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Further Examination of Segregation Pattern of Minke Whales in Antarctic Areas IV and V as revealed by a Logistic Regression Model

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ABSTRACT

To make clear the segregation pattern of minke whales in the Antarctic, a logistic model is applied incorporating a variable selection methods for biological parameters such as proportion of males, maturity rate for males and females. The results revealed the follows: the proportion of males related negatively to latitude of sighting position, and the decreased with latitude in both Areas, especially in Area V. The maturity rate was always high in both research areas and all the survey periods, and related positively to the size of whale schools, mature females were dominant in Area V and the females maturity rate related positively to latitude, and increased with latitude. Higher values were obtained in the southernmost regions such as the Prydz Bay and Ross Sea. Inter-annual variation was observed for the maturity rate in both sexes in Area V.

INTRODUCTION

The JARPA have been conducted since the 1987/88 austral season. One of the principal objectives of this programme is the estimation of biological parameters such as natural mortality rate, net recruitment rate, etc. of the Southern Hemisphere minke whales, *Balaenoptera acutorostrata*. It become to be important to make clear seasonal variations in the migration patterns of minke whales. The heterogeneities of some biological parameters such as the sex ratio, maturity rates and mean ages for both sexes in the research areas were studied, using model selection (Kato *et al.*, 1990, 1991; Fujise *et al.*, 1990, 1991, 1992; Fujise and Kishino, 1994; Kishino *et al.*, 1991a, 1991b). However, in these studies it could not concluded that the seasonal changes of these parameters into the analyses as serial variation factors.

In this paper, we modified a simple logistic regression model in previous study (Kishino *et al.*, 1991b, Fujise and Kishino, 1994) to incorporate variable selection method, and examined the temporal and spatial changes in the segregation of minke whales in the feeding ground, using data from the JARPA cruises from 1987/88 to 1995/96 seasons, and the segregation patterns of minke whales are discussed.

MATERIALS AND METHODS

Whale samples and data used

Minke whale samples used in this study were obtained by the JARPA survey conducted in Antarctic Areas IV and V from 1987/88 to 1995/96. A summary of the samples used in this study

is listed in Table 1. These samples were covered all over the research area (Fig. 1).

In order to examine the seasonal and areal changes in the proportion of males in samples and the mean maturity rates of both sexes, the following data were used: survey date, sighting position and school size. The survey date was converted to the cumulative day as the serial number of date from 1 November for each survey.

Sexual maturity

Females were regarded as sexually mature if at least one corpus luteum or albicans was presented in either side of ovaries. Sexual maturity of males was determined by the histological examination of testis tissues, which were collected from the center of the right testis. Males with seminiferous tubules over 100*u*m diameter (average of 15-20 measurements) or males with sperm in the tubule were determined to be sexually mature (Kato, 1986; Kato *et al.*, 1990, 1991).

Estimation of parameters and their variances

A biological parameter p, such as proportion of males or sexual maturity rates of males and females, is assumed to be expressed as following:

$$\log\left(\frac{p}{1-p}\right) = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \qquad (1),$$

where x_1 is latitude, x_2 longitude, x_3 survey date and x_4 size of whale school. Parameters of a and b_i (i=1,..,4) were estimated by pseudo maximum likelihood procedure (Skinner, 1989; Kishino *et al.*, 1991b). In this study, we applied a variable selection forward and backward method to make clear what parameter is most important to the variation of the biological parameter p. All variables were standardized before the analysis. To estimate variances for parameters a and b_i, we took into account of the aspect of the two stage random sampling procedure. Here, the primary sampling unit is the survey date, and the secondary one is the individual information.

RESULTS

Distribution pattern of whale samples

Figs. 2-5 show the geographic distribution of whale samples collected in JARPA surveys from 1987/88 to 1994/95, by sex and maturity status and by month. In these figures , the following trends are observed on the distribution of minke whale samples.

Mature females (Fig. 5) were migrated in December, and exist in the ice edge region which was allocated in the northward. With melt the sea ice in January, these animals were moved far south and migrated to near ice edge and the Prydz Bay and the Ross Sea in austral summer (February). In the summer, it is clear that the mature females were dominant in the Prydz Bay and the Ross Sea.

Mature males (Fig. 3) also migrated in December, and tend to be distributed in all over the research area although these animals moved with the melting of sea ice. The mature male also tend to be make a school in the near ice edge region.

In contrast, most of immature animals was observed in the offshore region (Figs. 2 and 4), although few animal was observed in near ice edge and the Prydz Bay and the Ross Sea in summer season. Immature females tend to be similar migrating pattern to mature males (Fig 4), however no trend was observed to make a school as shown for mature males. Immature males tend to migrated in later than other animals (Fig. 2).

Proportion of males

Table 2 shows the estimated parameters of the logistic model for the proportion of males in the sample with and without the variable selection.

When the all parameters are applied to this model, all estimates of parameter a in Area IV is positive values, and it differ significantly from zero in four of the five surveys in this Area. This parameter a is also selected even if the variable selection is applied. In contrast, the estimates of this parameter in Area V were negative or not significant, and this parameter is not selected or estimate a lower value when the variable selection applied. This indicate that the proportion of males is relatively high in Area IV in constant, but the proportion in Area V is relatively low and more fluctuated by year.

Estimated parameter b_1 for latitude showed negative values in all surveys in both Areas IV and V, and this parameter was selected in eight of the nine surveys even if the variable selection is applied. Furthermore, all of these estimates on Area V had values which were significantly different from zero . This indicates the proportion of males decreased with latitudes in both areas, especially Area V.

Parameter b_3 (cumulative day) was also significant in two of the four surveys in Area V, and also selected when the variable selection is applied.

Figs. 6 and 7 show the spatial and seasonal changes of the proportion of males in Areas IV and V, respectively, using the results of the applied variable selection. In these figures, other variables such as school size and the cumulative day from 1 November, were settled tentatively as follows: school of two whales, and four dates of the 45th, 76th, 107th and 145th days (i.e. 15 December, 15 January, 15 February and ca. 15 March).

In all the surveys in Areas IV and V, the proportion of males was high in the northern part of the research area, and decreased with latitude with except for those in 1987/88 season. Furthermore, the proportion in Area V tended to increase with progress of the season in three of the four surveys, but the seasonal changes of the proportion is not observed in Area IV.

Male maturity rate

Estimated parameter values of mean maturity rate on males are shown in Table 3. The results of the variable selection of the male maturity rate in Area IV and V are also shown in Figs. 8 and 9, respectively.

When all parameters were applied, all estimates of the parameter a were positive and significantly differ from zero in both Areas IV and V. This indicates that mature males were dominant in both Areas. In three of five surveys in Area IV, this maturity rate is also related to the size of whale school (b_4) positively. Eight of nine estimates for parameter b_1 (latitude) in both Areas IV and V are positive values, although only one estimate was significantly different from zero (1988/89 survey in Area V). The male maturity rate is also correlated significantly to the cumulative day (b_3) in two of the four surveys in Area V, but it was varied by survey season in this Area.

However, when the variable selection is applied, the results is differed the above. Most of the maturity rate are related to their school size, and seven of nine surveys the parameter (b_4) was selected. It is clear that the sexual maturity of male were remarkably related their school size (Figs. 8 and 9).

Female maturity rate

Estimated values of mean maturity rate in females are shown in Table 4. Figs. 10 and 11 show the results of the variable selection of the female maturity rate in Area IV and V, respectively.

When all variables are used, all estimates of the parameter a in Area V were positive and

significantly different from zero. This indicates that mature females were dominant in Area V.

If the variable selection is applied, in most of surveys the parameter b_1 (latitude) was selected in both Areas IV and V and the estimate is larger than other parameter. This suggests that maturity rate of female increased with latitude. Furthermore, in seven of the nine surveys the b_4 was selected and the maturity rate also related to the school size, although it was not significant. Fig. 12 shows the monthly changed of geographical pattern of the maturity rate in 1990/91 season, it is clear that most of variation of the rate was varied in the northern part of the research area.

Inter-annual variation of the biological parameters

Table 5 show the comparison of AIC's values to examine inter-annual changes of these biological parameters. The model for no inter-annual change of the male proportion are selected in both Areas IV and Area V. However, the maturity rates in both sexes are observed inter-annual changed in Area V.

