Further Examinations of the Segregation Pattern of Minke Whales in the Antarctic Area IV using a Logistic Regression Model, with Considerations on the Pack Ice Distribution

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ABSTRACT

In order to elucidate the segregation pattern of minke whales in the Antarctic, data on biological parameters from samples taken in the JARPA surveys from 1989/90 to 1997/98 were examined further by applying a logistic model. The logistic analysis shows that (1) males, especially mature males are dominant in the research area for all seasons. The proportion of males tends to decrease with increasing latitude. (2) maturity rate of males is related to their school size. Mature males tend to make larger schools. (3) females, especially mature females tend to be distributed in southern part of the research area. An exceptional case was observed for female maturity rate in the 1997/98 samples. In that season, the pack ice extended more northward than in normal years and covered the large part of the research area during the research period. The regression analysis showed the reversed distribution pattern for females than observed in previous surveys. In this survey the female maturity rate decreased with increasing latitude. To examine the effect of pack ice on the segregation pattern, the logistic analysis was conducted incorporating the distance from ice edge as one of the parameters. No indicative effect of the pack ice was detected for the examination for these biological parameters. The 1997/98 samples were examined further for sexual composition, seasonal distribution of the pack ice edge and for two indices of food availability: the body fat condition index and the fattyness. This additional analysis showed that reversed pattern in the 1997/98 season was not only caused by the lack of mature females but also by the existence of larger number of immature females in the southern part of the research area than in previous years. This pattern seems to be independent from food availability and the distribution of the pack ice.

INTRODUCTION

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) has been conducted since the 1989/90 austral summer season after two feasibility studies in 1987/88 and 1988/89. The main target species of this program is the Southern Hemisphere minke whale, *Balaenoptera acutorostrata.* Currently this program has been conducted under the following four principal objectives: 1) estimation of biological parameters of minke whales, 2) elucidation of the role of minke whales in the Antarctic ecosystem, 3) elucidation of the effect of environmental changes on the whale stock, 4) elucidation of stock structure of minke whales. For these objectives, especially for the estimation of biological parameters, it is desirable to clarify the feeding migration and distribution pattern of minke whales as well as to gather information on the geographical range of distribution of the stock.

In order to examine the temporal and spatial changes in the segregation of minke whales in the feeding ground of Antarctic Area IV, the heterogeneity of some biological parameters such as the sex ratio, maturity rates and mean ages of both sexes were studied, using the model selection method (Kato *et al.*, 1990, 1991; Fujise *et al.*, 1990, 1991, 1992; Fujise and Kishino, 1994; Kishino *et al.*, 1991a, 1991b). Further analyses have been examined by using a simple logistic regression model (Kishino *et al.*, 1991b, Fujise and Kishino, 1994, 1997).

At the 50th IWC/SC meeting, the cruise results of the 1997/98 JARPA survey were reported (Ishikawa *et al.*, 1998). It was reported that due to the large amount of pack ice covering most of the southern strata of the research area including Prydz Bay, it was not possible to conduct the survey inside Prydz Bay in that season. Some members of the IWC/SC expressed concerns with respect to the representativeness of the samples.

In this paper, we examine further the segregation of the minke whales in Antarctic Area IV by using some biological parameters (sex ratio and maturity rates for males and females) from the samples collected in the 1989/90 to 1997/98 JARPA surveys. Furthermore, we conducted a preliminary analysis of the relationship between the segregation patterns of minke whales and the distance from pack ice edge in Area IV.

MATERIALS AND METHODS

Whale samples and data used

Minke whales were collected in the JARPA surveys conducted in Antarctic Area IV from 1989/90 to 1997/98. Numbers of samples used in this study are listed in Table 1. Geographical locations of these samples are shown in Fig. 1.

In order to examine the temporal and spatial changes in the proportion of males in the samples and the maturity rates of both sexes, the following data were used: survey date (cumulative day as the serial number of date from 1st November for each survey), sighting position (latitude and longitude) and size of the whale school at the sighting (Fujise and Kishino, 1997). Furthermore, in order to examine on the effect of the ice edge on whale distribution, the distance from ice edge to the whale sample at sighting was used.

Furthermore, in order to compare the food availability of minke whales between 1997/98 and other seasons, the fattyness and the body fat condition index of minke whales were calculated for the samples collected in February in the western part of the research area (63°– 69°S, 70°– 100°E). In that analysis, the following data was used: sex, sexual maturity, body length, body weight, girth at the posterior end of ventral grooves.

Sexual maturity

Females were regarded as sexually mature if at least one corpus luteum or albicans was presented in either of the ovaries. Sexual maturity of males was determined by histological examination of testis tissues, which were collected from the center of the right testis. Males with seminiferous tubules over 100um 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).

However, the histological examination of testis tissues for the 1997/98 samples has not completed, therefore, maturity of the males taken from that season was determined tentatively by the weight of the heavier of the testes (0.4kg; Ohsumi *et al.*, 1970; Kato, 1986).

Distance from ice edge

The ice edge line and distance from ice edge was defined under the following procedure:

1. Position data on the ice edge was based on the record of observations actually made by the research vessels in the JARPA surveys.
2. It was lined automatically between these position data of ice edge within a survey stratum, with regardless of their distance. by the most reasonable approach.
3. As a result, map of ice edge line was made in each southern stratum.
4. Distance from ice edge to the whale was defined as the minimum distance from the location of whales at sighting to the nearest position of the ice edge.

5. Therefore, for the samples collected in the southern strata the distance was calculated from the ice edge map of the same stratum survey.
6. In the case of northern part of the research area, the distance from ice edge in each whale sample was estimated from the map that is nearest from sampled date of whales, or most reasonable map in considering with the ice edge movement.

