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

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ABSTRACT

In order to examine the spatial and seasonal changes in segregation of minke whales in the feeding ground, the proportion of males and sexual maturity rates of males and females were analyzed using a logistic regression model. In this analysis, we used minke whale samples from the Japanese Whale Research Programme Under Special Permit in the Antarctic (JARPA), conducted in Antarctic Areas IV and V from 1987/88 to 1992/93. By adopting a logistic regression model, the segregation of minke whales in the feeding ground show the following features: Males, especially mature males, were dominant in Area IV, and the proportion of males increases with progress of season, and with their school size. Mature females were dominant in Area V, and they were concentrated in the ice edge and the southernmost area such as the Prydz Bay (Area IV) and Ross Sea (Area V) in later survey season. Immature animals were distributed in the northern part of the research areas. The pattern of longitudinal distribution of immature animals varied by survey season.

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*, and the examination of the seasonal and areal changes of these parameters. Previously, the age distribution of the components which migrate to the research area in Antarctic Areas IV and V, have been studied. Also, 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; Kishino *et al.*, 1991a, 1991b). However, in these studies we did not incorporate the seasonal changes of these parameters into the analyses as serial variation factors.

In this paper, we applied a simple logistic regression model (Kishino *et al.*, 1991b) to examine 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 1992/93 seasons, and the usefulness of this model is 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 1992/93. A summary of the samples used in this study is listed in Table 1. Figs. 1a-1f. show the geographic distribution of whale samples from JARPA from 1987/88 to 1992/93, respectively, by sex and maturity status. 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 December 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 100um diameter (average of 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). 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

Proportion of males

The estimated parameters of the logistic model for the proportion of males in the sample are shown in Table 2.

All estimates of parameter a in Area IV were positive values, and it differ significantly from zero in two of the three surveys in this area. In contrast, the estimates of this parameter in Area V were negative or not significant. This suggests that the proportion of males is relatively high in Area IV. Estimated parameter b_1 for latitude showed negative values in all surveys in both Areas IV and V, and all of these estimates on Area V had values which were significantly different from zero. This indicates that the proportion of males decreased with latitudes, in both areas. Parameter b_3 (cumulative day) was also significant in two of the three surveys in Area V. Only one estimate for parameter b_2 (longitude) was significantly different from zero in Area V in the 1990/91 survey.

Figs. 2 and 3 show the spatial and seasonal changes of the proportion of males in Areas IV and V, respectively. In these figures, other variables such as school size and the cumulative day from 1 December, were settled tentatively as follows: school of two whales, and four dates of the 15th, 46th, 77th and 115th 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. Furthermore, the proportion tended to increase with progress of the season in the total area. In Area IV, this proportion was higher in the western part than in the eastern part. A reverse pattern was observed in Area V.

Male maturity rate

Estimated parameter values of mean maturity rate on males are shown in Table 3.

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 two of the three surveys in Area IV, this rate is also related to the size of whale school positively (parameter b_4). Although only one estimate was significantly different from zero (1988/89 survey in Area V), five of six estimates for parameter b_1 (latitude) in Areas IV and V are positive values. The male maturity rate was significantly related to the cumulative day (b_3) in two of the three surveys in Area V, and it showed that the rate varied by survey season in the area.

Figs. 3 and 4 show the spatial and seasonal changes of the male maturity rate in Area IV and V, respectively. Remarkable seasonal changes in this rate were detected in the northern part of the research areas. However, the pattern of longitudinal variation of this rate changed by year.

Female maturity rate

Estimated values of mean maturity rate in females are shown in Table 4.

In Area V, all estimates of the parameter a were positive and significantly different from zero. This indicates that mature females were dominant in Area V. Furthermore, estimated parameter b_1 (latitude) was also significantly different from zero on two of the three surveys in Area V. This suggests that maturity rate of female increased with latitude. In Area IV, only one estimate of parameter a on 1991/92 season was significantly positive value. Although all estimates of the parameter b_1 were not significant, positiveness of the estimates was obtained for all surveys in Area IV. This suggest that the maturity rate of females on Area IV also increased with latitude. The maturity rate of females was related to size of whale schools in the 1991/92 season.

The spatial distribution of the female maturity rate is shown in Figs. 5 and 6 for Areas IV and V, respectively. All analysis showed that the maturity rate increased with latitude, and the highest values were obtained in the Prydz Bay and Ross Sea region. However, the pattern of longitudinal changes of the rate varied among surveys. Maturity rate in 1989/90 (Area IV) and 1990/91 (Area V) were lower in the western part than in the eastern part of these areas. In contrast, a reverse pattern was found in 1991/92 (Area IV) and 1992/93 surveys (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. 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 decreased with latitude in both Areas, especially in Area V,
3) The proportion of males increased with progress of season,
4) Yearly variation was observed in the patterns of longitudinal segregation in the northern part of the research area.

Male maturity rate:

1) The maturity rate was always high in both research areas and all the survey periods,
2) In Area IV, this rate was related positively to the size of

whale schools,

3) This rate tended to increase with latitude,
4) Remarkable seasonal changes in this parameters were detected in the northern part of research area.

Females maturity rate:

1) Mature females were dominant in Area V,
2) The maturity rate increased with latitude, and higher values were obtained in the southernmost regions such as the Prydz Bay and Ross Sea,
3) Yearly variation was observed in the longitudinal segregation, in the northern part of the research area.

These trends obtained from this analysis, were generally consistent with the results of the previous studies (Fujise *et al.*, 1992). Furthermore, we could obtained a new information on segregation of minke whales that seasonal and yearly changes of these parameters occurred in the northern part of the research area. These results showed that this method is useful to outline the segregation pattern of minke whales.

However, we did not considered the interactions among these variables in this paper. If we take into account of interactions of these variables in the analysis, the formula (1) on page 2 will modified to the following formula:

$$\log\left(\frac{p}{1-p}\right) = a + \sum_{i=1}^{4} b_i x_i + \sum_{i=1}^{4}\sum_{j=i}^{4} b_{ij} x_i x_j \qquad (2)$$

We estimated the parameters tentatively on the maturity rate of females by use of samples from the 1992/93 survey in Area V. Result was shown in Fig. 8. The estimated logistic curve has a lower AIC values than the value which was estimated in the above section. The spatial and seasonal changes in the rate as shown in Fig. 8 fits well to the distribution patterns of whales in Fig. 1f, and suggests that there are interactions between these variables. We could not examined fully in this paper on these interactions, and further analysis should be done on this aspect in the future. Furthermore, in future analyses we should incorporate with the information abundance of minke whales, prey species such as Antarctic krill, and other oceanographical information.

ACKNOWLEDGMENTS

Our sincere thanks are due to all researchers and crews who were participated in the JARPA from 1987/88 to 1992/93 seasons. We thank to Ryoko Zenitani, Hajime Ishikawa, and Kunikazu Shimamoto, the Institute of Cetacean Research (ICR), for preparing the information on sexual maturity of whale samples, and for assisting of artwork. We also thank to Seiji Ohsumi, ICR, for his kindly reviewing of the document. We thank to Masahiro Kawasaki, ICR and Takashi Takabatake of University of Tokyo, for helpful assisting in the data calculations.

