate in SW stratum for 2000/01. The abundance estimate is 7,059.

stratum where coverage by the survey was small

As for PB in 2003/04, Table 7 shows correction factors and estimated density in this stratum given by formula (6) and (7). Estimated abundance is 26,467 whereas previous estimate in Hakamada *et al.* (2006) was 41,273.

As for NW stratum in Area V for 2004/05, correction factor was obtained shown in Table 8. Using this correction factor, extrapolated abundance is estimated as 15,780.

Gap between two strata

Table 9 shows comparison of abundance estimates in Area IV for 1995/96, 1999/2000, 2001/02 and 2003/04 in case using average density in the two strata as a reference case and sensitivity test. The difference in abundance estimate between two assumptions is small as shown in Table 9.

Abundance estimates accounting for change in order that the strata were surveyed

Table 10 shows estimated coefficients of the model in formula (8) applying data combined Areas IV and V, Area IV and Area V, respectively. The first two cases, coefficient of T^2 is positive contrary to our expectation before the analyses though estimated coefficients with respect to T and T^2 are not significantly different from 0. In the case of Area V, migration peak was estimated on 22 Feb. But this doesn't agree with previous study (Kasamatsu *et al*., 1996). It is suggested that model fails to estimate data of migration peak.

DISCUSSIONS

Re-estimation of detection function

Pooling data improve the shape of detection functions for most of the cases. But some of the functions (e.g. NE in 1990/91 for SSVs) still need further investigation on the shape of the function. For example, applying other key function (e.g. Half-normal function) and Kelker strip approach - average the first two bins. AIC selected covariate year for some cases whereas covariate EW was not selected except one case. But whether or not considering covariate of year, estimate of esw are not substantially different as shown in Table 3. Therefore, it is suggested that considering these covariates could not differ abundance estimate substantially even if the covariates are selected by AIC.

Extrapolation of unsurveyed areas or gaps between two strata.

Extrapolated abundance estimates don't differ substantially from previous estimates in Hakamada *et al*. (2006) except the case of PB in 2003/04 and NW in 2004/05. It is suggested that different method of extrapolation could not affect on abundance estimate significantly.

Abundance considering the migration peak

Form the estimated coefficients, estimated coefficients with respect to T and T^2 are not significantly different from 0 for the case of the combined Areas and the case of Area IV. Estimated migration peak is not plausible in Area V because this result doesn't agree with previous study (Ohsumi, 1979; Kato and Miyashita, 1991; Kasamatsu *et al*., 1996; Miyashita *et al*, 2001; Minamikawa *et al*., 2003). One possible reason is that most of sighting data in Areas IV and V used in this analysis were obtained in short-term in which abundance was stable as the peak of the migration (January and February). Fig 11 shows plot of mid-day of the survey period and logarithm of abundance estimate for each stratum in Areas IV and V, respectively. From the figure, no tendency of peak migration is observed. Further investigation of formula of the model and definition of T could improve the performance of the model. By improving formula (8), additional variance can be estimated which is correspond to recommendation 10 in Table 1. This improved model should be investigated in near future.

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REFERENCES

Hakamada, T., Matsuoka, K. and Nishiwaki, S. 2006. An update of Antarctic minke whales abundance estimate based on JARPA data. Paper SC/D06/J06 presented to Intersessional Workshop to review data and results from special permit research on Minke Whales in the Antarctic December 2006 (unpublished). 36pp.

International Whaling Commission. 2007. Report of the Intersessional Workshop to review data and results from special permit research on Minke Whales in the Antarctic, Tokyo 4-8 December 2006. Paper SC/59/Rep1 presented to IWC Scientific Committee May 2007. 48pp.

Kato, H. and Miyashita, T. 1991. Migration strategy of southern minke whales in relation to reproductive cycles estimated from foetal length. *Rep. int. Whal. Commn.* 41: 363-9.

Kasamatsu, F., Joyce, G. G., Ensor, P. and Mermoz, J. 1996. Current occurrence of baleen whales in the Antarctic waters. *Rep. int. Whal. Commn.* 46: 293-304.

Minamikawa, S., Miyashita, T. and Okamura, H. 2003. Further analysis on the JSV data of the Antarctic minke whale using the GLMs. Paper SC/54/IA12 presented to IWC Scientific Committee, May, 2002. (unpublished) 11pp.

Miyashita, T., Shono, H and Okamura, H. 2001. GLM analysis of the JSV data for the Antarctic minke whale. Paper SC/53/IA11 presented to IWC Scientific Committee, June, 2001. (unpublished) 6pp.

Ohsumi, S. 1979. Population assessment of the Antarctic minke whale. *Rep. int. Whal. Commn.* 29: 407-20.

Table 1. List of the tasks recommended at the workshop and suggested task (3 and 4) and their priority in the Advisory Group.

tasks	Priority
1. Estimation of detection function（Re-estimate in the cases where the number of detection is small ）	H
2. Investigation of sensitivities to pooling all vessels to estimate effective strip width and mean school size.	M
3. Investigate ‘shoulder’ of detection function	H
4. Sensitivity analysis without smearing	M
5. Variance estimation from the SSV data	M
6. Sensitivity analysis with appropriate weighting and/or bootstrapping	M
7. Abundance estimates treating as if abundance in gaps between two strata were 0.	L
8. Extrapolation of density in unsurveyed area	H
9. Abundance estimates accounting for change in order that the strata were surveyed	H
10. Estimation of additional variance	M
11. Revised annual increasing rate and its CV following suggestions1-8	M

Table 2. Comparison of effective half search width (esw) in each stratum with average among other years in the case that the detection function didn't has a clear shoulder. P_{old} represents abundance estimate in Hakamada *et al*. (2006). P_{new} represents abundance estimate substituting averaged esw instead of estimated one in the stratum.

stratum	Estimate (CV)	average	P_{old}	P_{new}/P_{old}
1991/92 NE in Area IV	0.504 (0.566)	0.672	2,828	0.750
1990/91 NE in Area V	0.260 (0.477)	0.639	26,152	0.407
1992/93 SE in Area V	0.668 (0.225)	0.729	25,795	0.916
1996/97 SE in Area V	0.596 (0.207)	0.729	63,532	0.818

Table 3. AIC and estimated esw for each model explained in the text. Bold letter indicates selected model by AIC.