DISCUSSION

In order to incorporate the variables of the sighting date and location as serial factors into the analysis of the segregation of southern minke whales in the Antarctic Areas IV and V, we adopted a simple logistic regression model incorporate to the variable selection. From this examination, the following patterns of segregation were obtained:

Sex ratio:

1) the proportion of males was relatively high in Area IV,
2) the proportion of males related negatively to latitude, and decreased with latitude in both Areas, especially in Area V,
3) the proportion of males increased with progress of season.

Male maturity rate:

1) the maturity rate was always high in both research areas and all the survey periods,
2) this rate was related positively to the size of whale schools,
3) inter-annual variation was observed in Area V.

Females maturity rate:

1) mature females were dominant in Area V,
2) the maturity rate related positively to latitude, and increased with latitude. Higher values were obtained in the southernmost regions such as the Prydz Bay and Ross Sea,
3) inter-annual variation was observed in Area V.

These trends obtained from this analysis, were generally consistent with the results of the previous studies (Fujise *et al.*, 1992, Fujise and Kishino, 1994). Furthermore, we could identified which parameter is most attributable to variation of the biological parameters such as proportion of males, sexual maturity rated for males and females.

However, we could not examined fully in this paper on the interactions of parameter, and further analysis should be done on this aspect in the future. Furthermore, in future analyses we would incorporate with the information abundance of minke whales, prey species such as Antarctic krill, and other oceanographical information after these database are completed.

ACKNOWLEDGMENTS

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REFERENCES

Fujise, Y., Kato, H. and Kishino, H. 1990. Reproductive segregation of the minke whale population in high latitudinal waters with some examination of pregnancy and sexual maturity rates, data from the Japanese research takes in 1987/88 and 1988/89. Paper SC/42/SHMi30 presented to the IWC Scientific Committee, June 1990 (unpublished). 20pp.

Fujise, Y., Kato, H. and Kishino, H. 1991. Some progress in examination on age distribution and segregation of the southern minke whale population using data from the Japanese research take. Paper SC/43/Mi18 presented to the IWC Scientific Committee, May 1991 (unpublished). 17pp.

Fujise, Y., Kato, H., Zenitani, R. and Kishino, H. 1992. Seasonal and areal changes in age distribution and segregation of the southern minke whales in Antarctic Area IV and V using data from the Japanese researches. Paper SC/44/SHB10 presented to the IWC Scientific Committee, June 1992 (unpublished). 37pp.

Fujise, Y. and Kishino, H. 1994. Patterns of segregation of minke whales in Antarctic Areas IV and V as revealed by a logistic regression model. Paper SC/46/SH11 presented to the IWC Scientific Committee, June 1994 (unpublished). 23pp.

Kato, H. 1986. Study on changes in biological parameters and population dynamics of southern minke whales. Doctoral Thesis, Hokkaido University. 145pp. (in Japanese).

Kato, H., Kishino, H. and Fujise, Y. 1990. Some analyses on age composition and segregation of southern minke whales using samples obtained by the Japanese feasibility study in 1987/88. *Rep. int. Whal. Commn* 40:249-56.

Kato, H., Fujise, Y. and Kishino, H. 1991. Age structure and segregation of southern minke whales by the data obtained during Japanese research take in 1988/89. *Rep. int. Whal. Commn* 41:287-92.

Kishino, H., Kato, H., Kasamatsu, F. and Fujise, Y. 1991a. Detection of heterogeneity and estimation of population characteristics from the field survey data: 1987/88 Japanese feasibility study of the Southern Hemisphere minke whales. *Ann. Inst. Statist. Math.* 43(3):435-53.

Kishino, H., Fujise, Y., Kato, H. and Taga, Y. 1991b. Maximum likelihood procedure for the estimation of the mean age at sexual maturity of minke whales using the data from Japanese research take. Paper SC/43/Mi23 presented to the IWC Scientific Committee, May 1991 (unpublished). 9pp.

Skinner, C.J. 1989. Domain means, regression and multi-variate analysis. pp. 59-88. *In:* C.J. Skinner, D. Holt and T.M.F. Smith (eds.) *Analysis of Complex Surveys.* John Wiley and Sons Ltd., New York, 309pp.

Table 1. Number of samples of minke whales used in this study.

Area IV

	1987/88	1989/90	1991/92	1993/94	1995/96*	Combined
Male	153	184	165	200	272	974
Female	119	142	123	130	167	671
Total	272	326	288	330	440	1,656

Area V

	1988/89	1990/91	1992/93	1994/95	Combined
Male	85	164	167	200	616
Female	151	159	160	130	600
Total	236	323	327	330	1,216

*: One male individual was unknown for maturity status.

Table 2. Estimated parameters of the logistic regression model for the proportion of males.

Area IV

	1987/88		1989/90		1991/92		1993/94		1995/96	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used										
a	0.323 *	0.133	0.222	0.168	0.367 *	0.171	0.368 *	0.148	0.396 *	0.117
b 1	-0.439	0.224	-0.353	0.268	-0.574 *	0.194	-0.414 *	0.183	-0.459 *	0.167
b 2	0.184	0.158	-0.078	0.161	-0.021	0.189	-0.189	0.282	0.172	0.172
b 3	0.043	0.159	-0.055	0.192	0.183	0.172	0.136	0.266	-0.123	0.215
b 4	0.251	0.203	0.120	0.145	-0.246	0.192	0.049	0.145	-0.034	0.137
AIC	369.5		460.1		380.9		452.4		571.5	
2. variable selection										
a	0.061	0.090	0.148	0.136	0.271	0.143	0.198	0.118	0.258 *	0.109
b 1			-0.394	0.594	-0.747	0.613	-0.243	0.493	-0.522	0.337
b 2									0.073	0.225
b 3	-0.252	0.234								
b 4										
AIC	361.0		439.1		373.5		439.6		555.7	

Area V

	1988/89		1990/91		1992/93		1994/95	
	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used								
a	-0.544 *	0.190	-0.225	0.201	0.047	0.158	0.384 *	0.187
b 1	-0.918 *	0.256	-1.800 *	0.385	-0.903 *	0.295	-1.062 *	0.497
b 2	0.002	0.191	0.739 *	0.233	0.159	0.238	-0.374	0.303
b 3	0.436 *	0.190	0.448	0.227	0.606 *	0.201	0.247	0.450
b 4	0.079	0.169	-0.046	0.105	-0.110	0.139	0.111	0.185
AIC	293.2		383.3		433.9		402.7	
2. variable selection								
a			0.024	0.079	0.024	0.079	0.455 *	0.114
b 1	-0.765 *	0.179	-0.903 *	0.295	-0.903 *	0.295	-0.889 *	0.295
b 2	0.415	0.272	0.159	0.238	0.159	0.238		
b 3			0.605 *	0.201	0.605 *	0.201		
b 4			-0.109	0.139	-0.109	0.139		
AIC	285.2		433.9		433.9		373.5	

*: the estimate significantly differ from zero.

Parameter: a: constant, b_1: latitude, b_2: longitude, b_3: cumulative day, b_4: school size

Table 3. Estimated parameters of the logistic regression model for male maturity rate

Area IV

	1987/88		1989/90		1991/92		1993/94		1995/96	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used										
a	1.634 *	0.494	3.286 *	0.742	2.647 *	0.537	1.673 *	0.357	2.550 *	0.385
b 1	0.216	0.453	0.641	0.393	0.313	0.320	0.413	0.262	0.256	0.214
b 2	0.100	0.296	0.785	0.442	-0.424	0.256	-0.323	0.337	0.039	0.314
b 3	-0.193	0.373	-0.353	0.364	0.250	0.243	-0.262	0.300	-0.145	0.359
b 4	1.966	1.148	2.284 *	0.832	1.997 *	0.762	1.561	0.959	2.482 *	0.594
AIC	190.4	7.4	124.1	9.9	138.3	7.2	209.7	9.7	249.9	9.7
2. variable selection										
a										
b 1	0.500	0.499	0.769	0.417					0.215	0.415
b 2	0.500	0.578								
b 3	0.500	0.703								
b 4	0.500	0.292	2.479 *	0.875	2.705 *	0.607	1.567 *	0.277	2.223 *	0.42
AIC	153.1		119.9		133.4		203.9		234.0	

Area V

	1988/89		1990/91		1992/93		1994/95	
	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used								
a	1.924 *	0.499	2.942 *	0.400	4.779 *	1.777	2.319 *	0.572
b 1	0.648 *	0.298	0.611	0.431	-0.871	0.510	0.992	0.548
b 2	-0.569	0.329	-0.213	0.490	0.784	0.475	-0.578	0.328
b 3	-1.299 *	0.460	-0.597	0.412	0.936 *	0.450	-0.382	0.405
b 4	-0.634	0.411	0.481	0.303	4.236	2.366	1.532	1.045
AIC	76.9	6.3	72.3	6.7	103.1	9.5	183.7	9.5
2. variable selection								
a	1.011 *	0.283	1.438 *	0.169				
b 1								
b 2	0.042	1.834						
b 3	-0.676	1.972						
b 4					4.975 *	1.263	2.413 *	0.624
AIC	69.6		70.1		99.6		180.9	

*: the estimate significantly differ from zero.