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

Area IV

	1987/88	1989/90	1991/92	Combined
Male	153	184	165	502
Female	119	142	123	384
Total	272	326	288	886

Area V

	1988/89	1990/91	1992/93	Combined
Male	85	164	167	416
Female	151	159	160	470
Total	236	323	327	886

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

Area IV

Parameter	1987/88		1989/90		1991/92		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	0.323*	0.133	0.222	0.168	0.368*	0.171	0.369*	0.108
b_1	-0.438	0.223	-0.352	0.267	-0.573*	0.194	-0.421*	0.195
b_2	0.183	0.158	-0.078	0.161	-0.020	0.189	-0.045	0.121
b_3	0.043	0.159	-0.055	0.192	0.183	0.172	0.207	0.120
b_4	0.250	0.202	0.119	0.145	-0.245	0.192	-0.097	0.091
AIC	369.5	7.0	460.1	7.1	380.9	8.4	1191.0	16.1

Area V

Parameter	1988/89		1990/91		1992/93		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	-0.544*	0.190	-0.225	0.201	0.047	0.158	-0.126	0.110
b_1	-0.916*	0.256	-1.797*	0.385	-0.902*	0.294	-1.277*	0.211
b_2	0.002	0.190	0.737*	0.233	0.159	0.238	0.356*	0.161
b_3	0.435*	0.189	0.447	0.227	0.605*	0.201	0.416*	0.119
b_4	0.079	0.169	-0.045	0.105	-0.110	0.139	-0.054	0.091
AIC	293.2	9.1	383.3	13.5	433.9	8.5	1080.0	20.5

*: 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

Parameter	1987/88		1989/90		1991/92		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	1.633*	0.493	3.291*	0.744	2.647*	0.536	2.347*	0.372
b_1	0.216	0.452	0.644	0.393	0.312	0.319	0.416	0.213
b_2	0.098	0.295	0.787	0.442	-0.422	0.255	-0.258	0.184
b_3	-0.194	0.372	-0.355	0.363	0.249	0.243	-0.161	0.198
b_4	1.958	1.143	2.279*	0.831	1.991*	0.760	2.234*	0.748
AIC	190.3	7.4	124.1	9.9	138.2	7.2	426.4	15.4

Area V

Parameter	1988/89		1990/91		1992/93		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	1.924*	0.498	2.943*	0.400	4.781*	1.780	2.064*	0.260
b_1	0.644*	0.296	0.610	0.430	-0.868	0.509	0.287	0.242
b_2	-0.565	0.327	-0.213	0.488	0.782	0.473	-0.128	0.286
b_3	-1.291*	0.457	-0.595	0.411	0.933*	0.449	-0.362	0.333
b_4	-0.630	0.409	0.479	0.302	4.227	2.362	0.523	0.418
AIC	76.9	6.3	72.3	6.7	103.1	9.5	342.7	18.7

*: 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

Parameter	1987/88		1989/90		1991/92		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	-0.456	0.267	0.429	0.231	1.134*	0.294	0.488*	0.142
b_1	2.162*	0.526	0.522	0.350	0.325	0.315	0.536	0.277
b_2	-0.043	0.286	0.288	0.281	-0.089	0.255	-0.042	0.162
b_3	0.087	0.240	0.182	0.247	-0.046	0.273	-0.318	0.203
b_4	0.582	0.318	-0.084	0.242	1.243*	0.519	0.653*	0.194
AIC	110.8	6.4	198.4	5.8	158.0	5.8	499.3	10.6

Area V

Parameter	1988/89		1990/91		1992/93		Combined	
	Est	SE	Est	SE	Est	SE	Est	SE
a	1.204*	0.246	2.125*	0.361	1.310*	0.252	1.457*	0.164
b_1	1.151*	0.302	0.924	0.640	0.854*	0.343	0.971*	0.206
b_2	0.273	0.323	0.404	0.454	-0.186	0.346	-0.088	0.205
b_3	-0.339	0.357	-0.538	0.271	-0.104	0.271	-0.355	0.190
b_4	-0.140	0.196	-0.196	0.172	-0.076	0.213	0.084	0.223
AIC	161.1	7.1	168.5	8.3	195.3	6.1	516.5	12.1

*: the estimate significantly differ from zero.
Parameter: a: constant, b_1: latitude, b_2: longitude, b_3: cumulative day, b_4: school size

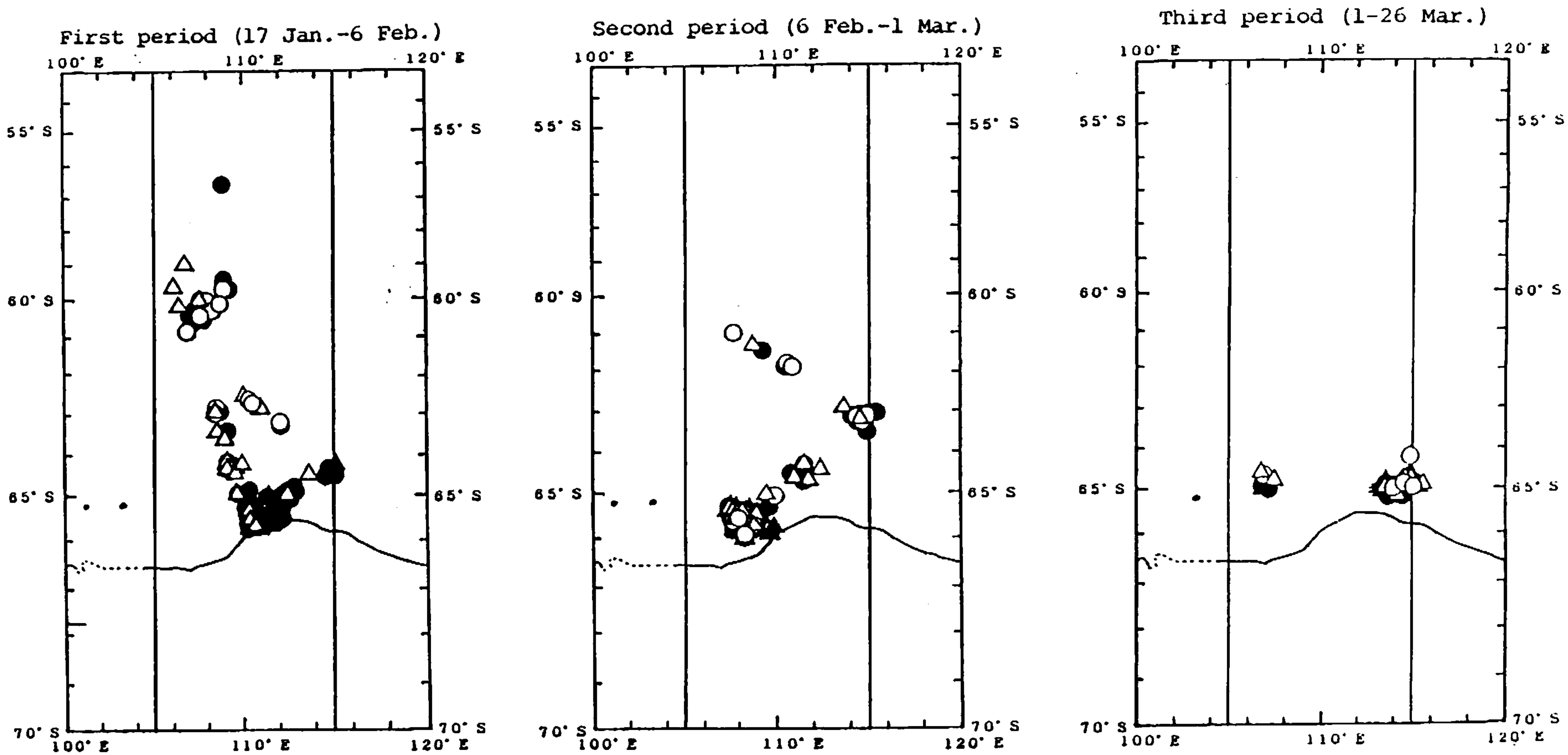
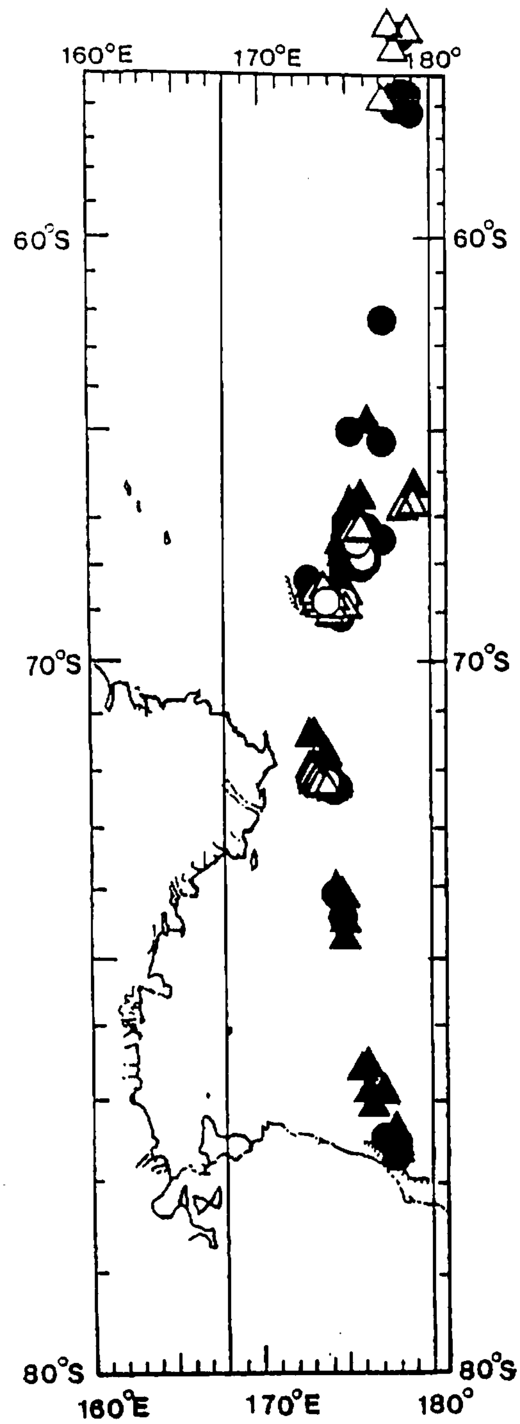
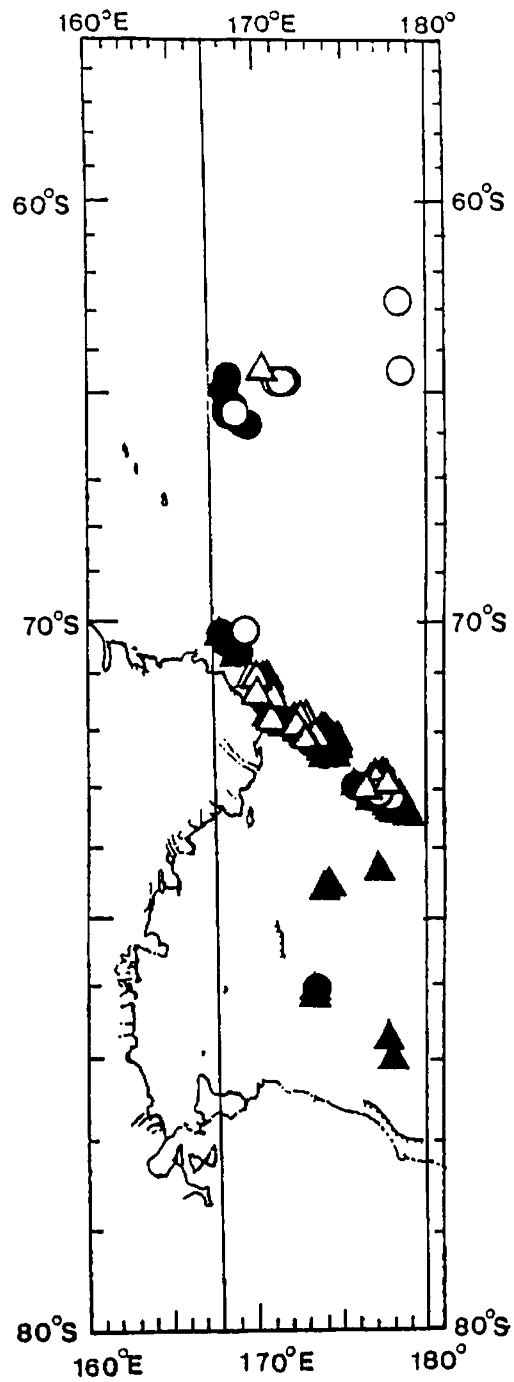