IV N in closing mode

covariates	AIC	esw	CV
none	**701.3**	**0.332**	**0.150**
EW	727.4	0.631	0.061
year	734.6	0.419	0.063
EW+year	736.6	0.628	0.063

IV N in passing mode

covariates	AIC	esw	CV
none	573.2	0.397	0.173
EW	574.0	0.347	0.091
year	**570.0**	**0.401**	**0.086**
EW+year	572.1	0.431	0.084

IV S in closing mode

covariates	AIC	esw	CV
none	**2251.8**	**0.522**	**0.082**
EW	2294.4	0.824	0.031
year	2259.2	0.512	0.040
EW+year	2260.2	0.486	0.041

IV S in passing mode

covariates	AIC	esw	CV
none	2622.5	0.803	0.041
EW	2604.1	0.746	0.032
year	2614.9	0.733	0.032
EW+year	**2597.0**	**0.708**	**0.034**

PB in closing mode

covariates	AIC	esw	CV
none	967.0	0.662	0.120
year	**965.4**	**0.539**	**0.074**

PB in passing mode

covariates	AIC	esw	CV
none	**1362.3**	**0.675**	**0.117**
year	1363.3	0.660	0.049

V N in closing mode

covariates	AIC	esw	CV
none	**1159.7**	**0.416**	**0.110**
EW	1164.2	0.437	0.056
year	1168.8	0.393	0.060
EW+year	1179.2	0.423	0.065

V N in passing mode

covariates	AIC	esw	CV
none	**1182.4**	**0.473**	**0.142**
EW	1191.9	0.680	0.048
year	1186.7	0.451	0.060
EW+year	1189.1	0.441	0.062

V S in closing mode

covariates	AIC	esw	CV
none	4370.0	0.604	0.069
EW	4378.9	0.627	0.026
year	**4366.3**	**0.521**	**0.032**
EW+year	4369.4	0.530	0.031

V S in passing mode

covariates	AIC	esw	CV
none	6159.4	0.609	0.059
EW	6162.2	0.599	0.022
year	**6154.5**	**0.601**	**0.023**
EW+year	6156.2	0.583	0.023

Table 3. Coefficient of detection functions selected by AIC shown in Fig 10.

Area IV

	a	$se(a)$	b	$se(b)$	EW	$se(EW)$	y(91/92)	se	y(93/94)	se	y(95/96)	se	y(99/00)	se	y(01/02)	se	y(03/04)	se
N in closing mode	0.160	0.042	1.454	0.195														
S in closing mode	0.281	0.043	1.440	0.151														
PB in closing mode	0.265	0.190	1.539	1.694			0.764	0.979	-0.766	1.016	-0.374	1.028	0.109	1.097	0.701	1.006	0.455	1.131
N in passing mode	2.327	10.760	1.462	2.878									-2.357	3.952	-2.740	3.963	-2.083	3.957
S in passing mode	0.792	1.263	2.378	1.478	-0.411	0.116							0.128	0.383	-0.363	0.371	-0.090	0.394
PB in passing mode	0.376	0.093	1.262	0.235														

Area V

	a	$se(a)$	b	$se(b)$	EW	$se(EW)$	y(92/93)	se	y(94/95)	se	y(98/99)	se	y(00/01)	se	y(02/03)	se	y(04/05)	se
N in closing mode	0.217	0.042	1.510	0.178														
S in closing mode	0.310	0.089	1.000	0.751			-0.677	0.376	0.067	0.381	-1.606	0.986	-1.474	0.729	-0.114	0.554	-0.039	0.494
N in passing mode	0.213	0.062	1.184	0.175														
S in passing mode	0.365	0.063	1.098	0.560							-0.549	0.323	0.162	0.273	-0.396	0.203		

* b estimate of 1.000 in S in passing mode for Area V is lower bound.

Table 4. Estimate of extrapolation factor in unserveyed longitude band in SW stratum in Area IV.

statisitics	estimate	statisitics	estimate
$X_{74,1989}$	1.913	$X_{78,1989}$	0.876
$X_{74,1991}$	1.438	$X_{78,1991}$	2.840
$\hat{X}_{74}$	1.675	$\hat{X}_{78}$	1.935

Table 5. Comparison between previous estimates in Hakamada et al (2006) and the extrapolated estimates using extrapolation factors in Table 4.

	1993/94	2001/02	2003/04
previous	4,000	2,087	8,780
extrapolated	4,285	2,609	10,682

Table 6. Estimate of extrapolation factor in unserveyed longitude band in SW stratum in Area V using data in 2002/03.

statistics	estimate
Estimated correction factor	1.140
Previous abundance estimate	6,613
Extrapolated abundance	7,059

Table 7. Ratio of whale density in SW to that in PB for years examined and estimated one in PB in 2003/04.

	SW	PB	D_{SW}/D_{PB}
1989/90	0.071	0.062	0.874
1991/92	0.073	0.331	4.557
1993/94	0.106	0.172	1.615
1995/96	0.097	0.086	0.891
1999/00	0.241	0.257	1.068
2001/02	0.078	0.730	9.388
average			3.066
2003/04	0.278	0.702	

Table 8. Ratio of whale density in NW to that in NE for years examined and estimated one in NW in 2004/05.

	NE	NW	D_{NE}/D_{NW}
1990/91	0.076	0.128	1.699
1994/95	0.060	0.042	0.695
1996/97	0.052	0.036	0.684
average			1.026
2004/05	0.055	0.057	

Table 9. Comparison of abundance estimate in Area IV for between reference case (i.e. using average density of two strata) and sensitivity test.

	reference	sensitibity
1995/96	28,678	28,919
1999/00	45,549	42,852
2001/02	47,268	46,877
2003/04	55,363	46,975

Table 10. Estimated coefficients of the model in formula (8) applied to combined Areas IV and V, Area IV and Area V, respectively.

Combined Areas IV and V

	Estimate	Std. Error	t value	Pr(>|t|)
factor(S)41	7.681	0.704	10.912	<2e-16
factor(S)42	7.909	0.705	11.223	<2e-16
factor(S)43	8.441	0.660	12.793	<2e-16
factor(S)44	8.602	0.716	12.024	<2e-16
factor(S)45	8.256	0.711	11.606	<2e-16
factor(S)51	8.793	0.665	13.216	<2e-16
factor(S)52	9.890	0.735	13.46	<2e-16
factor(S)53	9.389	0.732	12.827	<2e-16
factor(S)54	9.834	0.694	14.175	<2e-16
factor(M)2	-0.113	0.218	-0.517	0.606
factor(M)3	-0.270	0.176	-1.536	0.127
y	-0.002	0.012	-0.16	0.873
I(T)	0.00754	0.02129	0.354	0.724
I(T^2)	0.00005	0.00017	0.272	0.786

Area IV

	Estimate	Std. Error	t value	Pr(>|t|)
factor(S)41	9.257	0.979	9.454	9.03E-15
factor(S)42	9.511	0.987	9.633	3.97E-15
factor(S)43	9.906	0.928	10.679	< 2e-16
factor(S)44	10.227	1.009	10.136	4.03E-16
factor(S)45	9.763	0.970	10.065	5.56E-16
factor(M)2	-0.194	0.301	-0.647	0.5196
factor(M)3	-0.281	0.249	-1.129	0.2623
y	0.0004	0.017	0.022	0.9827
I(T)	-0.04707	0.03079	-1.529	0.1302
I(T^2)	0.00048	0.00025	1.926	0.0576

Area V

	Estimate	Std. Error	t value	Pr(>|t|)
factor(S)51	6.949	0.992	7.005	1.59E-09
factor(S)52	7.851	1.086	7.226	6.41E-10
factor(S)53	7.328	1.080	6.785	3.90E-09
factor(S)54	7.975	0.999	7.979	2.89E-11
factor(M)2	0.031	0.311	0.1	0.9203
factor(M)3	-0.271	0.243	-1.114	0.2691
y	-0.011	0.016	-0.671	0.5043
I(T)	0.07155	0.03132	2.284	0.0256
I(T^2)	-0.00042	0.00023	-1.806	0.0755