Parameter: a: constant, b_1: latitude, b_2: longitude, b_3: cumulative day, b_4: school size

Table 4. Estimated parameters of the logistic regression model for female maturity rate

Area IV

	1987/88		1989/90		1991/92		1993/94		1995/96	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used										
a	-0.455	0.266	0.429	0.231	1.133 *	0.294	0.028	0.255	0.766 *	0.220
b 1	2.166 *	0.525	0.523	0.352	0.326	0.316	0.899 *	0.344	1.078 *	0.315
b 2	-0.041	0.286	0.289	0.282	-0.089	0.256	-0.243	0.450	-0.067	0.258
b 3	0.088	0.240	0.183	0.248	-0.046	0.274	0.202	0.410	-0.795 *	0.305
b 4	0.587	0.320	-0.084	0.243	1.248 *	0.521	0.337	0.429	0.756	0.438
AIC	110.9	6.4	198.4	5.8	158.0	5.8	167.3	6.1	202.1	
2. variable selection										
a	-2.781 *	0.558							0.383 *	0.110
b 1	2.218 *	0.442	0.523 *	0.211			0.711 *	0.347	1.077 *	0.315
b 2									-0.068	0.258
b 3									-0.795 *	0.305
b 4	-0.013	0.309			1.017 *	0.289	1.316	1.556	0.758	0.439
AIC	105.9		186.9		147.0		144.2		202.1	

Area V

	1988/89		1990/91		1992/93		1994/95	
	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used								
a	1.204 *	0.246	2.125 *	0.361	1.310 *	0.252	1.170 *	0.291
b 1	1.155 *	0.303	0.925	0.643	0.857 *	0.344	0.906	0.577
b 2	0.274	0.324	0.406	0.456	-0.187	0.347	-0.461	0.390
b 3	-0.340	0.359	-0.540	0.272	-0.104	0.272	0.620	0.535
b 4	-0.140	0.197	-0.196	0.172	-0.077	0.214	0.886 *	0.441
AIC	161.1	7.1	168.5	8.3	195.3	6.1	147.2	6.9
2. variable selection								
a			1.060 *	0.179	0.711 *	0.132		
b 1	1.076 *	0.234	0.924	0.641	0.622 *	0.279	1.117 *	0.260
b 2	0.460	0.517	0.402	0.455				
b 3			-0.539	0.272				
b 4			-0.196	0.172	0.781	0.883	1.089	0.564
AIC	155.7		168.4		180.7		139.5	

*: the estimate significantly differ from zero.

Parameter: a: constant, b_1: latitude, b_2: longitude, b_3: cumulative day, b_4: school size

Table 5. Comparison of AIC's values in models including or excluding inter-annual variation of the biological parameters such as proportion of males, maturity rates for male and females.

	Area IV		Area V		Combined	
	Changed by year	Unchaned by year	Changed by year	Unchanged by year	Changed by year	Unchanged by year
Proportion of males	2234.4	2169.0	1513.1	1444.0	3747.5	3582.0
Male maturity rate	912.4	851.4	436.0	493.6	1348.4	1418.0
Female maturity rate	836.7	825.7	672.1	692.0	1508.8	1547.0

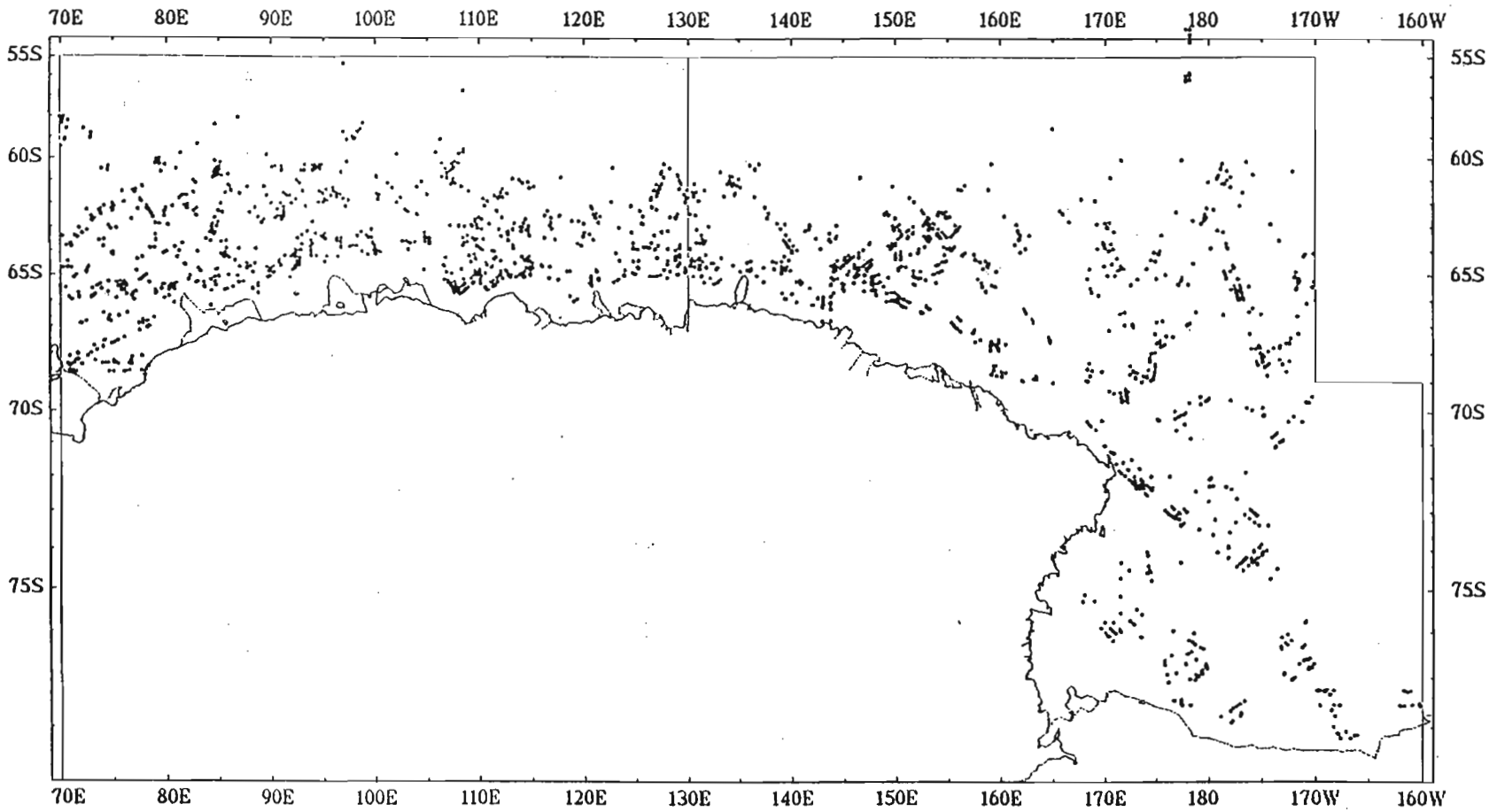

Fig. 1. Geographical distribution of 2,872 minke whales collected by the JARPA surveys during 1987/88 - 1995/96.