Fig. 1a. Geographical distribution of minke whale samples, by sex and maturity status in the 1987/88 JARPA survey in Area IV. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.



First period (13 Jan.-22 Feb.)



Second period (23 Feb.-31 Mar.)

Fig. 1b. Geographical distribution of minke whale samples, by sex and maturity status in the 1988/89 JARPA survey in Area V. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.

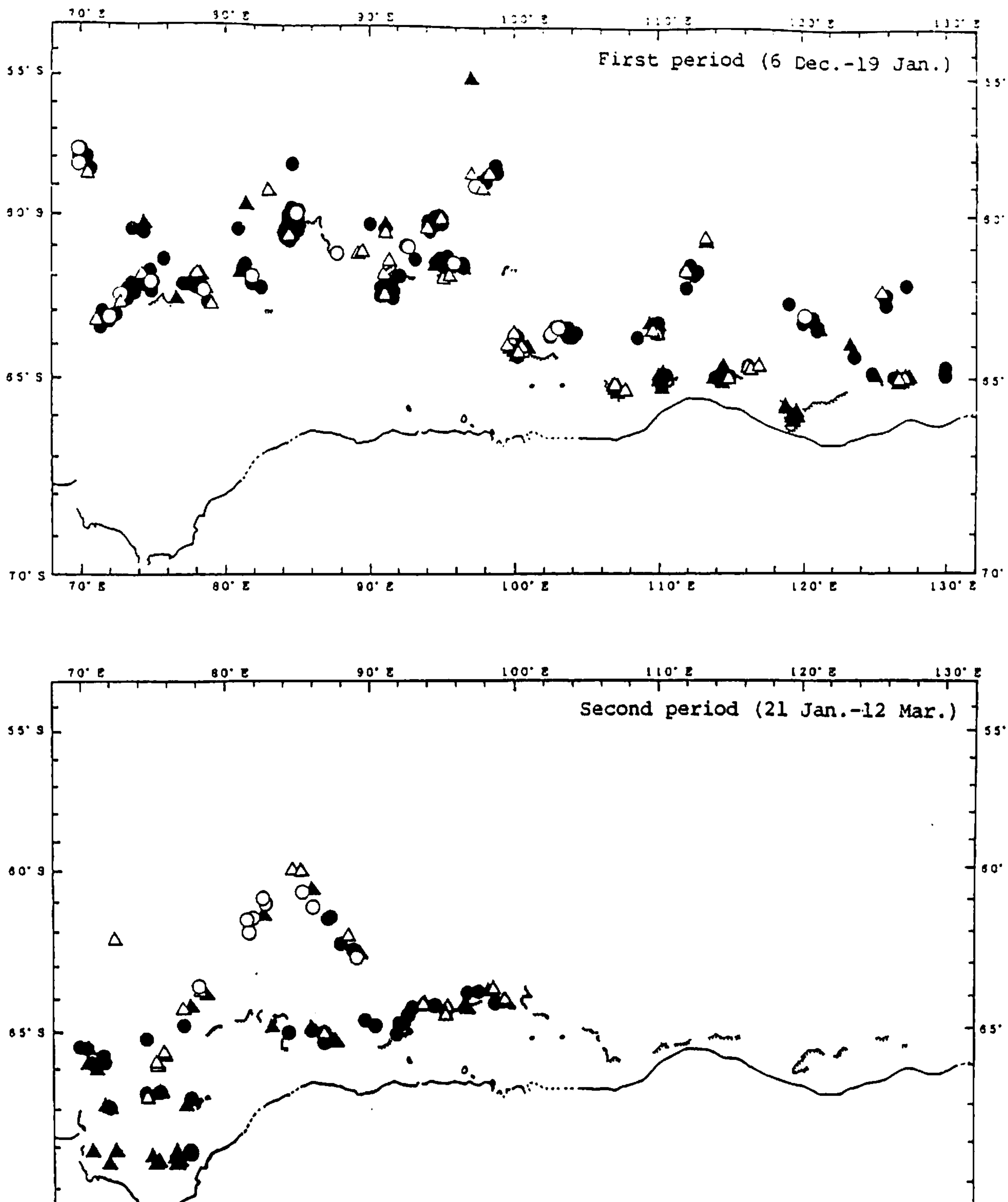
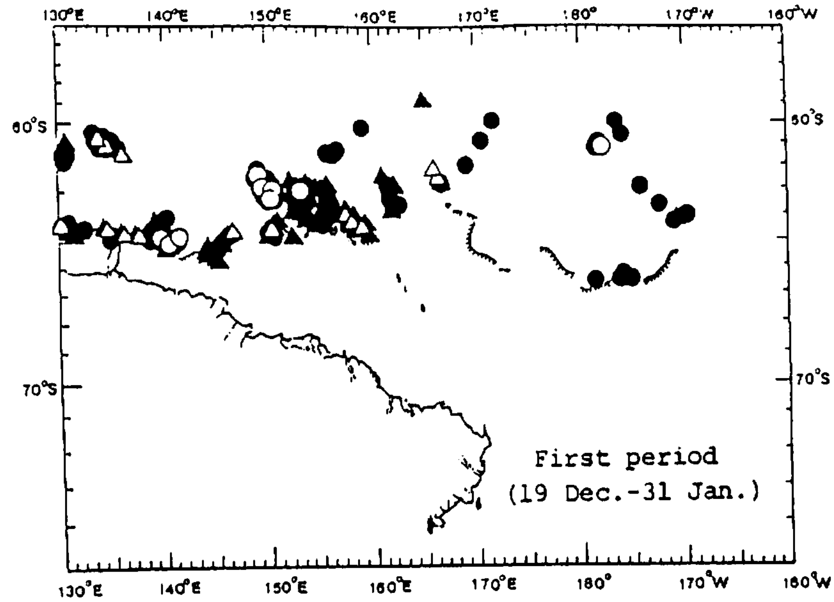