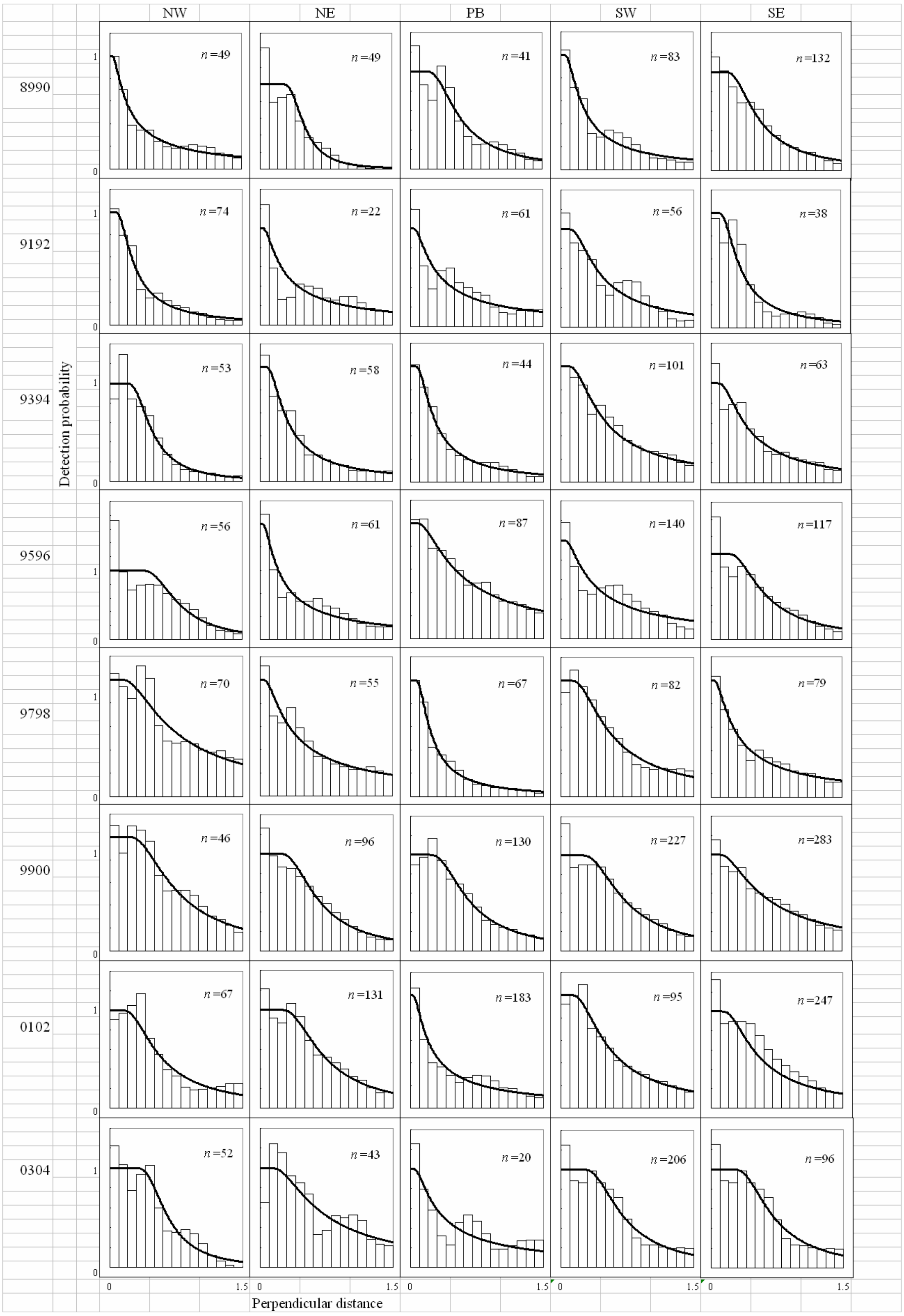


Fig. 1. Detection functions for each stratum in Area IV by SSVs. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

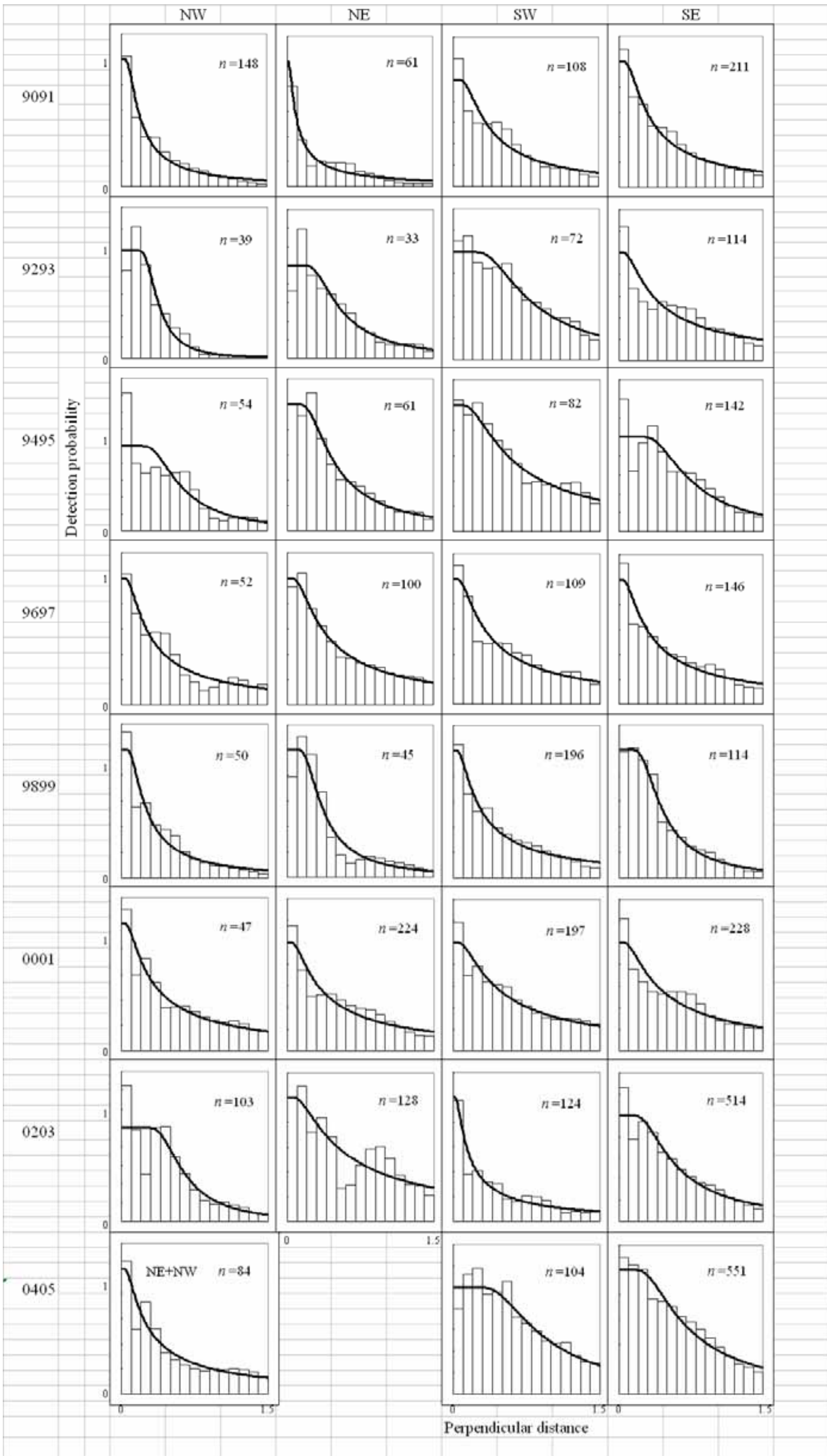


Fig. 2. Detection functions for each stratum in Area V by SSVs. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