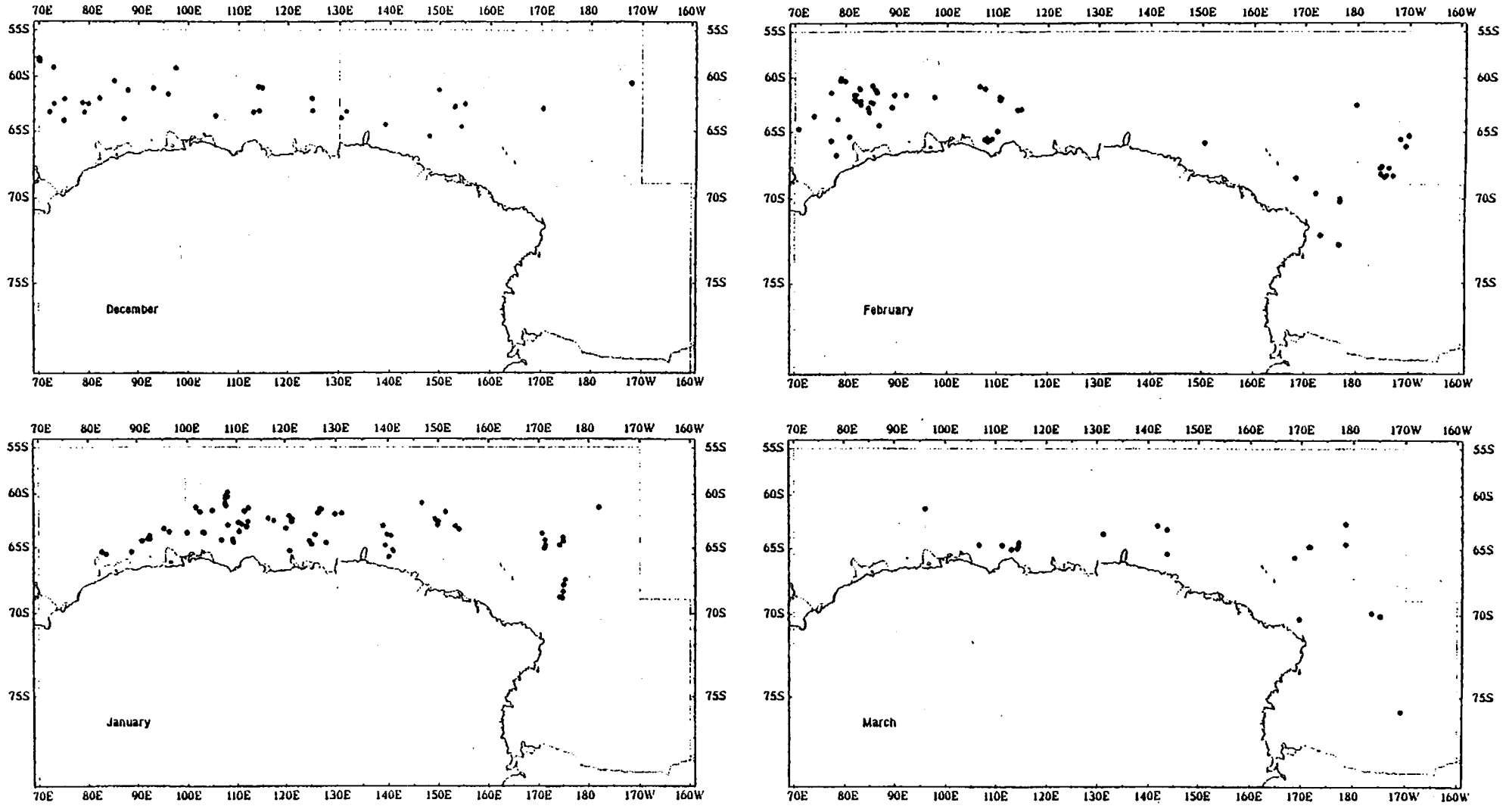

Fig. 2. Monthly changes of geographical distribution of immature male minke whales collected by the JARPA surveys during 1987/88 - 1994/95.

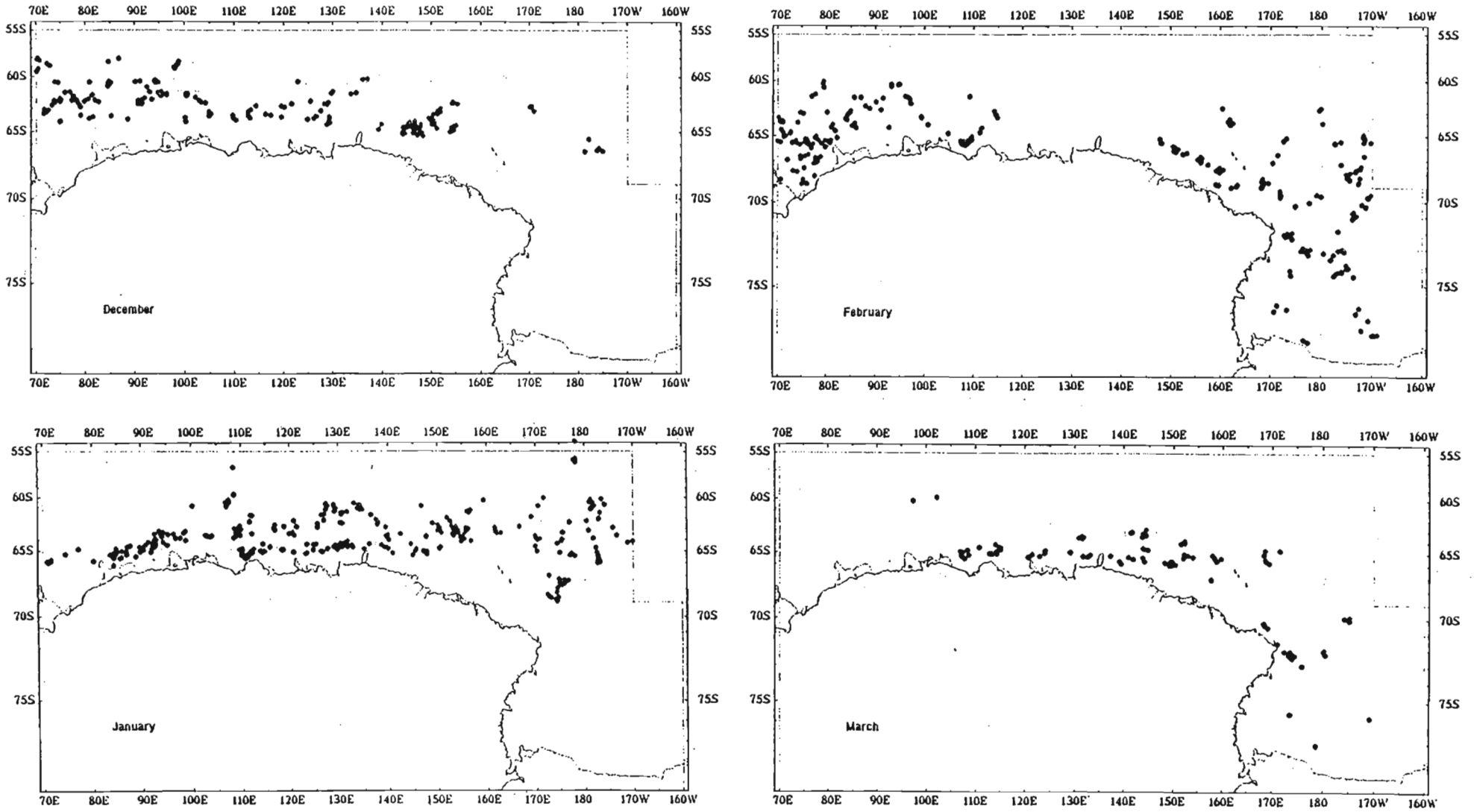

Fig. 3. Monthly changes of geographical distribution of mature male minke whales collected by the JARPA surveys during 1987/88 - 1994/95.