The defined lines from the nearest point of ice edg to the whale for the 1989/90 JARPA survey in the first period are shown in Appendix I as an example.

Estimation of parameters and their variances

As in previous studies (Fujise and Kishino, 1997), a biological parameter p, such as the proportion of males, sexual maturity rates of males and females, is assumed to be expressed as follows:

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

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 maximum likelihood procedure. To take account of unequal sampling fractions of units, individuals in the samples were weighted inversely proportional to the sampling fractions (Skinner, 1989; Kishino *et al.*, 1991b; Kishino and Bar-Hen, 1998). In this study, we applied a variable selection forward and backward method to clarify 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 two stage random sampling procedure. Here, the primary sampling unit is the survey date, and the secondary one is the individual information.

In order to examine the effect of the pack ice, distance from ice edge was added to the above equation (1) as a parameter x_5 .

Calculation of the fattyness and the body fat condition index

We calculated fattyness and the body fat condition index of minke whales in relation to ice-edge distribution as follows:

The body fat condition index (b) was calculated with equation (2) (Ohsumi, 1995; Ichii *et al.*, 1998):

$$b = G / L * 100 \qquad (2),$$

where G is girth at the posterior end of ventral grooves in cm and L is body length in cm.

Fattyness (f) was calculated with equation (3) (Doi, 1978; Ohsumi *et al.*, 1997):

$$f = W / L^3 \qquad (3),$$

where W is body weight in kg and L is body length in cm.

RESULTS

1. Logistic regression analysis using four variables

In this study, we used two types of regression analysis. One in which all parameters are applied and the other using a variable selection method. Tables 2-1, 3-1 and 4-1 show the results of estimation of the parameters of the logistic model for the proportion of males in the sample, maturity rate for males and maturity rate for females, respectively using all four parameters including latitude (b_1), longitude (b_2), date (b_3) and school size (b_4). The results from the variable selection method are shown in Tables 2-2, 3-2 and 4-2. The asterisks in these tables indicate that the estimate of the parameter was significantly different from zero.

1.1. Proportion of males

The estimate of the constant (parameter a) showed a positive value for all survey seasons if all parameters are applied (Table 2-1). These estimates were significant in four of the five seasons in Area IV. This indicates that males were dominant in this research area though the research period.

The proportion of males was also correlated to the latitude negatively. The estimates of parameter b_1 (latitude) show a negative value for all survey seasons in Area IV (Table 2-1).

Among these estimates, three estimates were significantly different from zero. Furthermore, the variable selection analysis revealed that this parameter was selected for all seasons, and showed a negative value for all surveys (Table 2-2). This indicates that males tend to be distributed in the northern part of the research area, and that the proportion of males decreased with increasing latitude. In the southern part of the area, the proportion of females was relative high.

In the 1997/98 season, no significant difference from other surveys seasons in the proportion of males in the samples was observed.

1.2. Male maturity rate

Estimates for parameter a show a positive value for all survey seasons, and these are significantly different from zero (Table 3-1). This indicates that larger number of mature males was distributed in whole the research area in comparison with those of immature males.

The maturity rate was found to be positively related to the size of whale school (parameter b_4). Four of five estimates for this parameter were significant (Table 3-1). Furthermore, this relationship was also obtained in all surveys when the variable selection method was applied (Table 3-2). All of these estimates were significant.

In the 1997/98 season, no significant difference from other surveys seasons in the male maturity rate was observed.

1.3. Female maturity rate

The female maturity rate was positively correlated to the latitude (parameter b_1), except for the 1997/98 season (Table 4-1). The estimate ranges from 0.326 to 1.812. This suggests that mature females tend to be distributed in the southern part of the research area. However, the estimate in the 1997/98 season showed a negative value (-0.937), and it was significant.

Similar results were observed when the variable selection method was applied (Table 4-2).

2. *Distributions of mature and immature females*

As mentioned in item 1.3, female maturity rate in 1997/98 shows a different pattern from other surveys.

Fig. 2 compare the latitudinal distribution pattern of female maturity rates of minke whales for the 1989/90 to 1997/98 seasons, when the surveys were designed to sample the entire Area IV. This female maturity rate was calculated by one degree of latitude. Female maturity rate tend to increase with increasing latitude, but the ratio in the 1997/98 season tend to show a reversed (decreasing) pattern with increasing latitude.

Fig. 3 shows the proportion of mature females in the samples in each research stratum from the 1989/90 to 1997/98 seasons. The JARPA surveys in Area IV were conducted by dividing the area into five strata as the East-North, the East-South, the West-North, the West-South, and Prydz Bay. As noted above, relative large proportion of mature females in the samples was found in the southern strata, especially in the Prydz Bay stratum. This means that large number of mature females migrated into the southern strata. However, an exception of this pattern is observed in the 1997/98 season. In this season, proportion of mature females in the samples was remarkably small in the southern strata, especially the

Prydz Bay stratum.

Fig. 4 shows the ratio of immature females to both immature and mature males by each stratum by survey season. This analysis was made in order to examine whether the female maturity rate reflected only the lack of mature females or a change in the distribution pattern of females in the 1997/98 season. It is clear that in the 1997/98 season a larger proportion of immature females are distributed in the southern part of the research area compared with that for male individuals. In contrast, in the northern stratum this ratio seems to be similar for survey seasons.