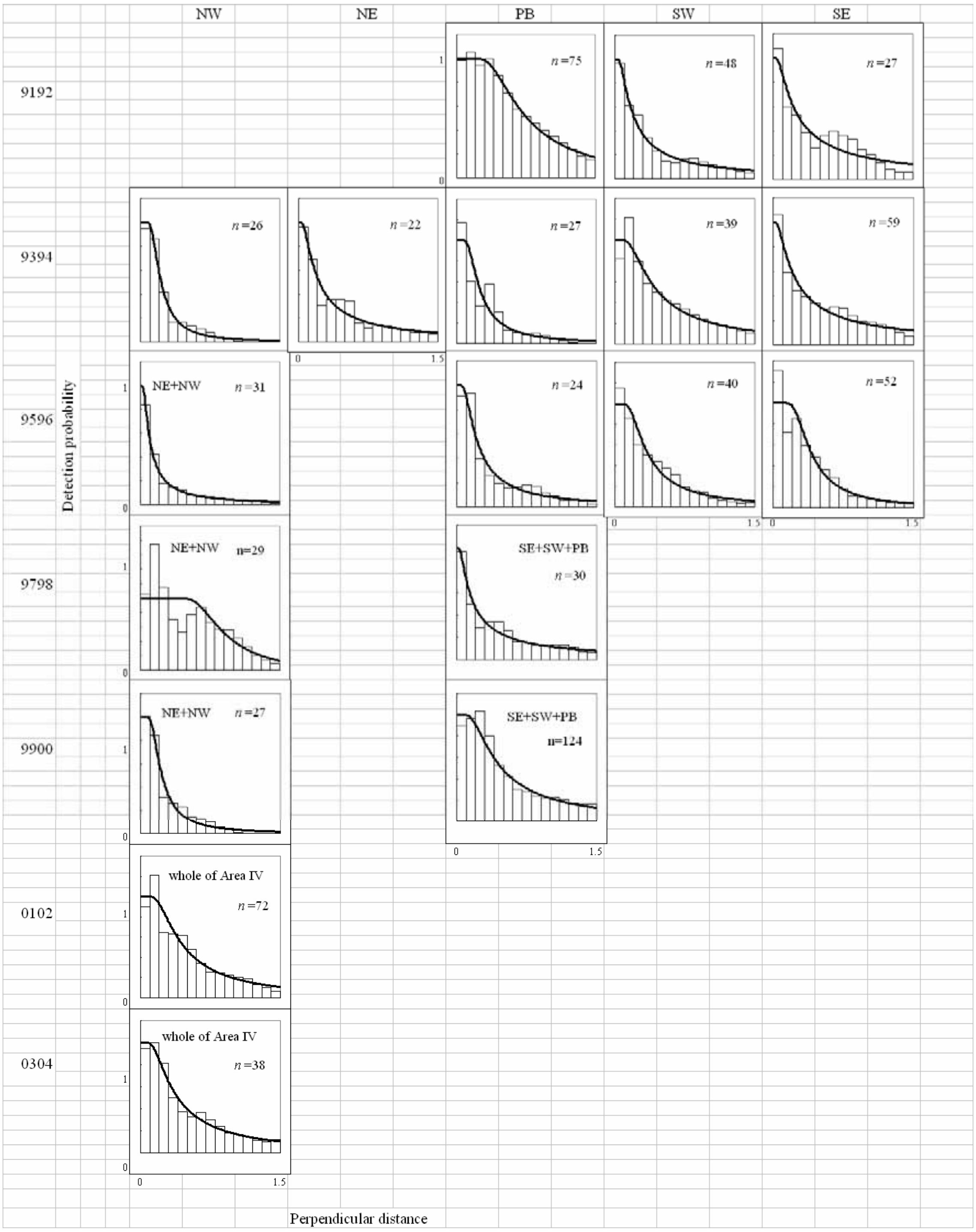


Fig. 3. Detection functions for each stratum in Area IV by SV in closing mode. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