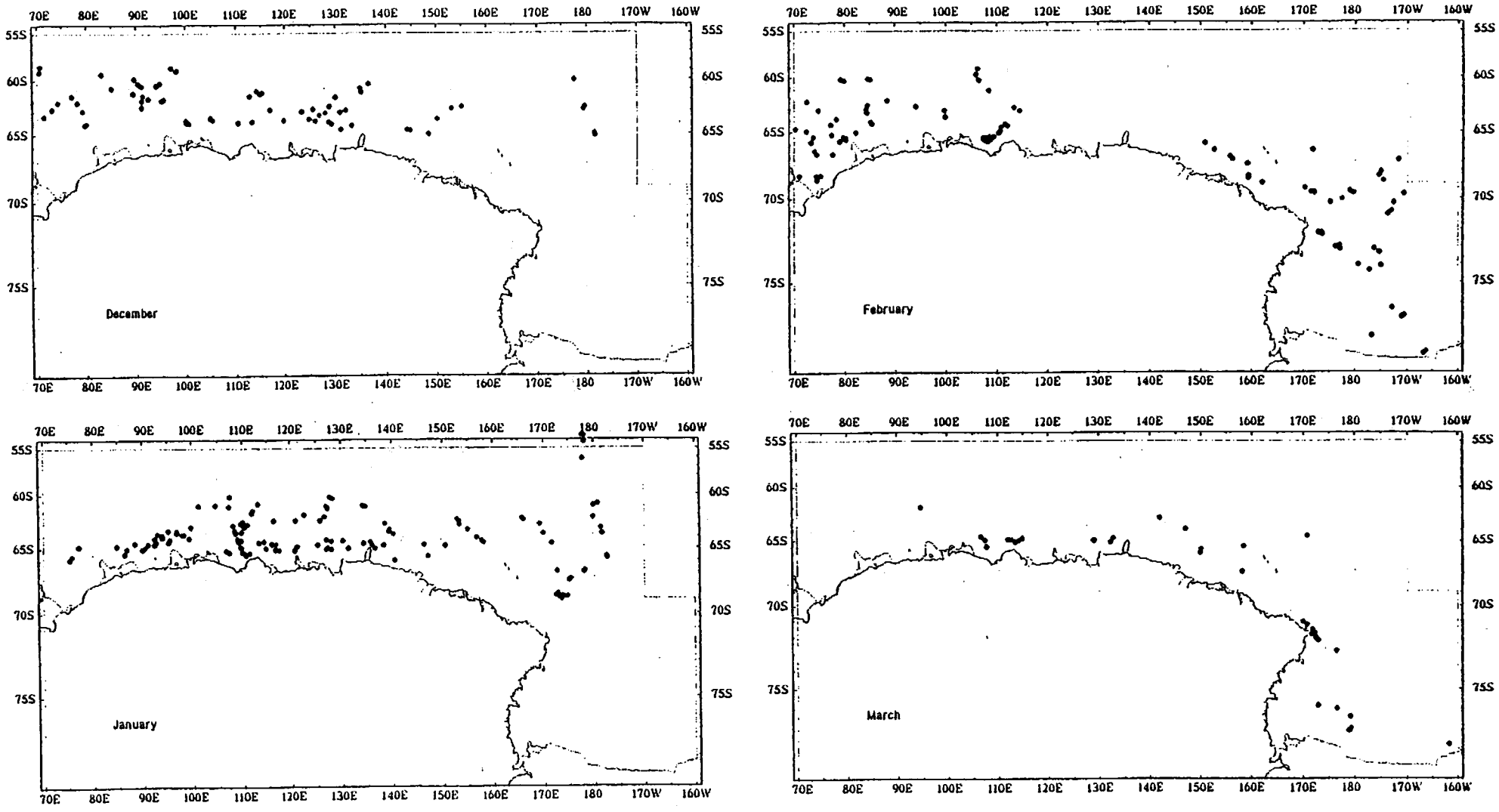

Fig. 4. Monthly changes of geographical distribution of immature female minke whales collected by the JARPA surveys during 1987/88 - 1994/95.

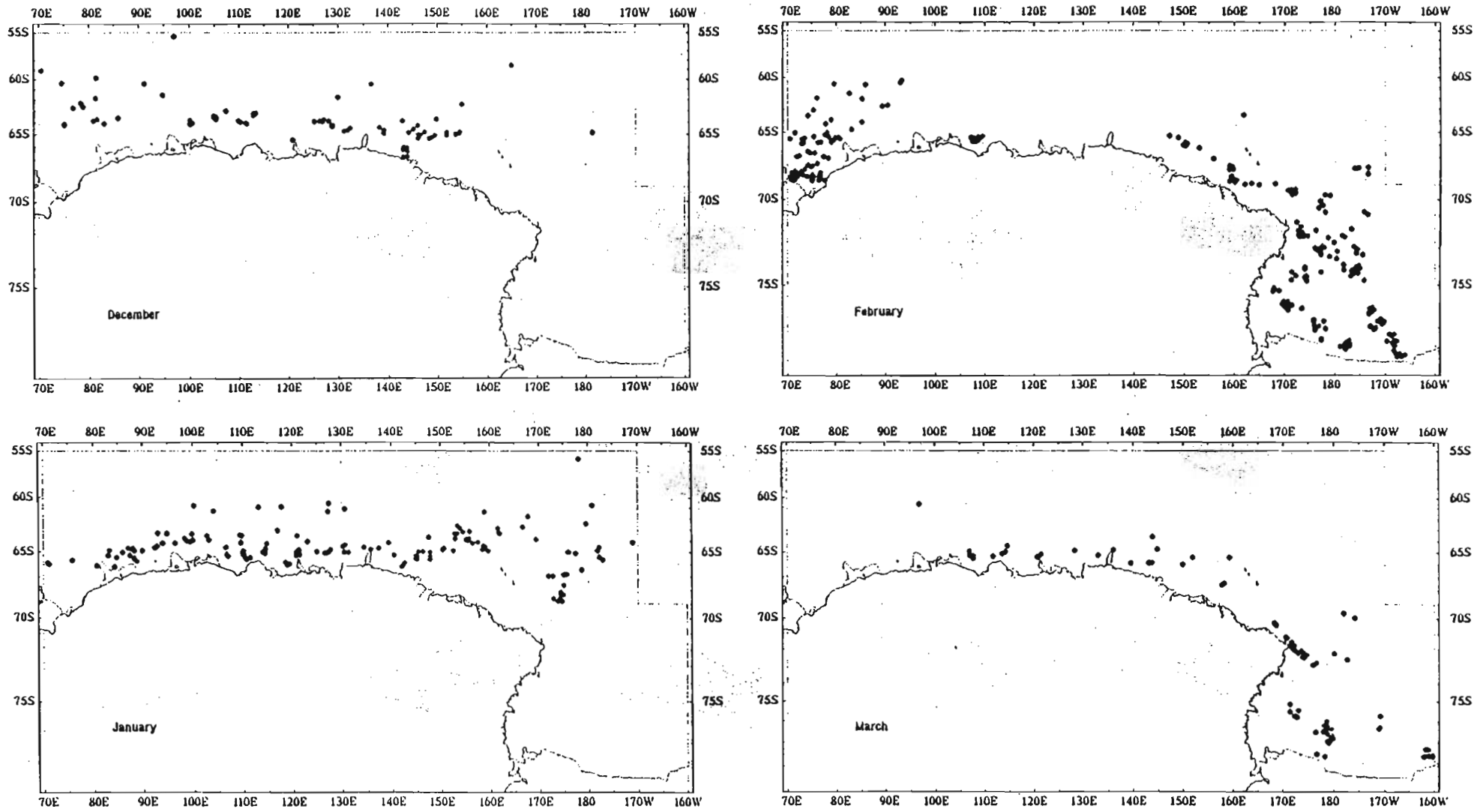

Fig. 5. Monthly changes of geographical distribution of mature female minke whales collected by the JARPA surveys during 1987/88 - 1994/95.