3. Preliminary examination of the ice edge effect on the segregation pattern

In order to examine the effect of the distribution pattern of pack ice on the segregation pattern of minke whales, the regression model was applied again by adding the distance from ice edge to the whale samples as parameter b_5. The results are shown in Tables 5, 6 and 7 for the proportion of males, maturity rate for males, and maturity rate for females, respectively.

3.1. Proportion of males

As was the case for the four-variable analysis mentioned above in section 1.1, parameter a shows a positive value and parameter b_1 shows a negative value (Table 5-1). When variable selection method was applied, it also selected parameter b_1 as in the above analysis (Table 5-2).

Parameter b_5 (distance from ice edge) was selected for three surveys, 1989/90, 1993/94 and 1997/98. However, the results are not the same as a negative value was obtained for the 1989/90 season, while positive values for 1993/94 and 1997/98.

3.2. Male maturity rate

The results from both the all variables and variable selection method were almost similar to those described in section 1.2 (Tables 6-1, 6-2). No remarkable correlation in this parameter was observed for the distance from the ice edge, except for results from 1989/90. In that survey, parameter b_5 was selected and showed a negative value, but this parameter was not significantly different from zero.

3.3. Female maturity rate

This parameter also gave the same results as the four-variable analysis mentioned above in section 1.3 (Tables 7-1, 7-2). No remarkable correlation in this parameter was observed for parameter b_5 (distance from ice edge) except for the 1997/98 survey. In that survey, parameter b_5 was selected and showed a positive value when the variable selection method was applied (Table 7-2).

Results of these preliminary examinations indicate that the distance from ice edge was not correlated to the proportion of males, maturity rate for males, and maturity rate for females.

4. Body fat condition and fattyness by reproductive class of minke whale

4.1. The body fat condition index of minke whale

The body fat condition index of minke whales in February in western part of Area IV is shown in Fig. 5 by reproductive class. The index of the samples taken in the 1997/98 surveys was not significantly different from those for the other years. The Mann-Whitney U-test results are as the follows:

Immature males:	$p = 0.84$,
Mature males:	$p = 0.34$,
Immature females:	$p = 0.30$,
Mature females:	$p = 0.41$.

4.2. The fattyness of minke whale

The fattyness of minke whales collected in February in the western part of Area IV is shown in Fig. 5 by reproductive class. As for the body fat condition index, these results show that the fattyness of the samples collected in the 1997/98 survey are not significantly different from those in the other survey seasons. The Mann-Whitney U-test results are as follows:

Immature males:	$p = 0.90$,
Mature males:	$p = 0.11$,
Immature females:	$p = 0.45$,
Mature females:	$p = 0.90$.

DISCUSSION

Segregation pattern of southern minke whales

The segregation pattern of minke whales was re-examined by using a logistic model with additional data from the 1997/98 season. The results obtained in this study were similar to the previous results:

Sex ratio:

1) the proportion of males was relatively high,
2) the proportion of males related negatively to latitude, and decreased with increasing latitude.

Male maturity rate:

1) the male maturity rate was always high over the survey period,
2) this rate was related positively to the size of the whale school.

Females maturity rate:

1) the female maturity rate related positively to latitude, and increased with increasing latitude.
2) However, the female maturity rate in the 1997/98 season showed the reverse pattern from that in the other seasons, and decreased with increasing latitude.

Distribution pattern of females in the 1997/98 season

It has been known that mature females concentrated in the southernmost part of the research area (Kato, 1986; Harwood, 1990). In this study, the results from logistic regression analysis showed that female maturity rate was correlated with latitude for all survey seasons. This is the same as the results from past studies, except for one season. In the 1997/98 season, the female maturity rate decreased with increasing latitude. This may be caused by a lack of mature females in the southern part of surveyed area. In this season, pack ice did not melt as normal years, and a large amount of pack ice existed in the southern part of the research area during the research period. For this reason, the survey could not be conducted in most of the Prydz Bay (Ishikawa *et al.*, 1998). It was expected that most of the mature females had moved to the inner side of the pack ice zone where the research vessels could not enter. Furthermore, comparison of the number of immature females to that of both mature and immature males, suggests that a relatively large number of immature females had migrated into the southern part of the surveyed area compared to other seasons. These results suggest that there was a different segregation pattern of females in the 1997/98 season.

Body fat condition and fattyness by reproductive class of minke whales

One possible reason for the different segregation pattern observed for females in the 1997/98 season may be due to a change of the food availability of minke whales. It has been reported that body fat condition index and fatyness were useful indices to express the food availability of whales (Lockyer, 1986, 1987; Ohsumi *et al.*, 1997; Ichii *et al.* 1998). Therefore, these indices for the 1997/98 samples were compared with other survey samples. However, no significant difference was obtained for these indices. The values for the 1997/98 samples are within the range of interannual variation of them.

In summary, this paper confirmed the characteristics of the segregation pattern of southern minke whales in Antarctic Area IV as shown in previous studies. A different segregation pattern of females was observed in the 1997/98 season. This different segregation pattern resulted from differences in occurrence of both mature females and immature females. Although the distance from nearest pack ice edge to the whale was partly correlated the female maturity rate, this was only observed for the samples from the 1997/98 season. The indices for the food availability did not explain the different segregation pattern that occurred in 1997/98. No conclusion concerning the cause of this difference can be drawn from this study.

It should be pointed out that a genetic survey in Areas IV and V found considerable mtDNA heterogeneity in a group of minke whales sampled in the western part of Area IV in the early period (Pastene *et al.*, 1996). This finding suggested the occurrence of more than one stock in that sector. The occurrence of different stocks and the possible inter-season variation in their distribution pattern, should be considered in future segregation analyses.