Fig. 1c. Geographical distribution of minke whale samples, by sex and maturity status in the 1989/90 JARPA survey in Area IV. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.



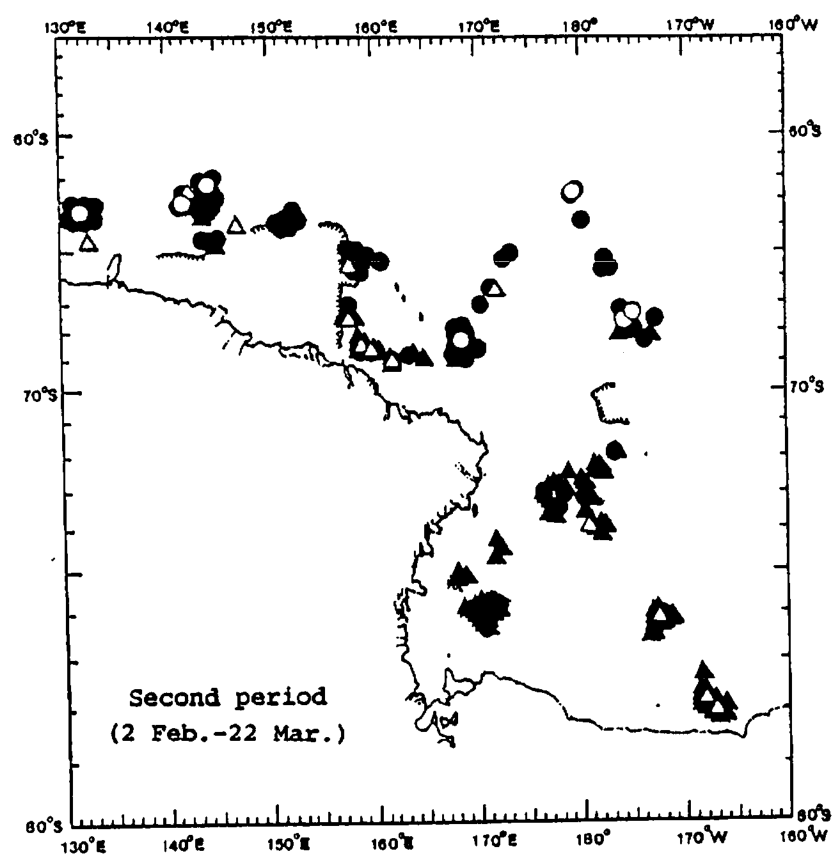


Fig. 1d. Geographical distribution of minke whales sampled, by sex and maturity status in the 1990/91 JARPA survey in Area V. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.

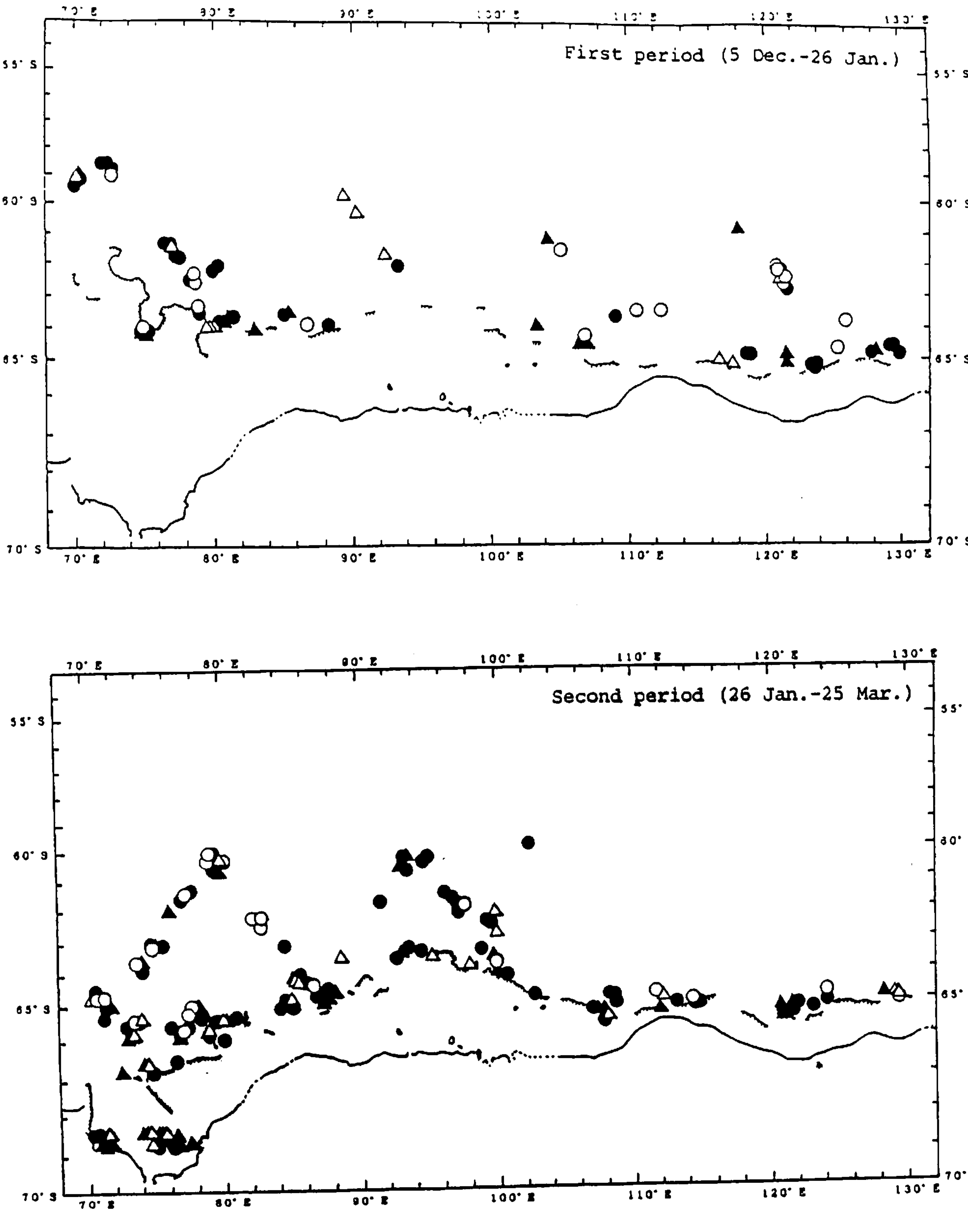


Fig. 1e. Geographical distribution of minke whale samples, by sex and maturity in the 1991/92 JARPA survey in Area IV. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.