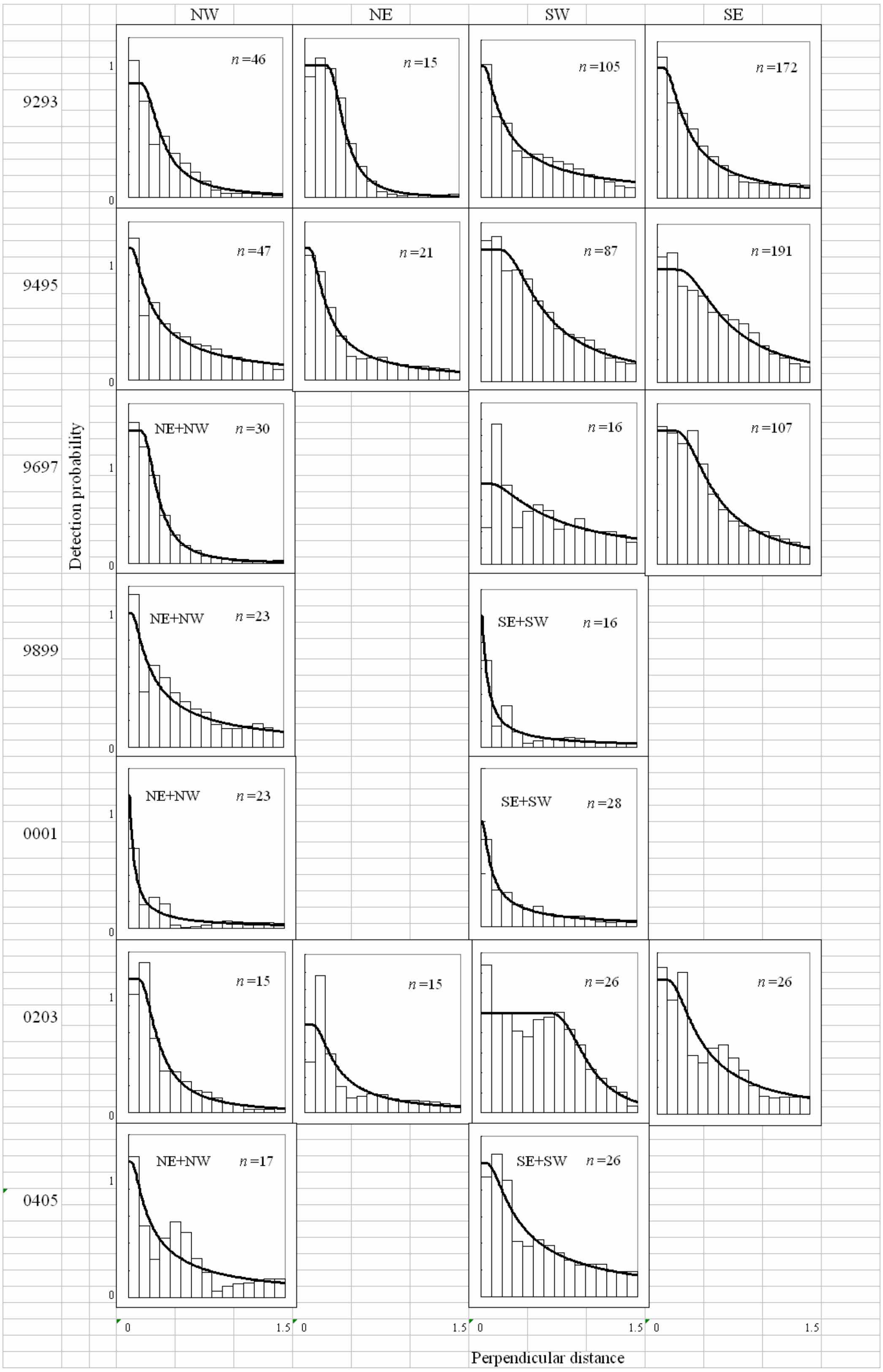


Fig. 4. Detection functions for each stratum in Area V by SV in closing mode. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

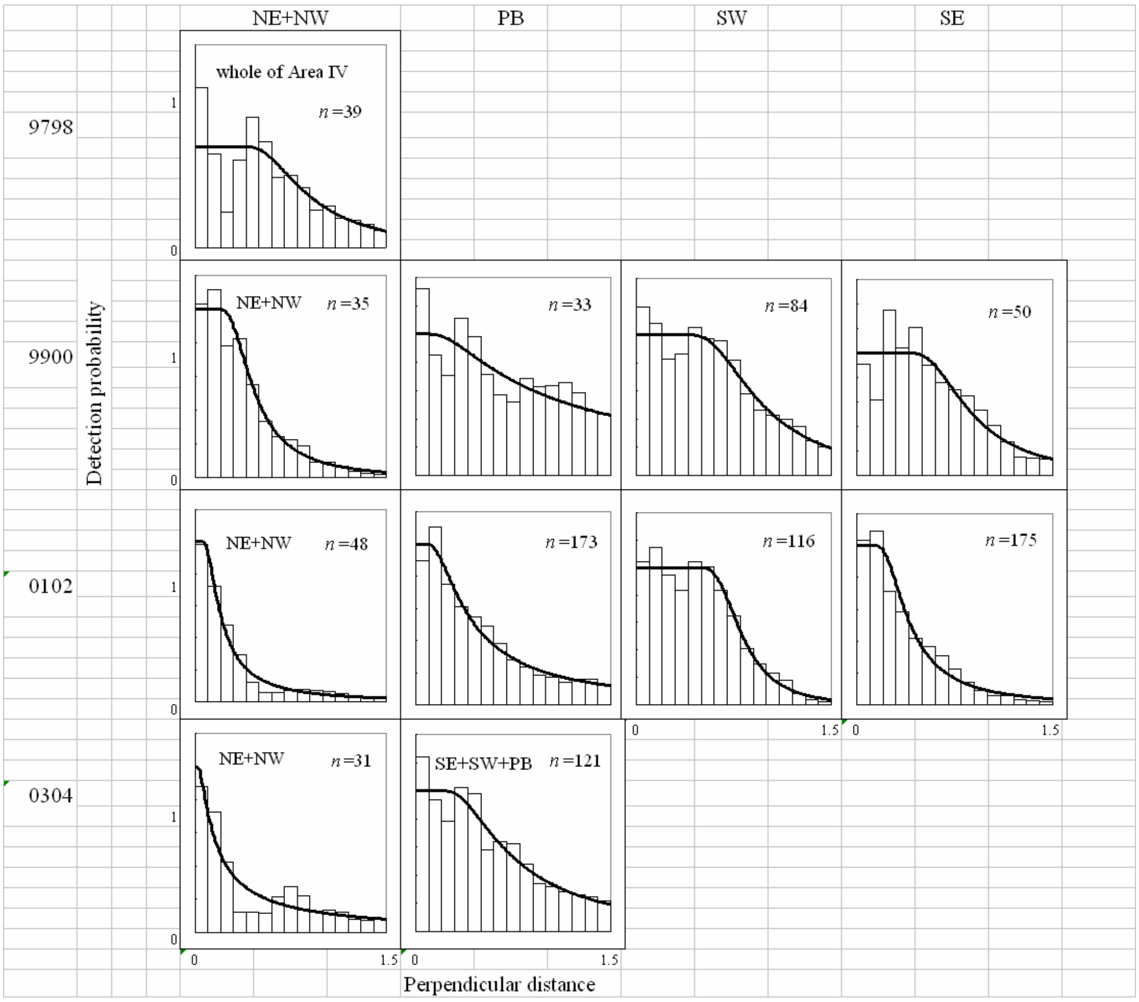


Fig. 5. Detection functions for each stratum in Area IV by SV in passing mode. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