Furthermore, future analysis should be conducted by incorporating environmental factors such as oceanographic and geographic information (GIS) and the interactions of these factors. Further analysis should consider information on the abundance of minke whale prey species such as Antarctic krill. The JARPA will provide such opportunity of research through its long-term execution.

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Table 1. Number of minke whale samples used in this study, which were collected during the JARPA surveys in Antarctic Area IV from 1989/90 to 1997/98.

Season	Female		Male		Total	
	Immature	Mature	Immature	Mature	Immature	Mature
89/90	57	85	24	160	81	245
91/92	39	84	30	135	69	219
93/94	61	69	42	158	103	227
95/96	50	76	34	170	84	246
97/98	95	28	64	141	159	169

Table 2-1. Estimated parameters of the logistic regression model for the proportion of males of minke whales in Antarctic if all variables are used

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	0.222	0.168	0.367 *	0.171	0.368 *	0.148	0.578 *	0.126	0.437 *	0.157
b1	-0.353	0.268	-0.574 *	0.194	-0.414 *	0.183	-0.676 *	0.169	-0.247	0.157
b2	-0.078	0.161	-0.021	0.189	-0.189	0.282	0.100	0.178	-0.011	0.170
b3	-0.055	0.192	0.183	0.172	0.136	0.266	-0.384	0.207	-0.208	0.210
b4	0.120	0.145	-0.246	0.192	0.049	0.145	-0.090	0.122	0.540	0.335
AIC	460.1		380.9		452.4		377.9		446.4	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 2-2. Estimated parameters of the logistic regression model for the proportion of males of minke whales in Antarctic if the variables selection method applied

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a					0.181 *	0.075	0.291 *	0.061		
b1	-0.404	0.239	-0.682 *	0.203	-0.420 *	0.176	-0.740 *	0.125	-0.267	0.148
b2					-0.299	0.172				
b3			0.260 *	0.124			-0.299 *	0.133		
b4	0.166	0.108							0.483 *	0.150
AIC	448.6		373.5		445.3		374.4		435.2	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 3-1. Estimated parameters of the logistic regression model for the maturity rate of male minke whales in Antarctic if all variables are used

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
1. all variable used										
a	3.286 *	0.742	2.647 *	0.537	1.673 *	0.357	2.757 *	0.492	1.545 *	0.399
b1	0.641	0.393	0.313	0.320	0.413	0.262	-0.087	0.323	0.222	0.237
b2	0.785	0.442	-0.424	0.256	-0.323	0.337	-0.967	0.494	0.027	0.260
b3	-0.353	0.364	0.250	0.243	-0.262	0.300	0.773	0.514	-0.138	0.257
b4	2.284 *	0.832	1.997 *	0.762	1.561	0.959	2.108 *	0.699	1.915 *	0.815
AIC	124.1		138.3		209.7		166.7		223.3	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 3-2. Estimated parameters of the logistic regression model for the maturity rate of male minke whales in Antarctic if the variables selection method applied

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	0.760	0.422					1.372 *	0.236		
b1					0.474 *	0.233				
b2	0.793	0.413					-0.893 *	0.367		
b3							0.690	0.364		
b4	2.521 *	0.849	2.705 *	0.607	1.679 *	0.322	2.075 *	0.682	1.540 *	0.294
AIC	119.6		133.4		199.9		163.1		212.5	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 4-1. Estimated parameters of the logistic regression model for the maturity rate of female minke whales in Antarctic if all variables are used

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	0.429	0.231	1.133 *	0.294	0.028	0.255	0.578 *	0.219	-1.683 *	0.318
b1	0.523	0.352	0.326	0.316	0.899 *	0.344	1.812 *	0.537	-0.937 *	0.375
b2	0.289	0.282	-0.089	0.256	-0.243	0.450	0.853 *	0.420	-1.563 *	0.449
b3	0.183	0.248	-0.046	0.274	0.202	0.410	-1.280 *	0.484	-0.295	0.352
b4	-0.084	0.243	1.248 *	0.521	0.337	0.429	0.423	0.358	0.090	0.198
AIC	198.4		158.0		167.3		146.6		119.6	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 4-2. Estimated parameters of the logistic regression model for the maurity rate of female minke whales in Antarctic if the variables selection method applied

	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a										
b1	0.523 *	0.211			0.350	0.189	1.795 *	0.547	-0.980 *	0.356
b2					-0.639 *	0.273	0.856 *	0.423	-1.707 *	0.325
b3							-1.290 *	0.497		
b4			1.017 *	0.289			0.532 *	0.220		
AIC	186.9		147.0		156.5		145.3		113.2	

*: the estimate sighnificant differ from zero.

Parameter a = constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size

Table 5-1. Estimated parameters of the logistic regression model for the proportion of males of minke whales in Antarctic Area IV (1989/90 - 1997/98) if all five variables are used.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	0.248	0.167	0.351 *	0.168	0.368 *	0.148	0.574 *	0.126	0.436 *	0.148
b1	-1.071 *	0.345	-0.734 *	0.300	-0.370	0.249	-0.384	0.376	-0.229	0.273
b2	-0.053	0.176	-0.049	0.211	-0.196	0.284	0.325	0.342	-0.016	0.178
b3	0.394	0.266	0.224	0.205	0.101	0.291	-0.679	0.415	-0.199	0.244
b4	0.179	0.145	-0.251	0.197	0.054	0.144	-0.096	0.123	0.543	0.335
b5	-0.664 *	0.325	-0.181	0.333	0.078	0.250	0.215	0.246	0.025	0.332
AIC	449.3	6.5	385.2	8.0	457.3	6.9	379.0	12.3	449.0	7.7

*: the estimate significant differ from zero.

Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

Table 5-2. Estimated parameters of the logistic regression model for the proportion of males of minke whales in Antarctic Area IV (1989/90 - 1997/98) if the variable selection applied.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a							0.291 *	0.061		
b1	-0.888 *	0.272	-0.682 *	0.203			-0.740 *	0.125		
b2										
b3	0.273	0.139	0.260 *	0.124			-0.299 *	0.133		
b4									0.456 *	0.139
b5	-0.575 *	0.278			0.330 *	0.124			0.295	0.168
AIC	441.1		373.5		444.3		374.4		434.4	

*: the estimate sighnificant differ from zero.

Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

Table 6-1. Estimated parameters of the logistic regression model for the maturity rate of male minke whales in Antarctic Area IV (1989/90 - 1997/98) if all five variables are used.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	3.306 *	0.806	2.552 *	0.518	1.696 *	0.353	2.701 *	0.409	1.554 *	0.401
b1	0.490	0.853	-0.216	0.381	0.654	0.341	0.129	0.231	0.055	0.335
b2	0.780	0.426	-0.432	0.242	-0.397	0.350	-0.415	0.401	0.046	0.257
b3	-0.257	0.715	0.388	0.285	-0.437	0.329	-0.031	0.349	-0.199	0.283
b4	2.344 *	0.998	1.909 *	0.752	1.504	0.942	2.484 *	0.606	1.905 *	0.815
b5	-0.167	0.823	-0.536	0.427	0.372	0.318	-0.565	0.328	-0.205	0.347
AIC	130.2	10.1	139.5	7.6	210.5	9.6	246.6	9.3	224.4	8.4

*: the estimate sighnificant differ from zero.
Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

Table 6-2. Estimated parameters of the logistic regression model for the maturity rate of male minke whales in Antarctic Area IV (1989/90 - 1997/98) if the variable selection applied.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	1.678 *	0.412								
b1					0.474 *	0.233				
b2	0.787 *	0.390								
b3										
b4	2.530 *	0.894	2.705 *	0.607	1.679 *	0.322	2.548 *	0.397	1.540 *	0.294
b5	-0.524	0.336								
AIC	118.6		133.4		199.9		234.8		212.5	

*: the estimate sighnificant differ from zero.
Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

Table 7-1. Estimated parameters of the logistic regression model for the maturity rate of female minke whales in Antarctic Area IV (1989/90 - 1997/98) if all five variables are used.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a	0.440	0.243	1.242 *	0.317	0.058	0.266	0.597 *	0.239	-1.681 *	0.297
b1	1.080 *	0.459	0.881	0.565	1.123 *	0.404	2.678 *	1.071	-0.623	0.319
b2	0.279	0.300	0.026	0.294	-0.261	0.497	1.526	1.085	-1.783 *	0.554
b3	-0.154	0.365	-0.199	0.302	0.076	0.462	-1.984 *	0.924	-0.031	0.372
b4	-0.132	0.236	1.364 *	0.506	0.360	0.427	0.405	0.384	0.094	0.196
b5	0.464	0.421	0.485	0.397	0.305	0.346	0.502	0.614	0.725	0.550
AIC	199.3	5.3	158.0	5.8	169.7	6.2	149.5	7.2	118.5	6.3

*: the estimate sighnificant differ from zero.
Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

Table 7-2. Estimated parameters of the logistic regression model for the maturity rate of female minke whales in Antarctic Area IV (1989/90 - 1997/98) if the variable selection applied.

Parameter	1989/90		1991/92		1993/94		1995/96		1997/98	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
a										
b1	0.523 *	0.211			0.350	0.189	1.795 *	0.547	-0.581	0.390
b2					-0.639 *	0.273	0.856 *	0.423	-1.680 *	0.266
b3							-1.290 *	0.497		
b4			1.017 *	0.289			0.532 *	0.220		
b5									0.711	0.386
AIC	186.9		147.0		156.5		145.3		110.9	

*: the estimate sighnificant differ from zero.
Parameter a=constant, b1=latitude, b2=longitude, b3=cumulative day, b4=school size, b5=distance from ice edge