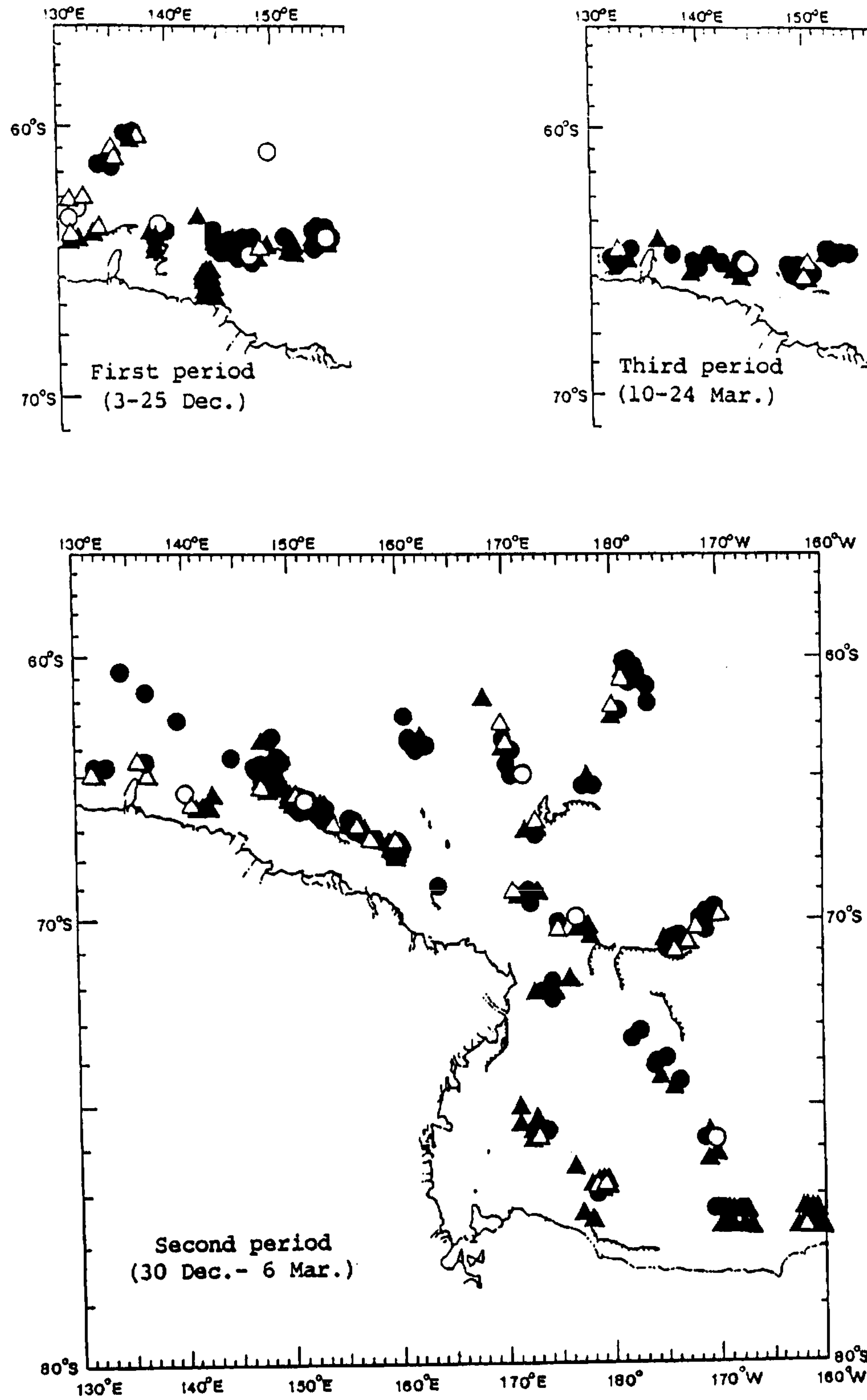


Fig. 1f. Geographical distribution of minke whale samples, by sex and maturity status in the 1992/93 JARPA survey in Area V. Closed circles represent mature males, open circles immature males, closed triangles mature females, open triangles immature females.

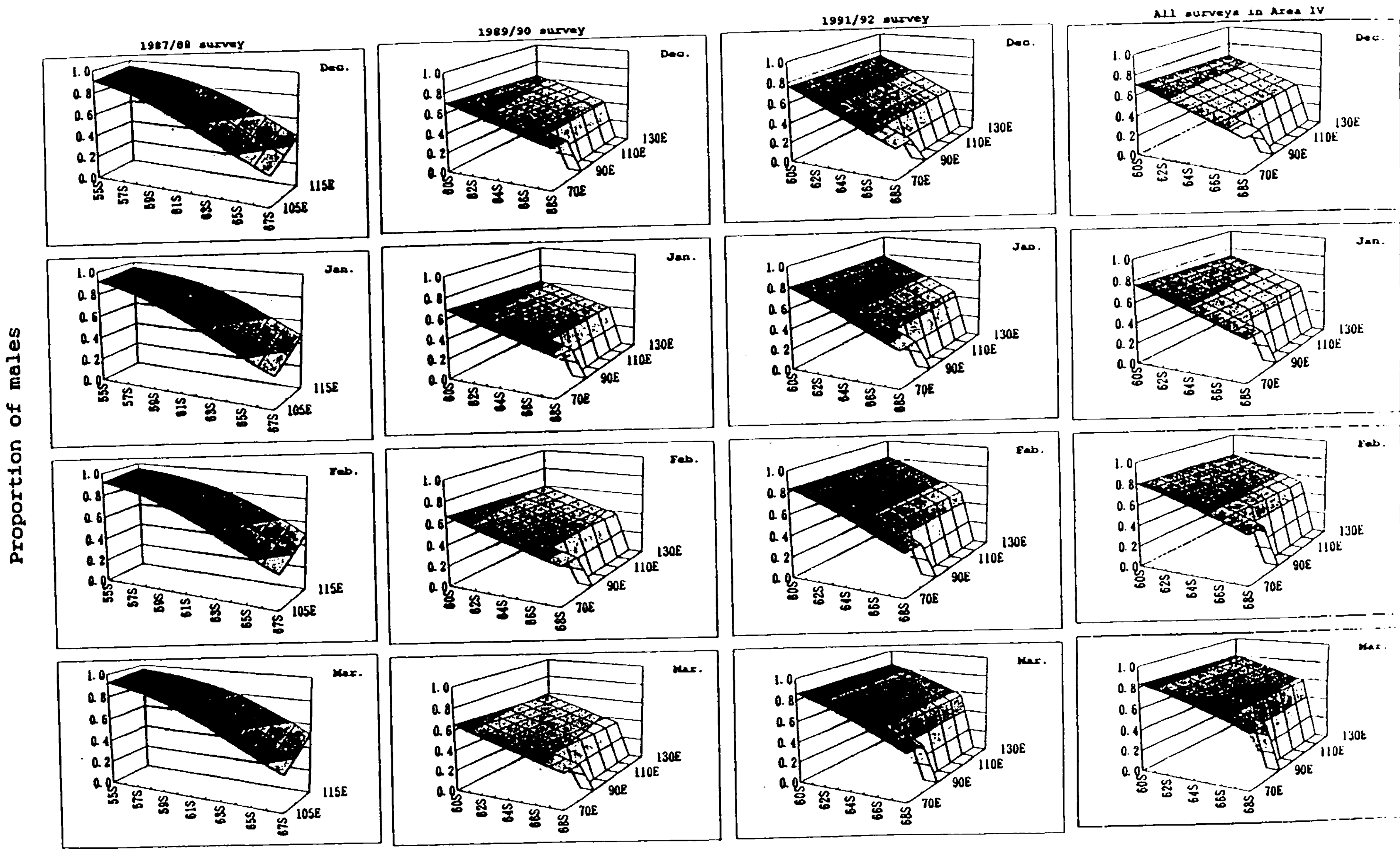


Fig. 2. Geographical and seasonal changes of the proportion of males in Area IV estimated from the logistic regression analysis. □0.00-0.20, □0.20-0.40, □0.40-0.60, ■0.60-0.80, ■0.80-1.00.