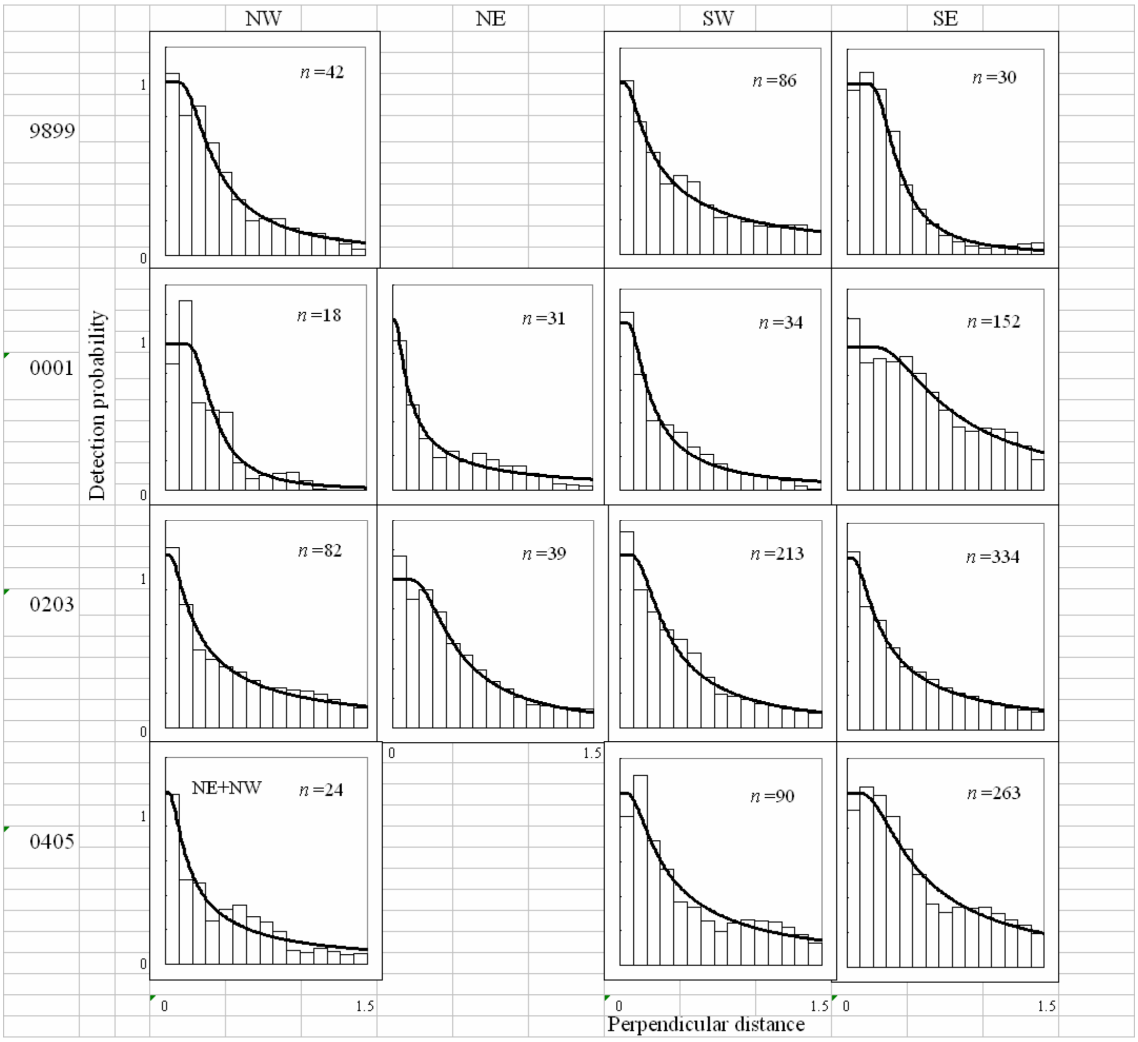
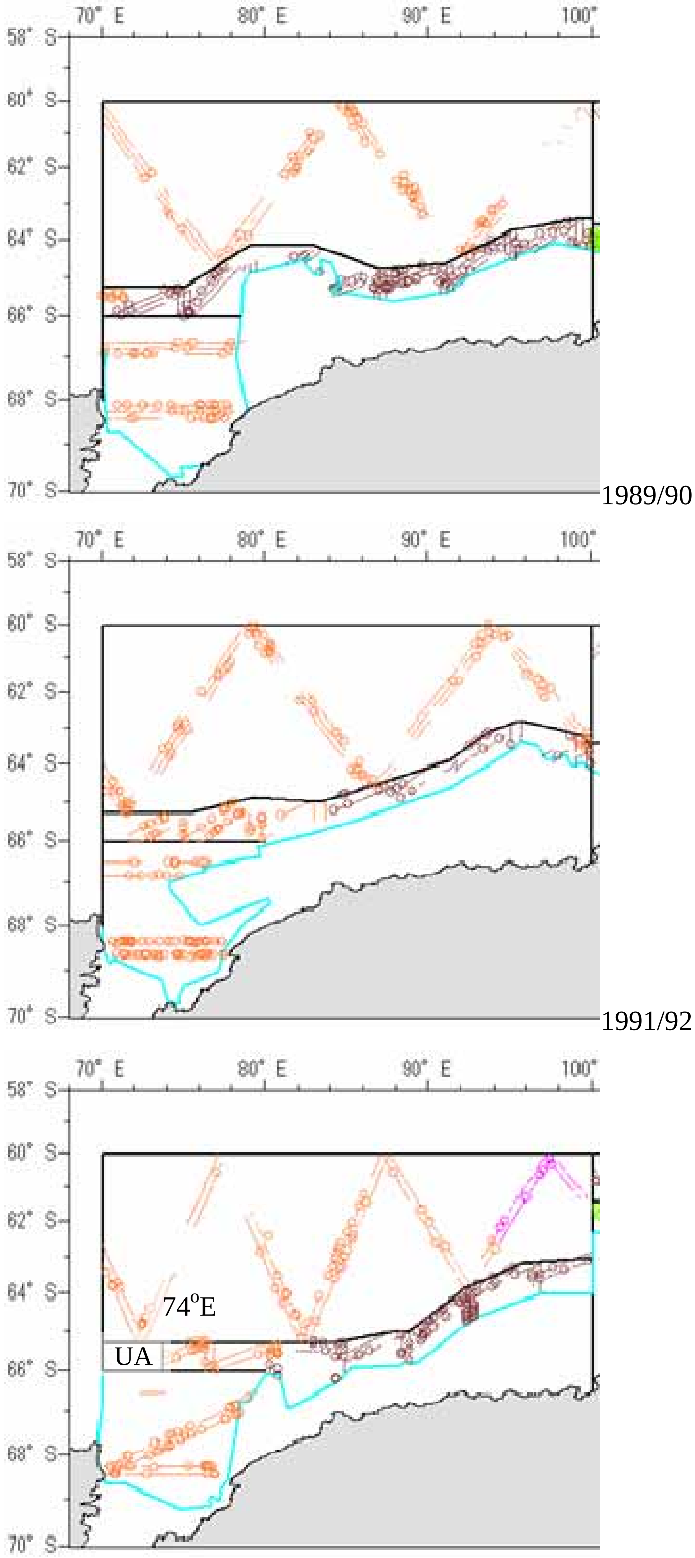
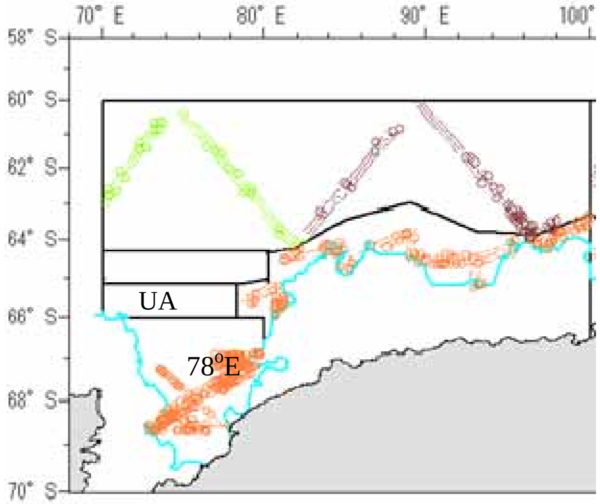


Fig. 6. Detection functions for each stratum in Area V by SV in passing mode. *n* is the number of sightings within stratum (before smearing) used for estimation of detection function.

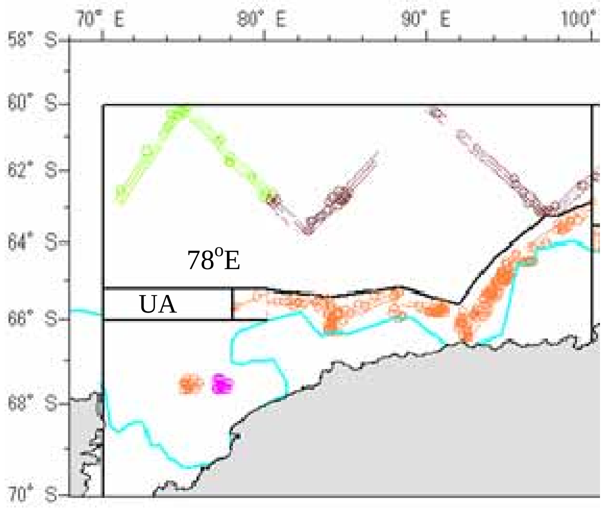


1993/94

Fig. 7. Distribution of sighting effort in western part of Area IV (70-100°E) south of 60°S for 1989/90, 1991/92, 1993/94, 2001/02 and 2003/04 and unsurveyed area (UA) in SW stratum from the top for 1993/94, 2001/02 and 2003/04, respectively.