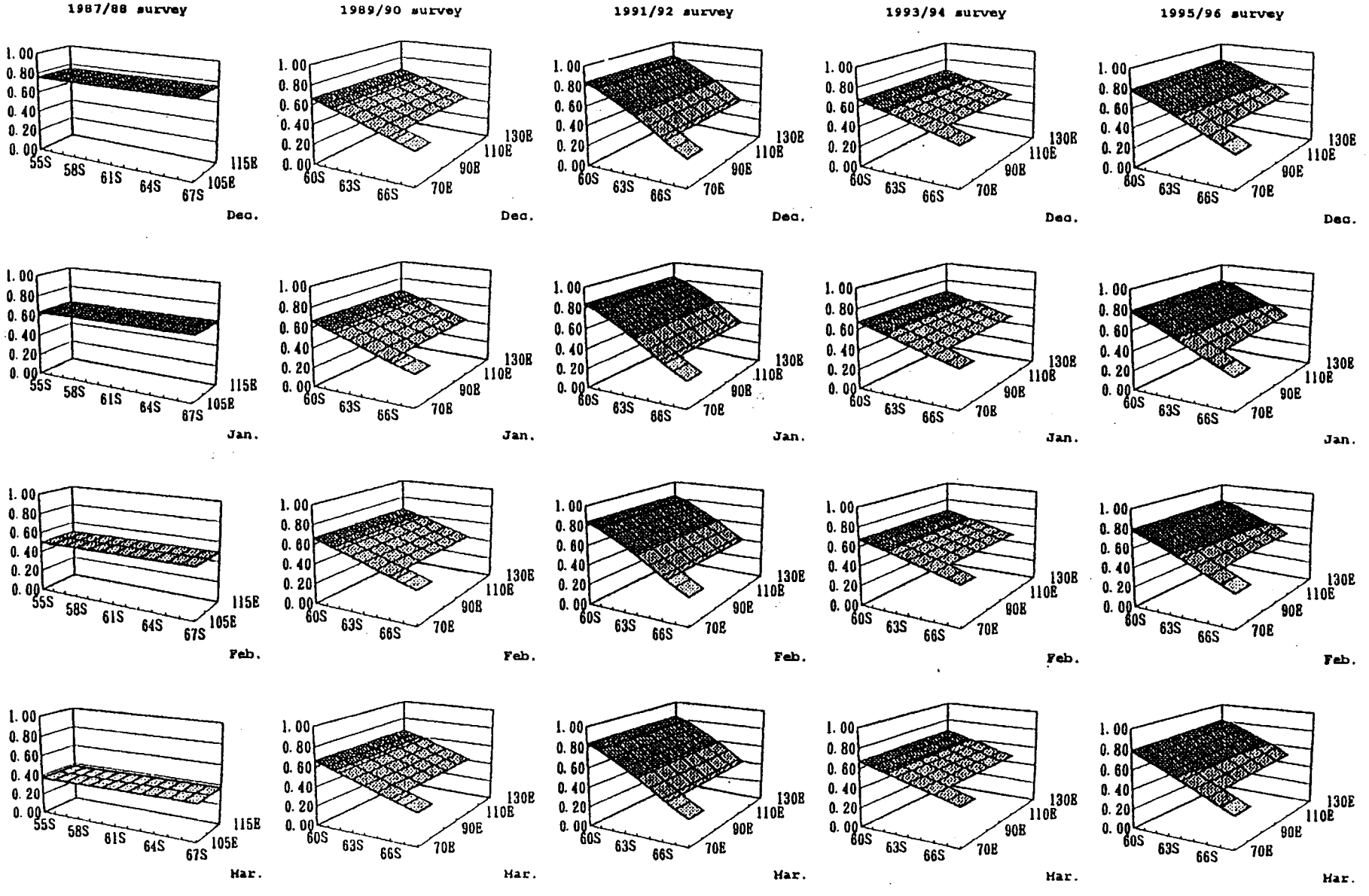

Fig. 6. Geographical changes of the proportion of males in Area IV estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 45day (Dec. 15) , 76day (Jan. 15), 107day (Feb. 15) and 135day (ca. Mar. 15), school size: 2.

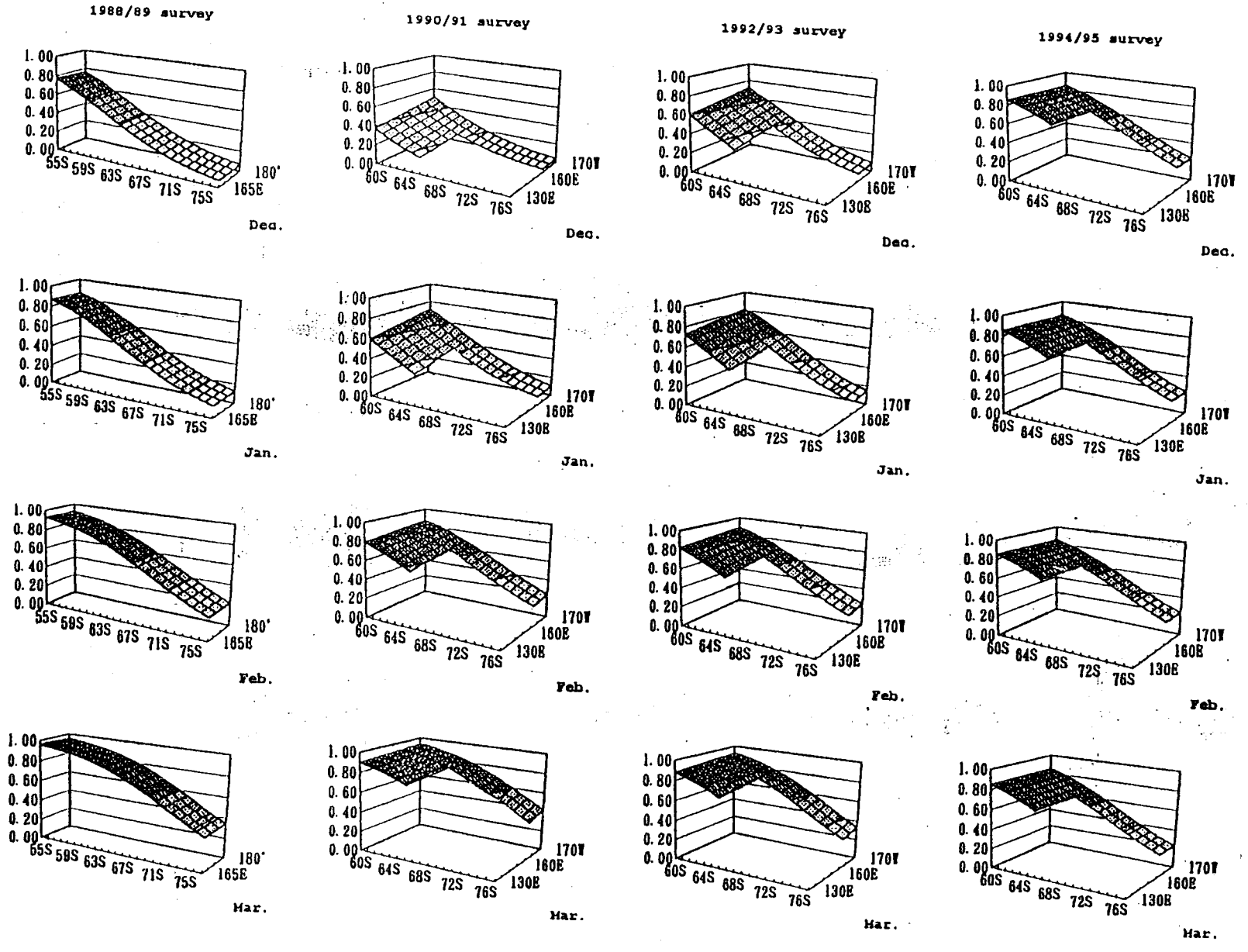

Fig. 7. Geographical and monthly changes of the proportion of males in Area V estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 45day (Dec. 15) , 76day (Jan. 15), 107day (Feb. 15) and 135day (ca. Mar. 15), school size: 2.