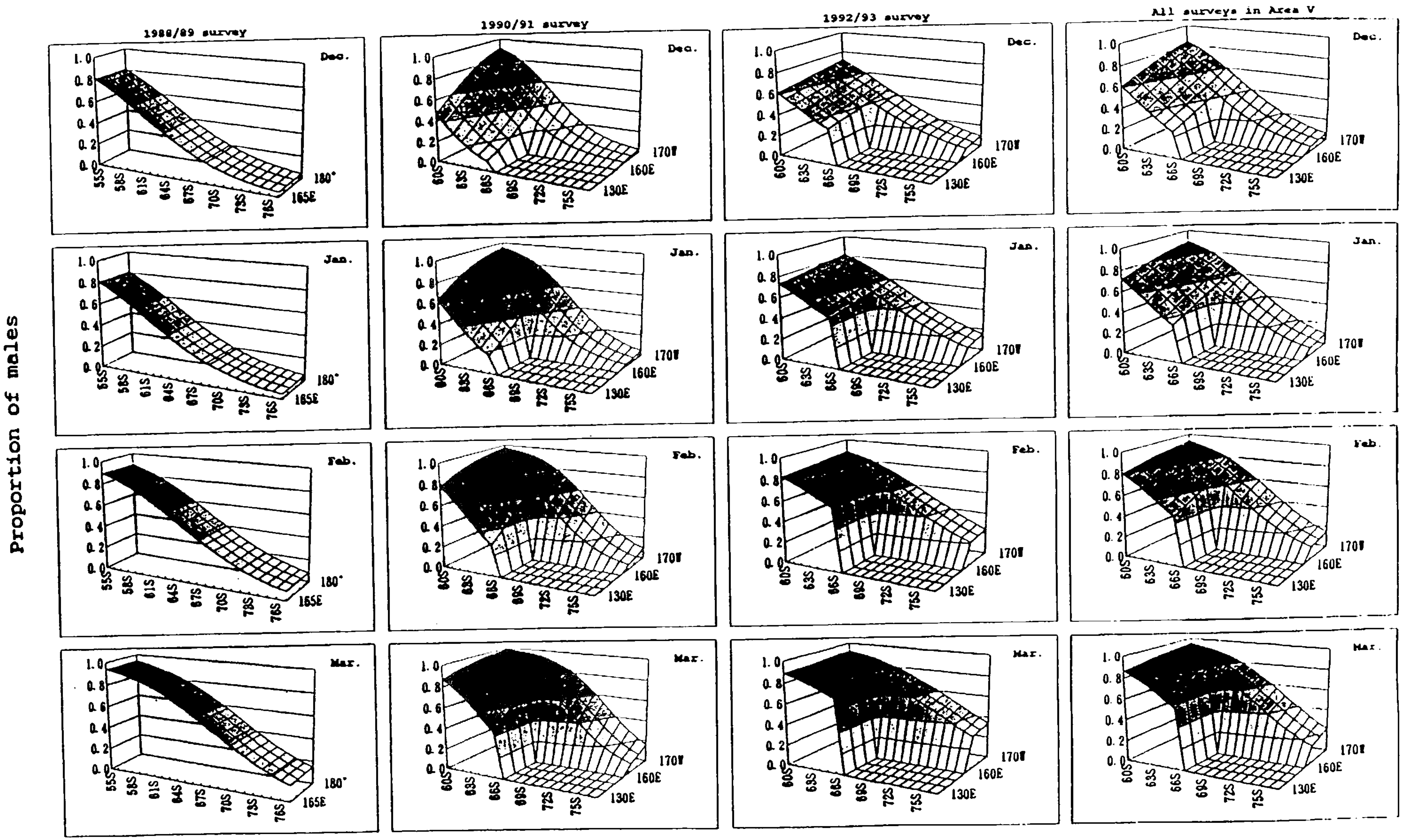


Fig. 3. Geographical and seasonal changes of the proportion of males in Area V estimated from the logistic regression analysis. □0.00-0.20, □0.20-0.40, ▣0.40-0.60, ▩0.60-0.80, ■0.80-1.00.

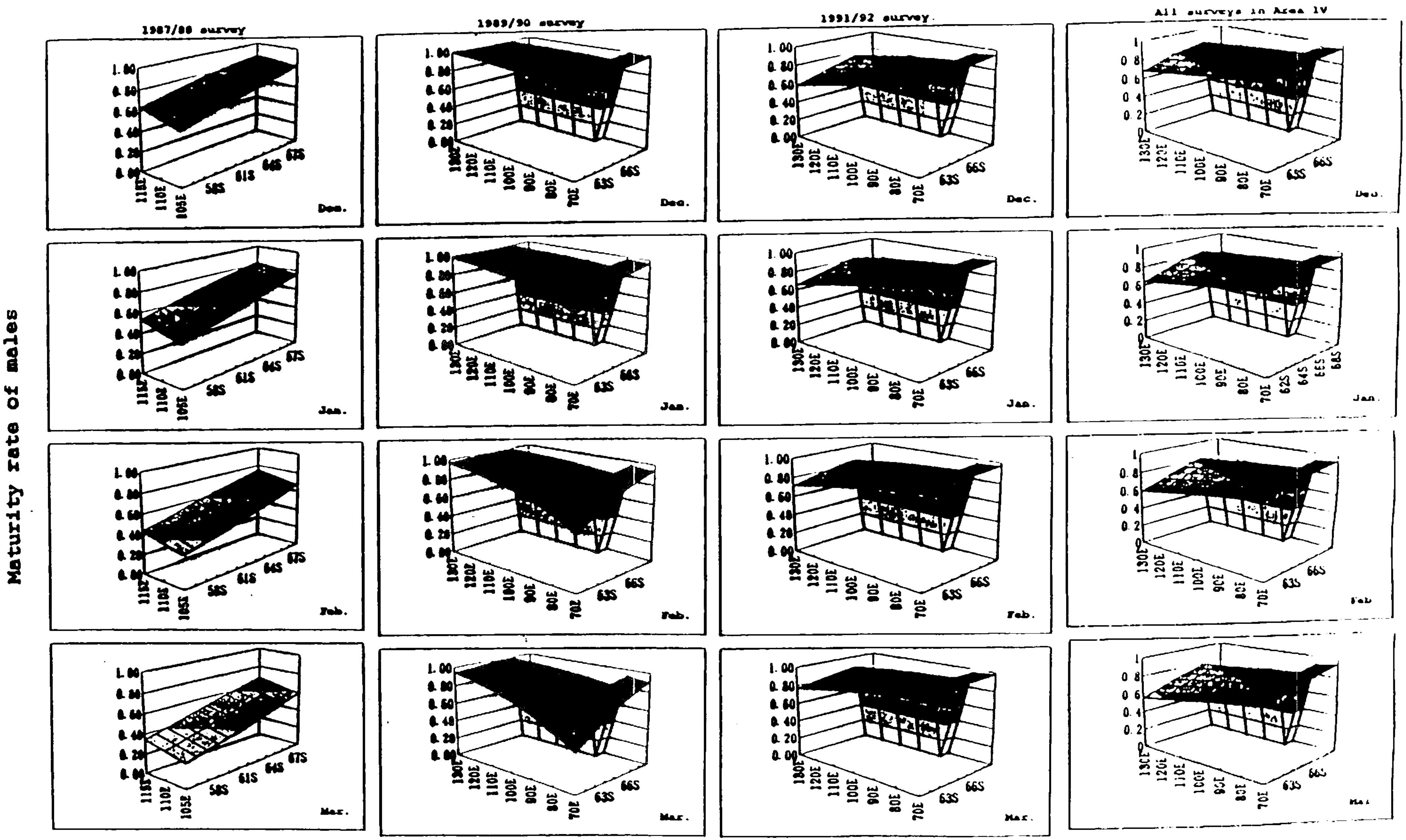


Fig. 4. Geographical and seasonal changes of the mean maturity rate of males in Area IV estimated from the logistic regression analysis. □0.00-0.20, □0.20-0.40, □0.40-0.60, ■0.60-0.80, ■0.80-1.00.