2001/02



2003/04

Fig 7 (continued).

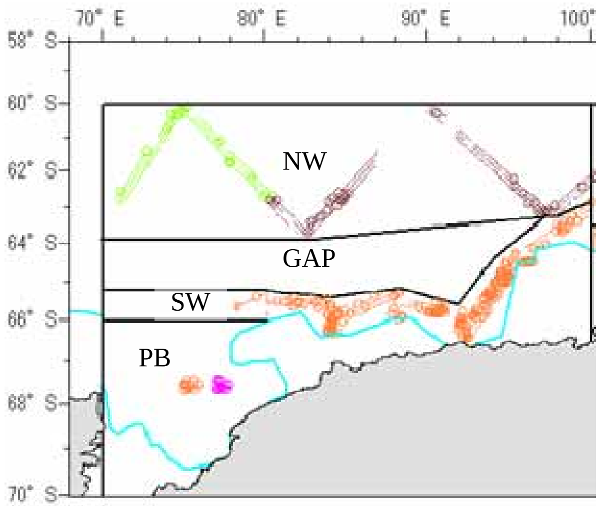
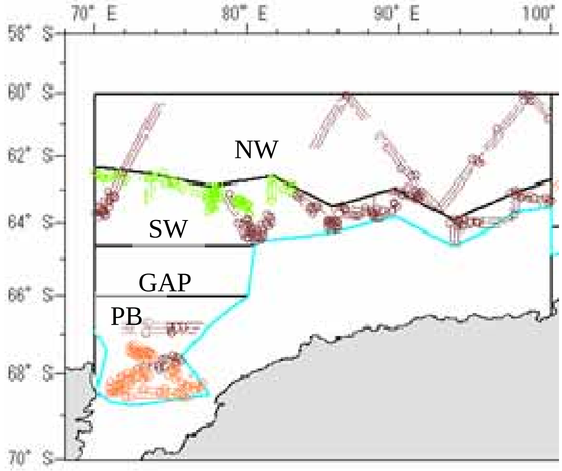
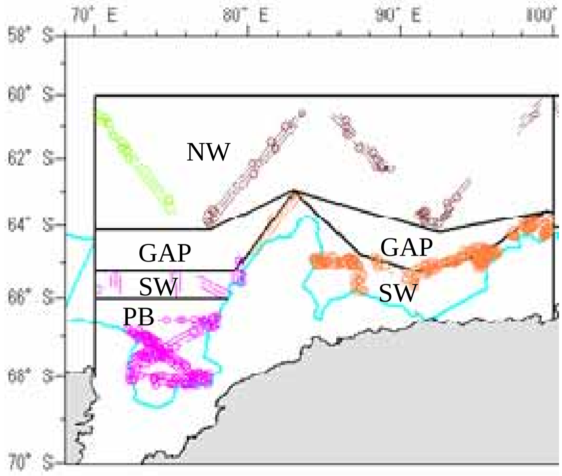


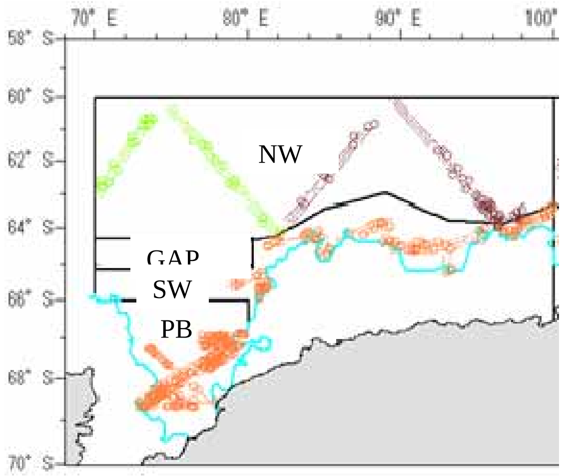
Fig. 8.Coverage in Prydz Bay (south of 66°S) was low in 2003/04. NW, SW, PB and GAP represents North-West, South-West, Prydz Bay strata and the gap respectively.



1995/96

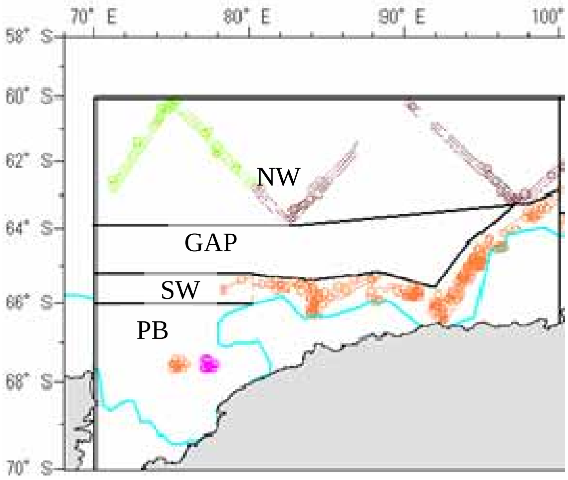


1999/2000



2001/02

Fig 9. Gaps between two strata in western part of Area IV for 1995/96, 1999/2000, 2001/02 and 2003/04.



2003/04

Fig. 9. (Continued.)