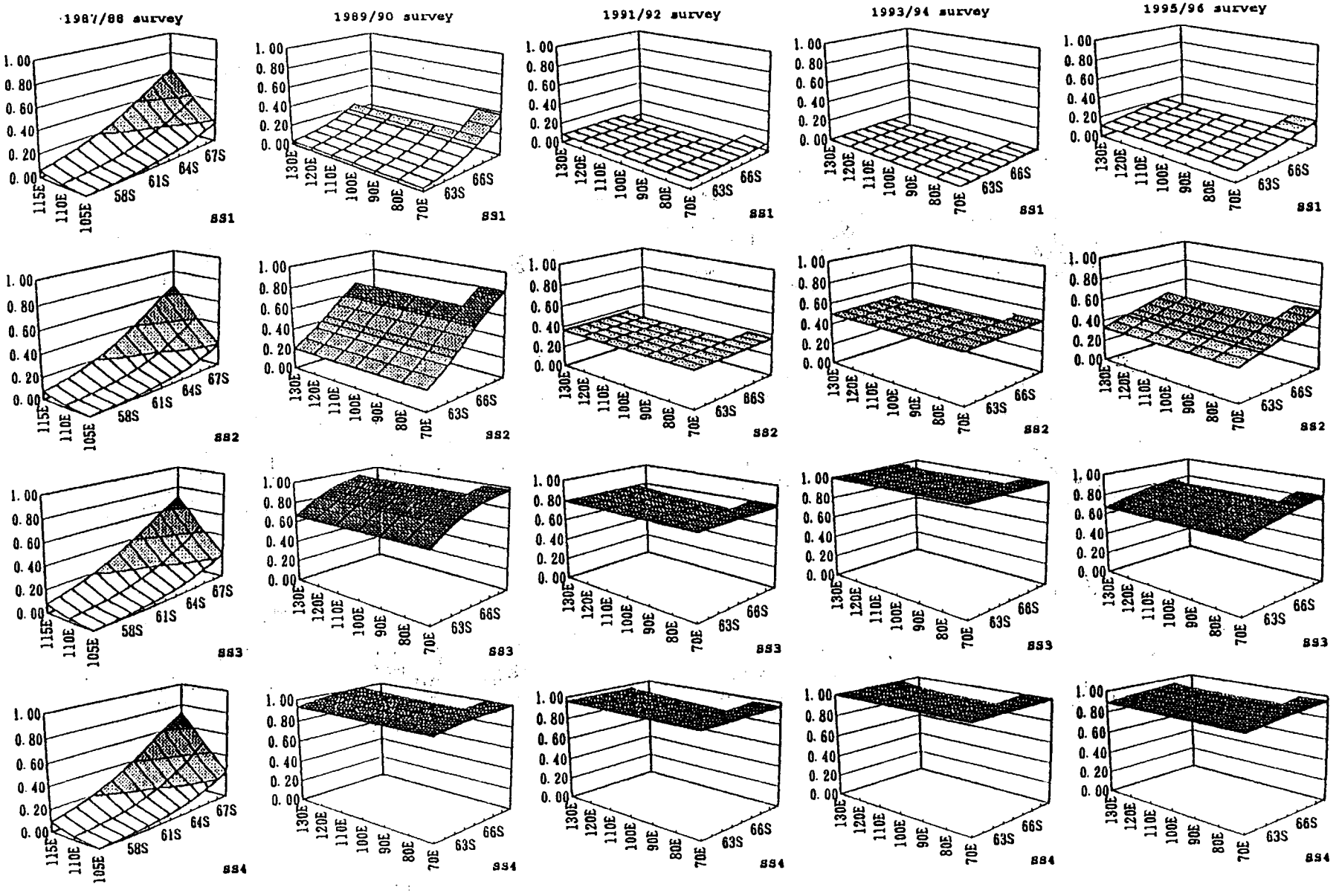

Fig. 8. Changes of geographical distribution of the mean maturity rate of males in Area IV with their school size, which was estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 76day (Jan. 15).

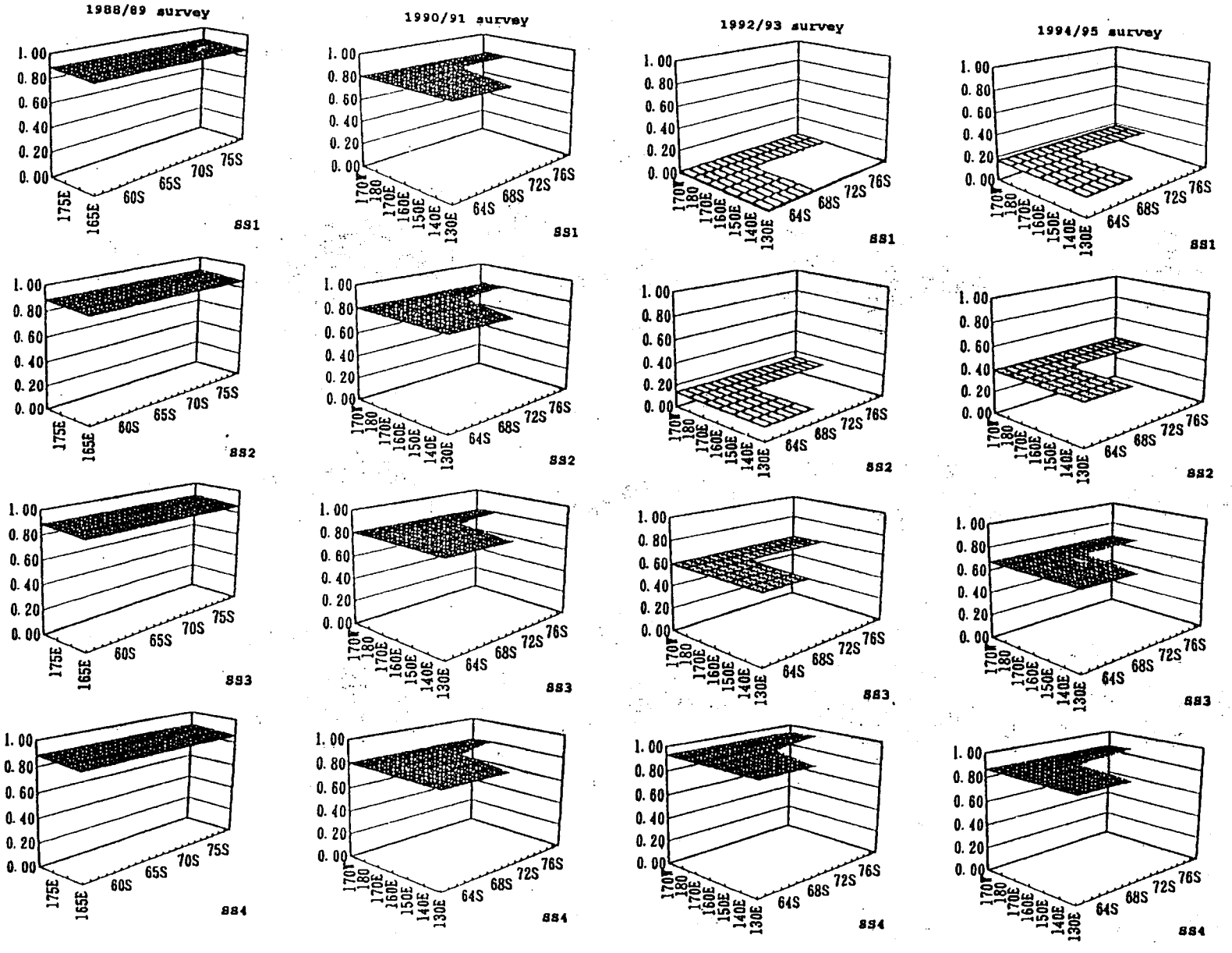

Fig. 9. Changes of geographical distribution of the mean maturity rate of males in Area V with their school size, which was estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 76day (Jan. 15).