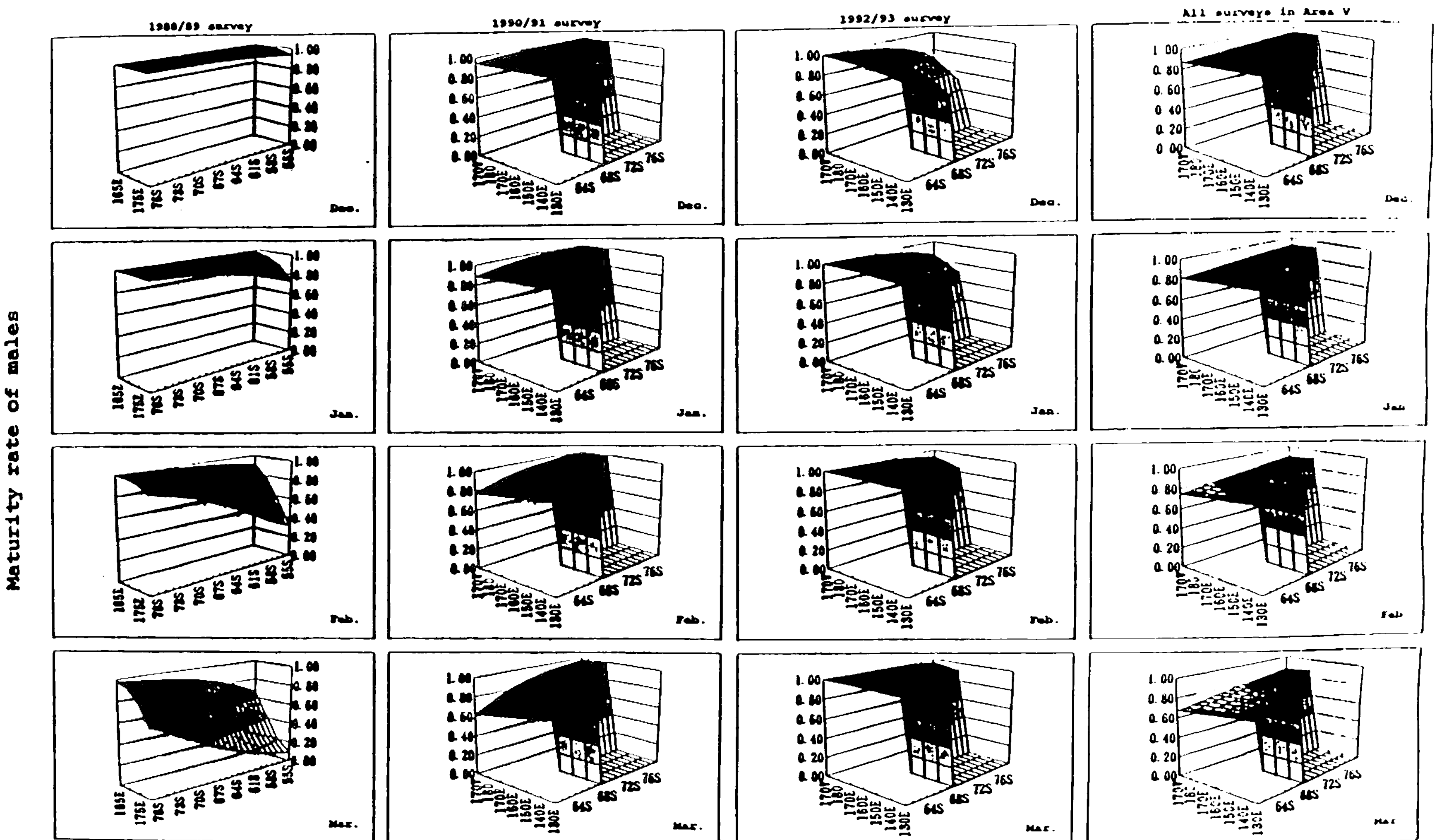


Fig. 5. Geographical and seasonal changes of the mean maturity rate of males in Area V estimated from the logistic regression analysis. □0.00-0.20, □0.20-0.40, □0.40-0.60, ■0.60-0.80, ■0.80-1.00.

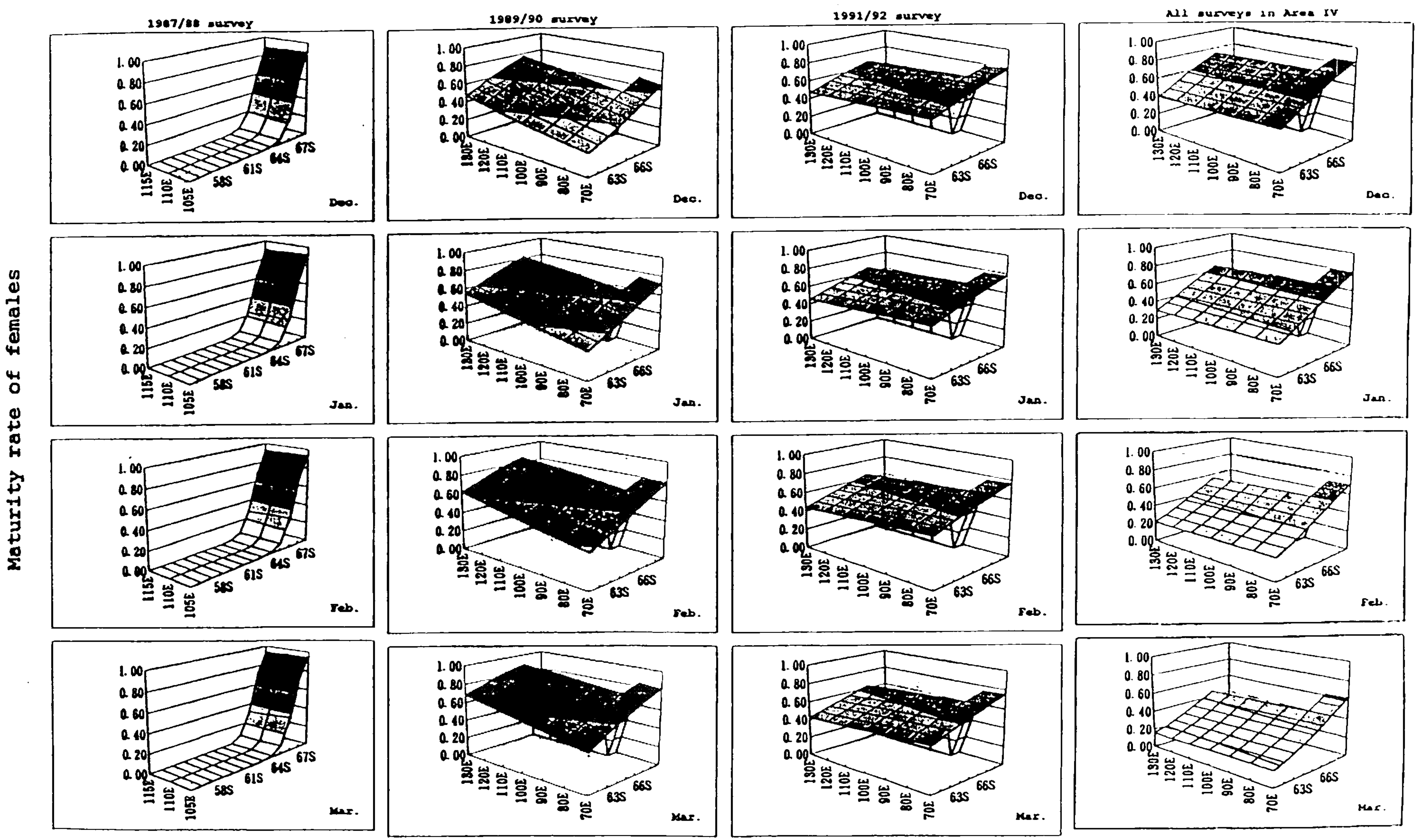


Fig. 6. Geographical and seasonal changes of the mean maturity rate of females estimated in Area IV from the logistic regression analysis. □0.00-0.20, □0.20-0.40, ⊡0.40-0.60, ■0.60-0.80, ■0.80-1.00.