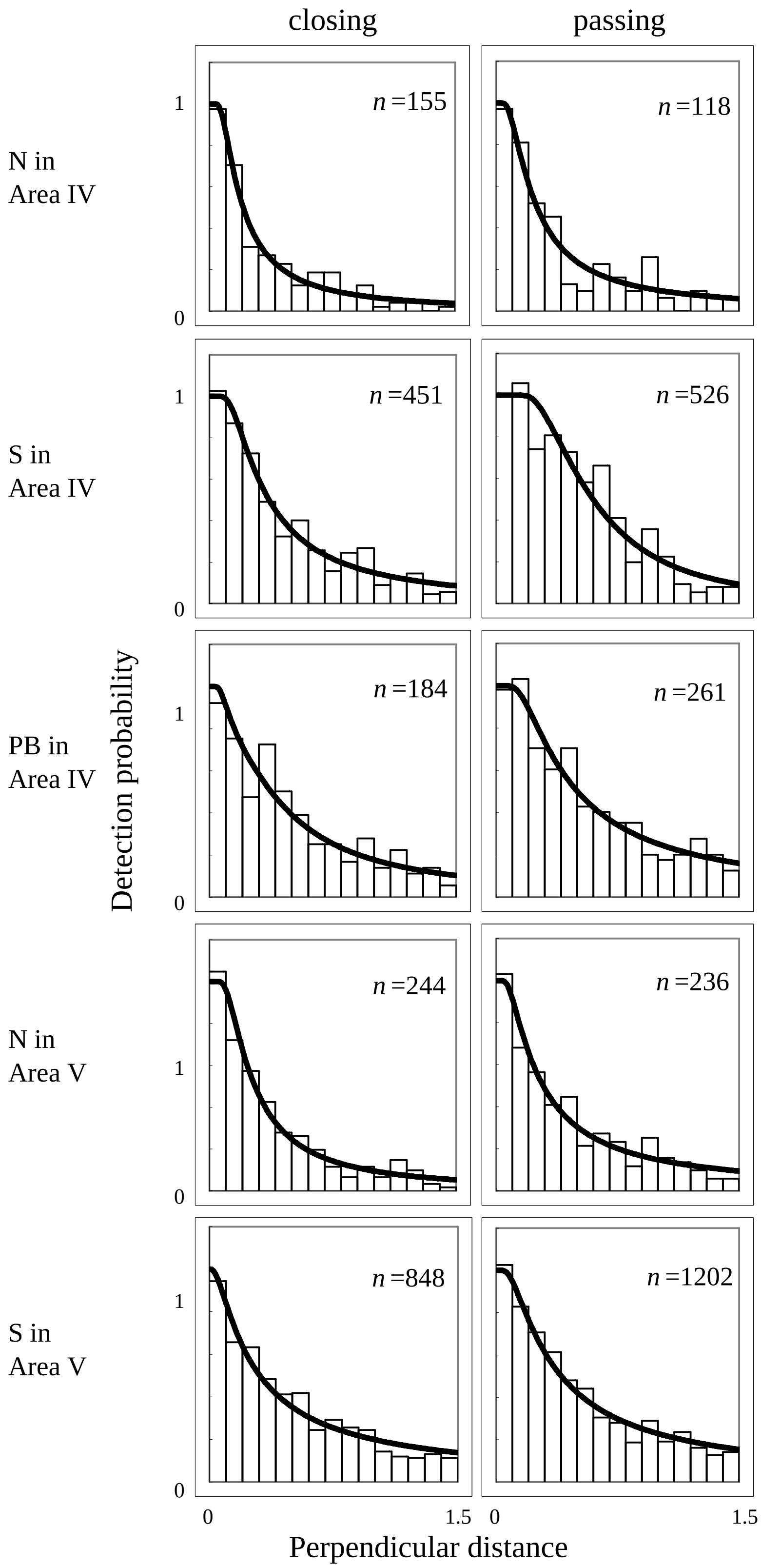
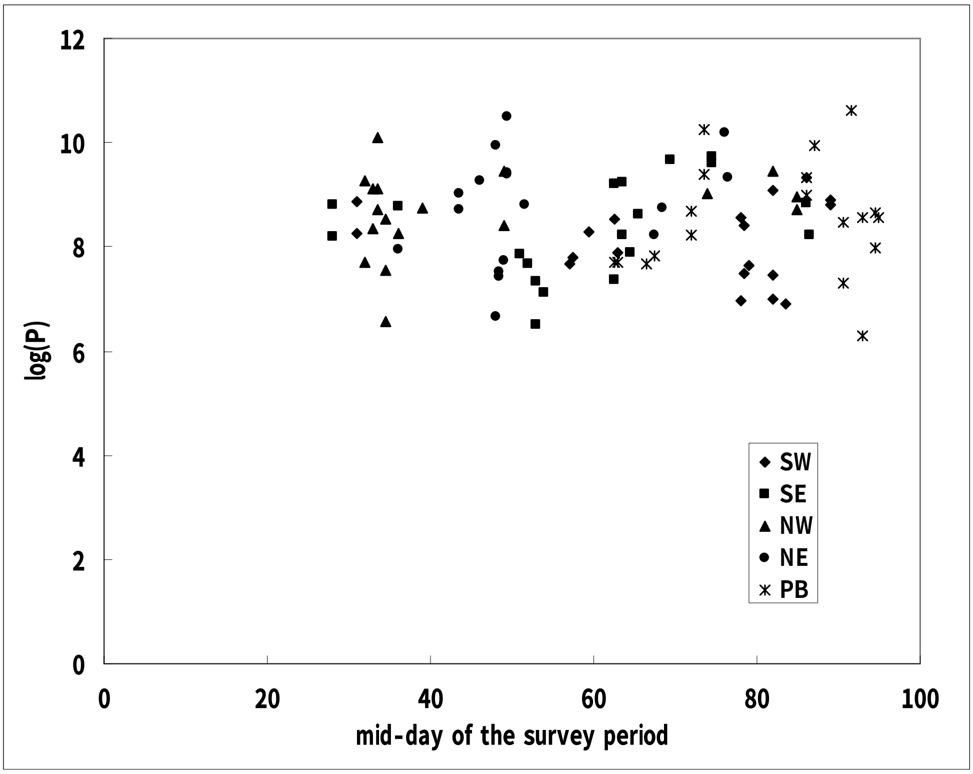


Fig. 10. Detection function pooled data over years for SV incorporating covariates.

Area IV



Area V

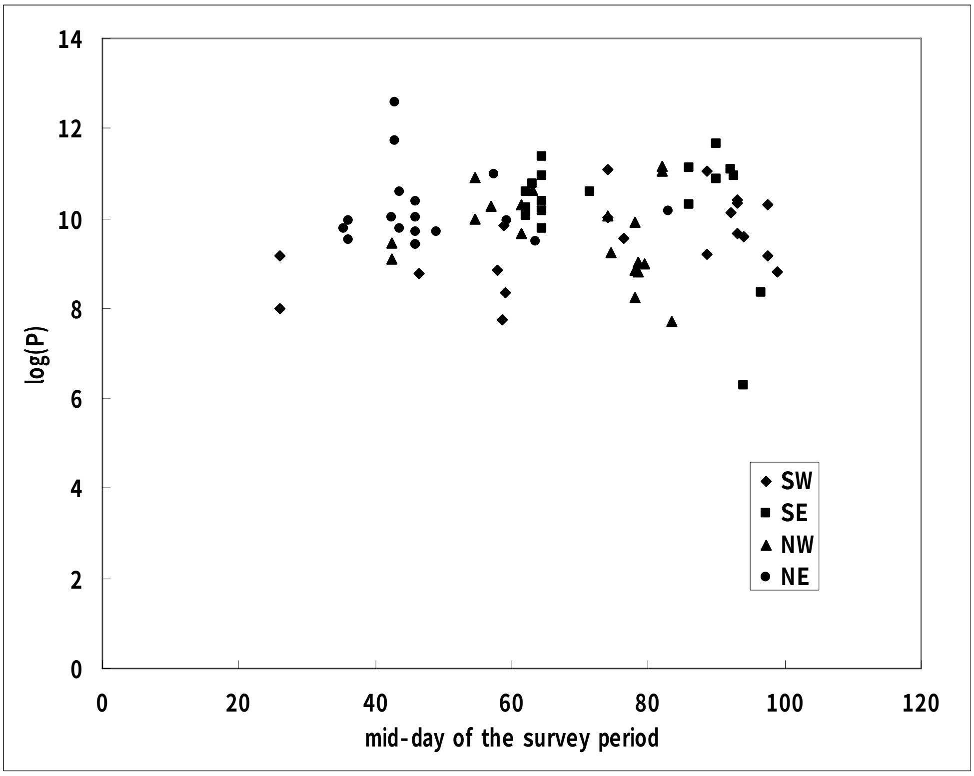


Fig. 11. Plot of mid-day of the survey period and log of abundance estimate for each stratum.