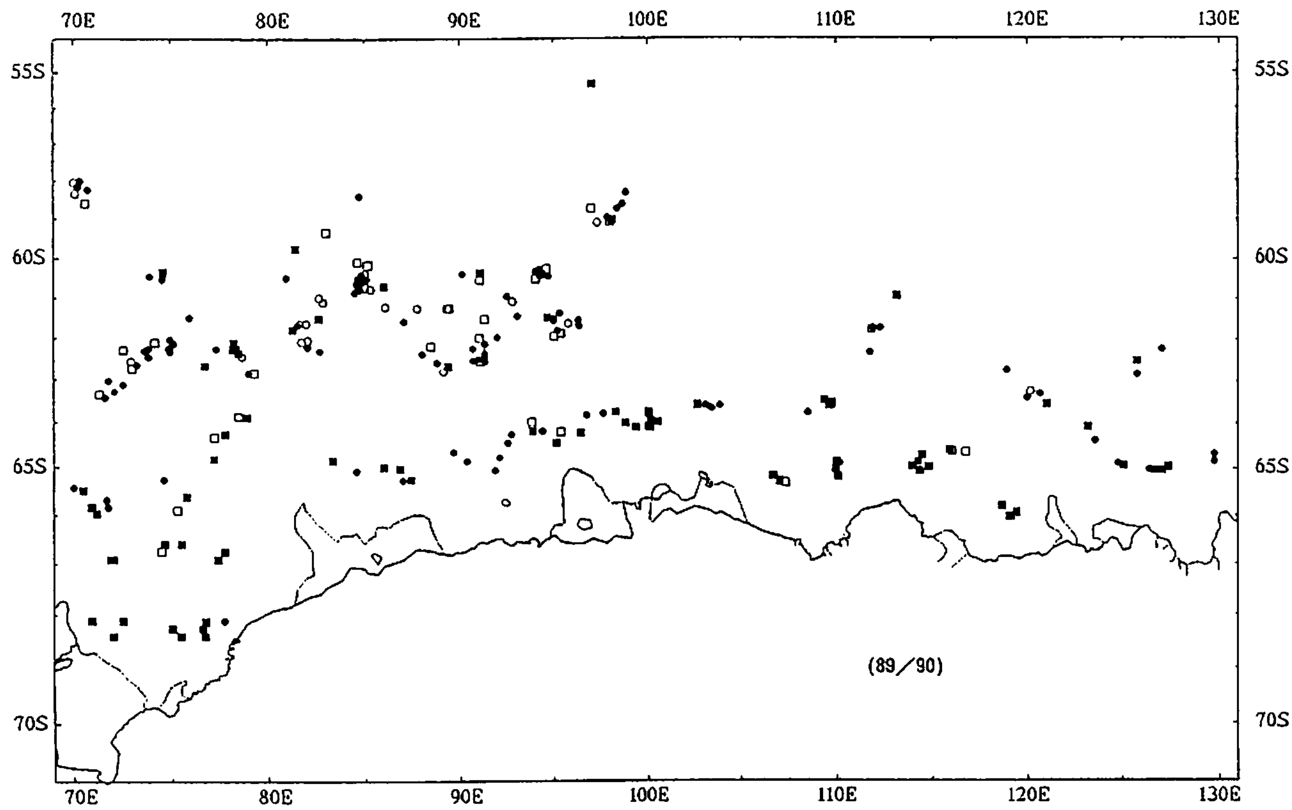

Fig. 1-a. Geographical distribution of 326 minke whales collected by the 1989/90 JARPA survey. (○:Immature male, □:Immature female, ●: Mature male, ■: Mature female)

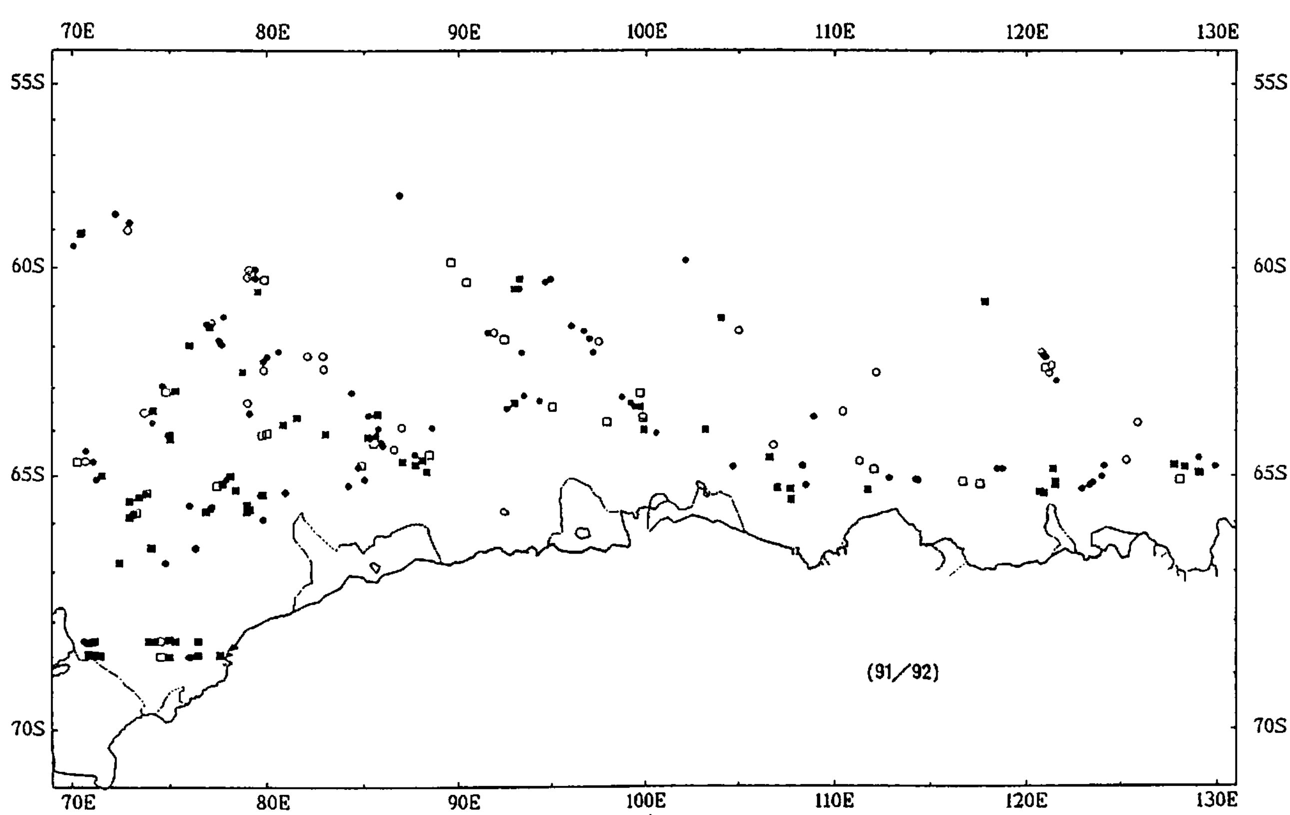

Fig. 1-b. Geographical distribution of 288 minke whales collected by the 1991/92 JARPA survey. (○:Immature male, □:Immature female, ●: Mature male, ■: Mature female)