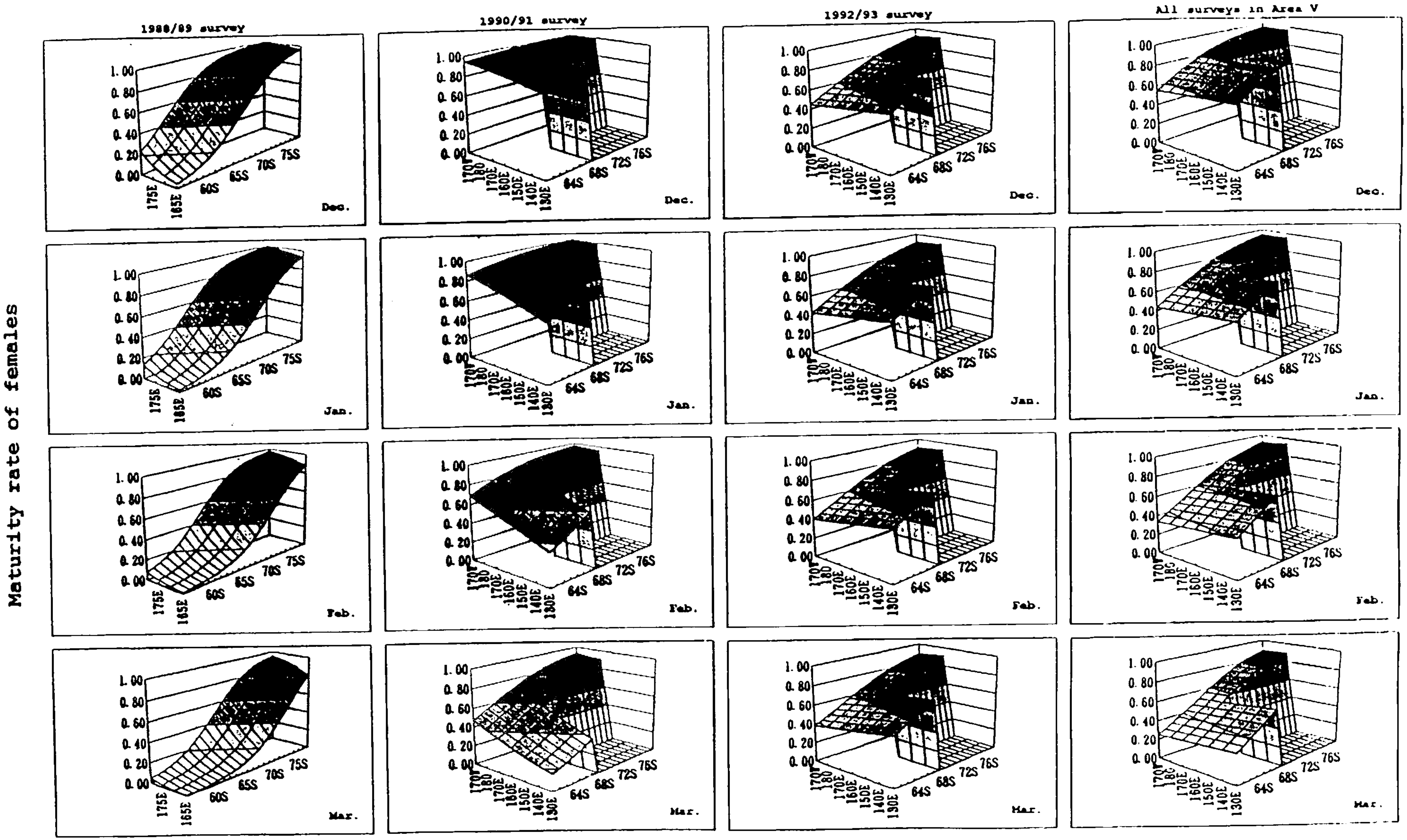


Fig. 7. Geographical and seasonal changes of the mean maturity rate of females in Area V estimated from the logistic regression analysis. □0.00-0.20, □0.20-0.40, ▦0.40-0.60, ▩0.60-0.80, ■0.80-1.00.

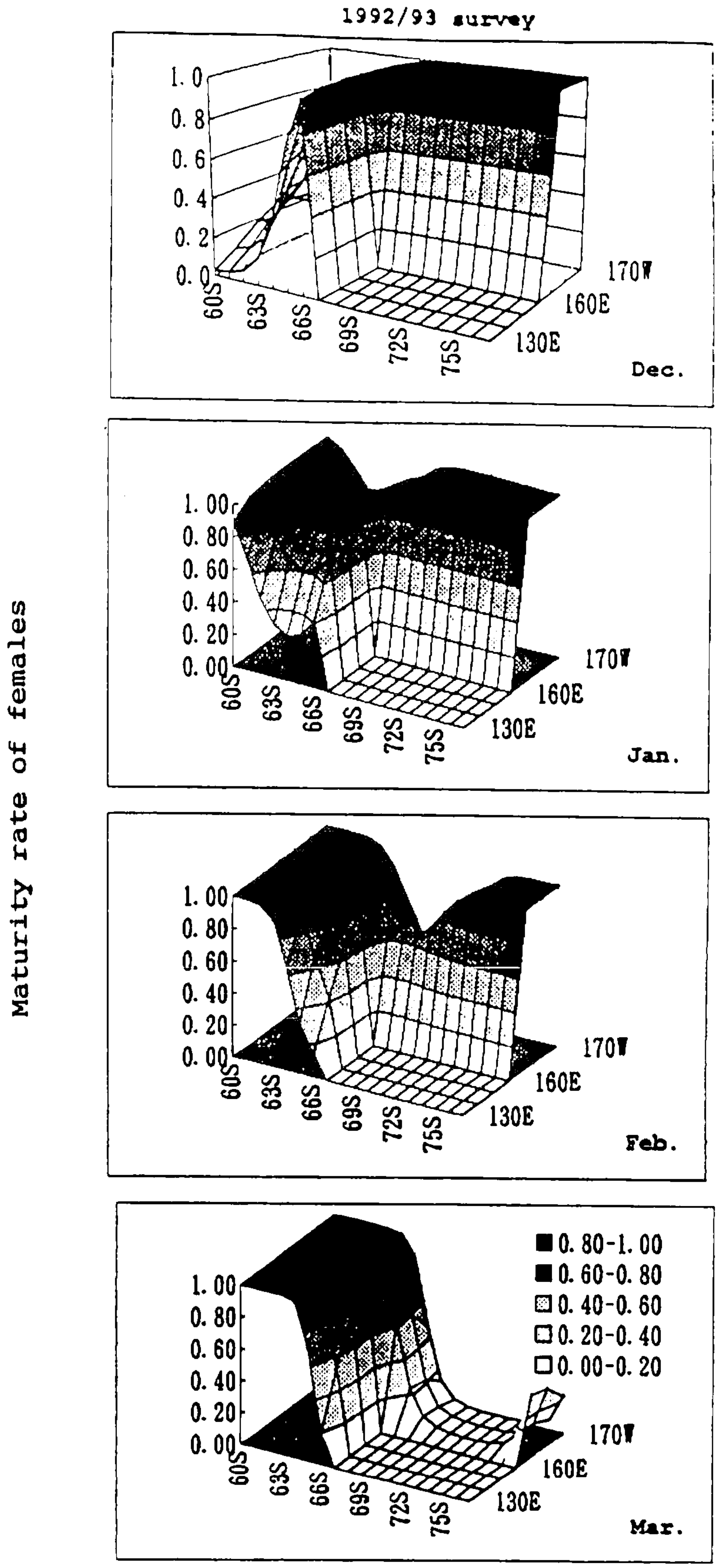


Fig. 8. Geographical and seasonal changes of the estimated mean maturity rate of females in 1992/93 survey in Area V obtained from the logistic regression analysis with interactions between parameters.