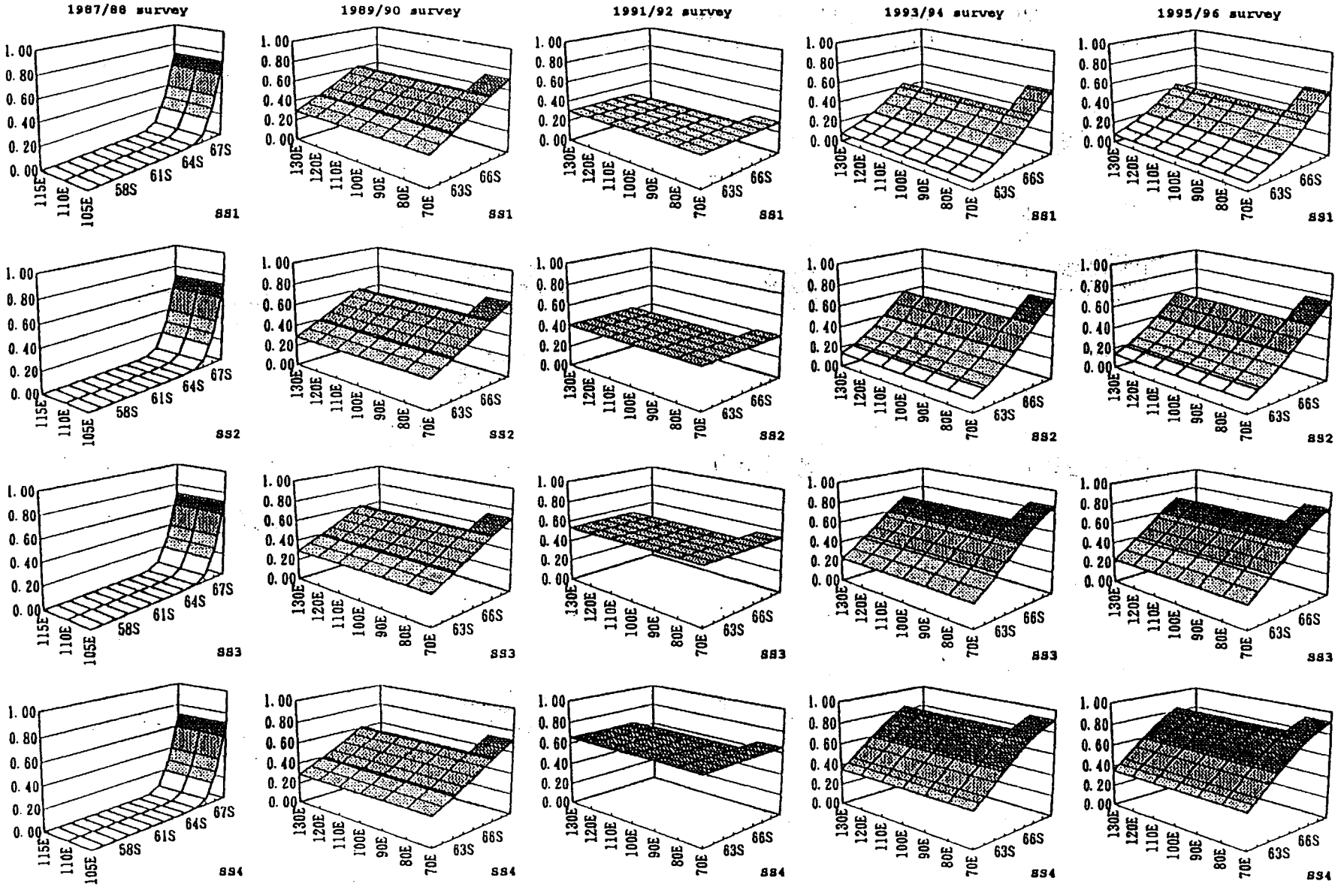

Fig. 10. Changes of geographical distribution of the mean maturity rate of females in Area IV with their school size, which was estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 76day (Jan. 15).

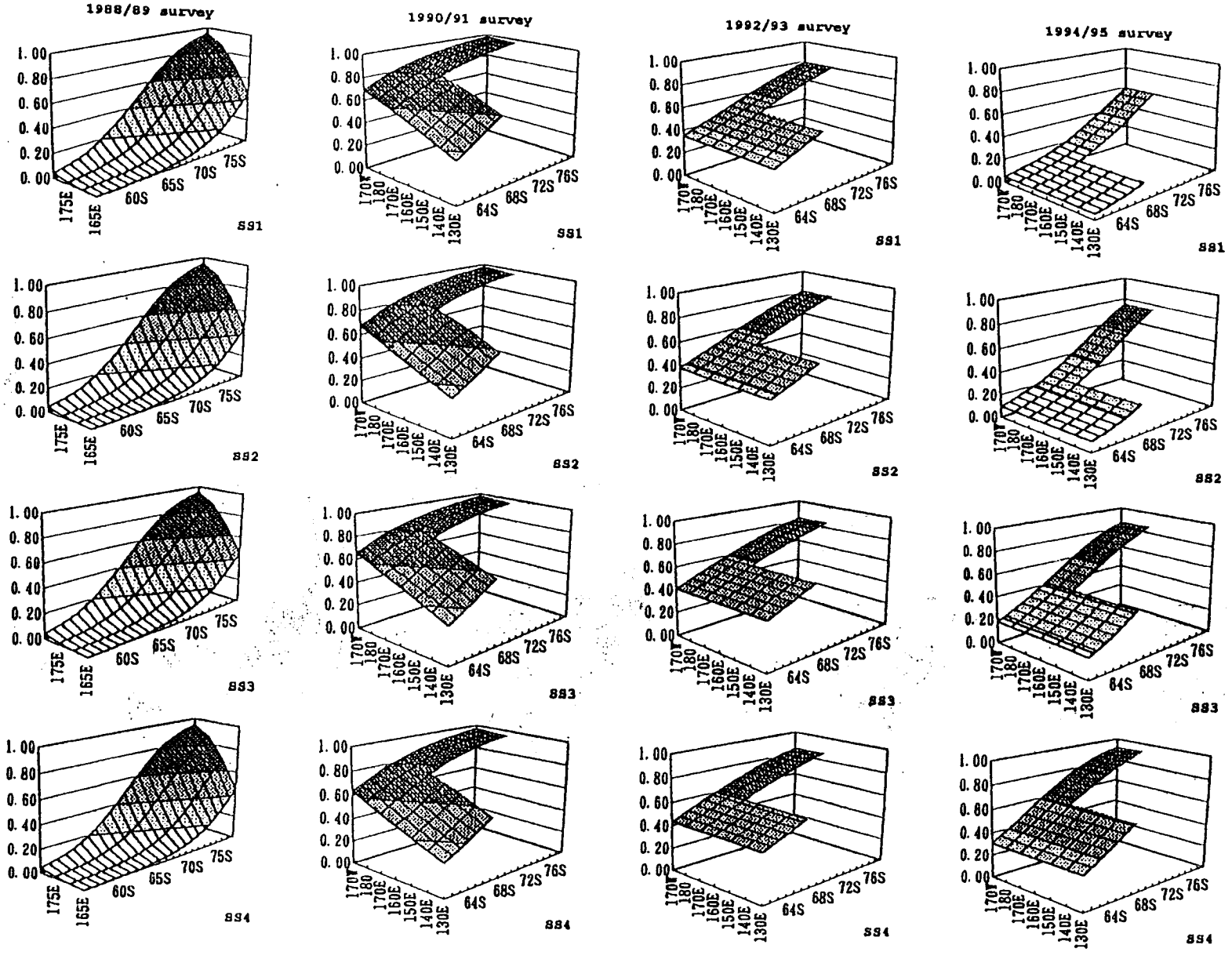

Fig. 11. Changes of geographical distribution of the mean maturity rate of females in Area V with their school size, which was estimated from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 76day (Jan. 15).

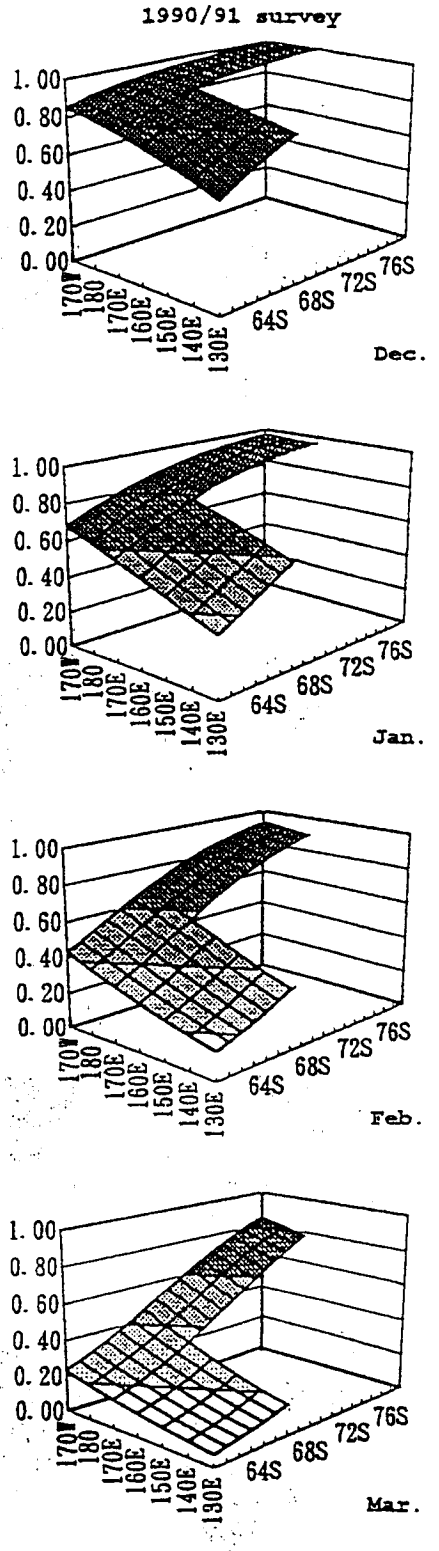

Fig. 12. Geographical and monthly changes of the mean maturity rate of females estimated in 1990/91 (Area IV) from the logistic regression analysis incorporating with the variable selection. Condition of calculation: cumulative day : 45day (Dec. 15), 76day (Jan. 15), 107day (Feb. 15) and 135day (ca. Mar. 15), school size: 2.