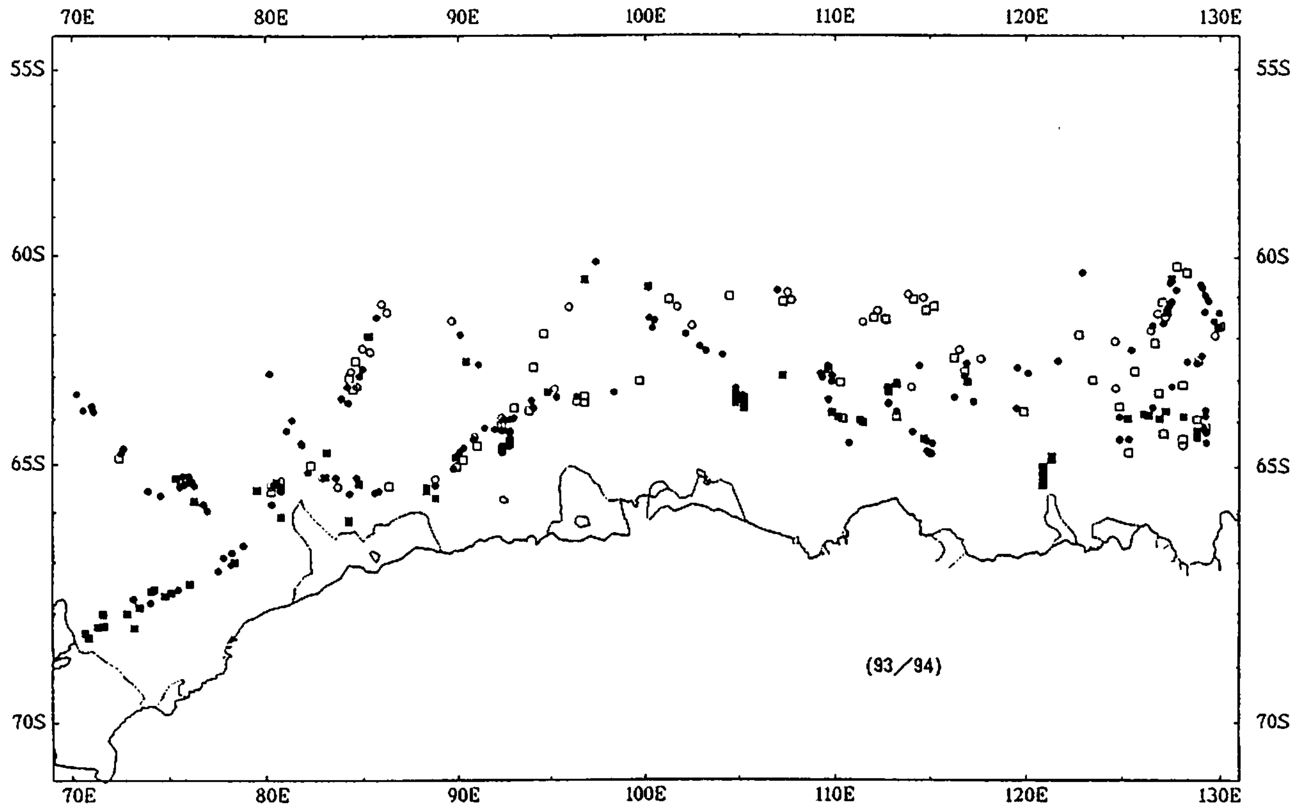

Fig. 1-c. Geographical distribution of 330 minke whales collected by the 1993/94 JARPA survey. (○:Immature male, □:Immature female, ●: Mature male, ■: Mature female)

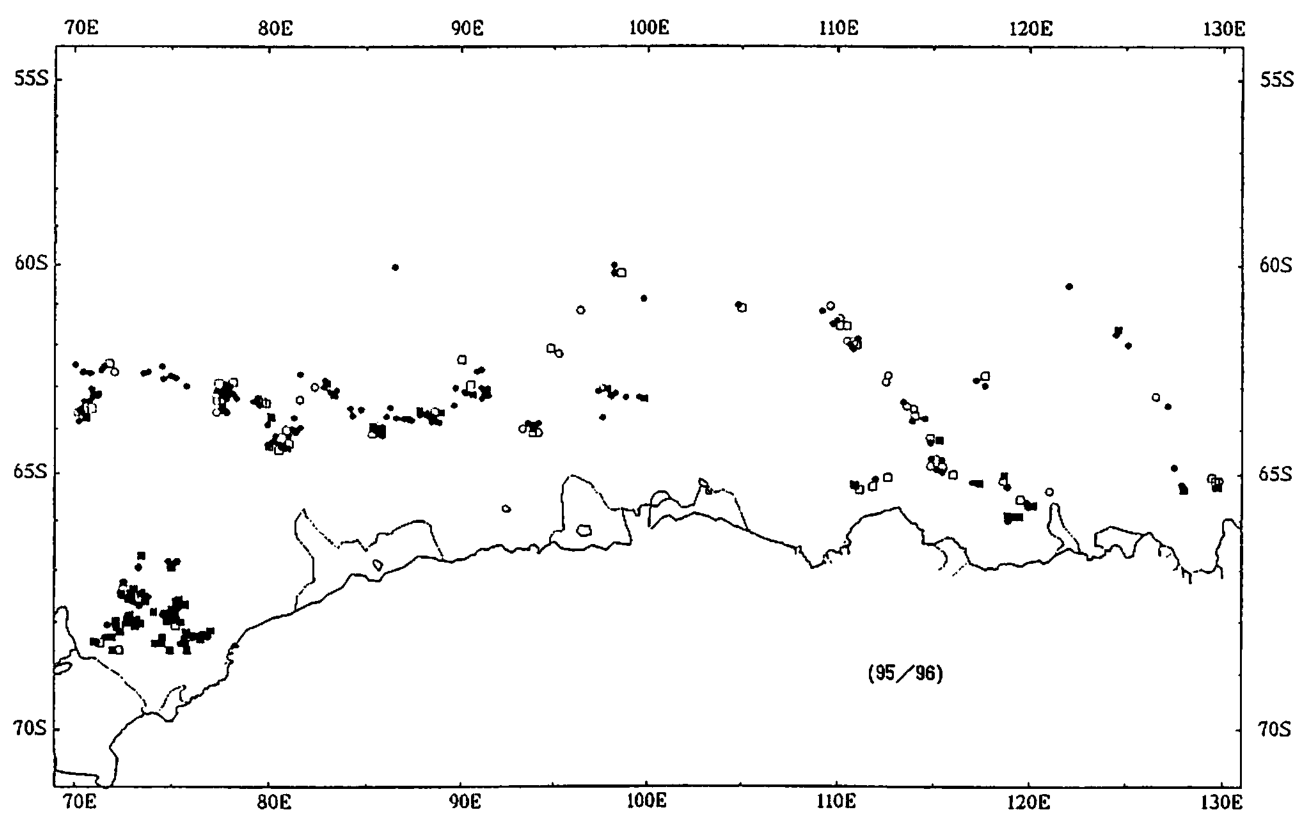

Fig. 1-d. Geographical distribution of 330 minke whales collected by the 1995/96 JARPA survey. (○:Immature male, □:Immature female, ●: Mature male, ■: Mature female)

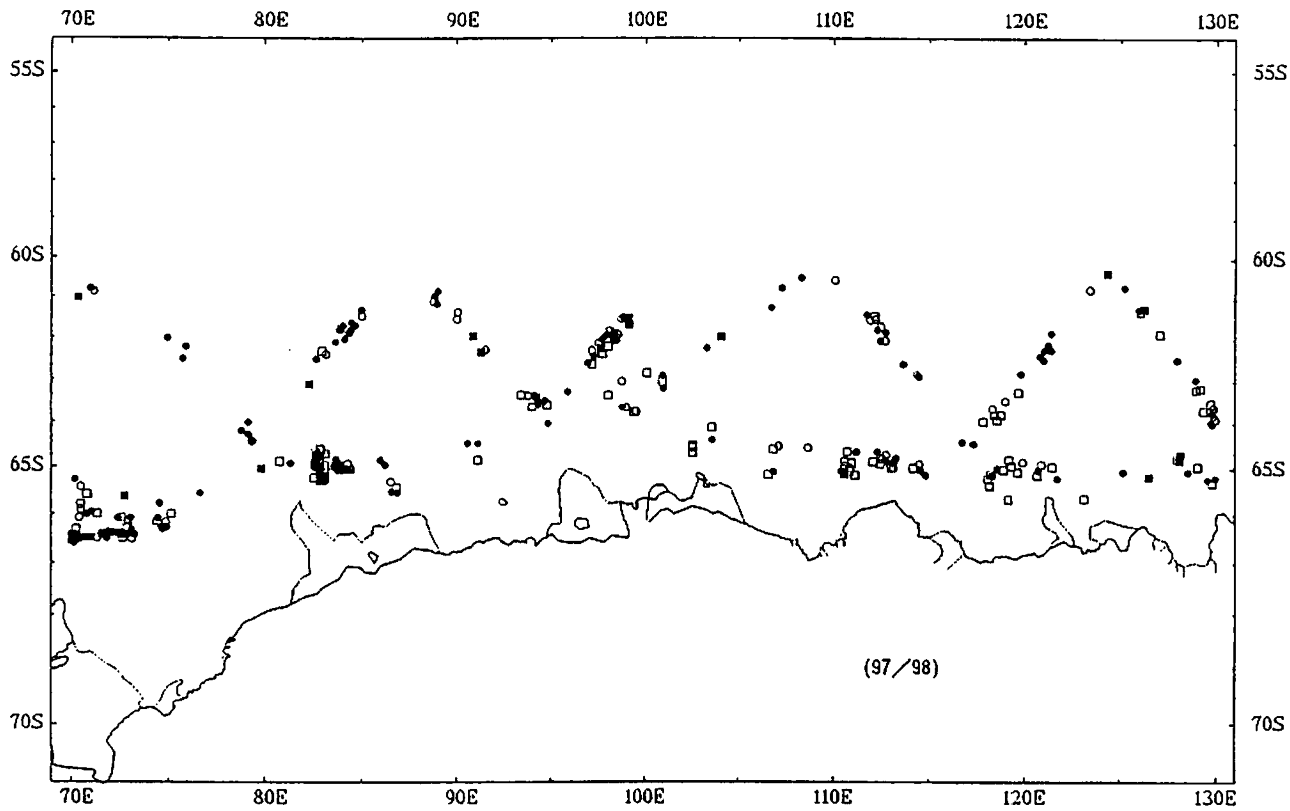

Fig. 1-e. Geographical distribution of 328 minke whales collected by the 1997/98 JARPA survey.
(○:Immature male, □:Immature female, ●: Mature male, ■: Mature female)

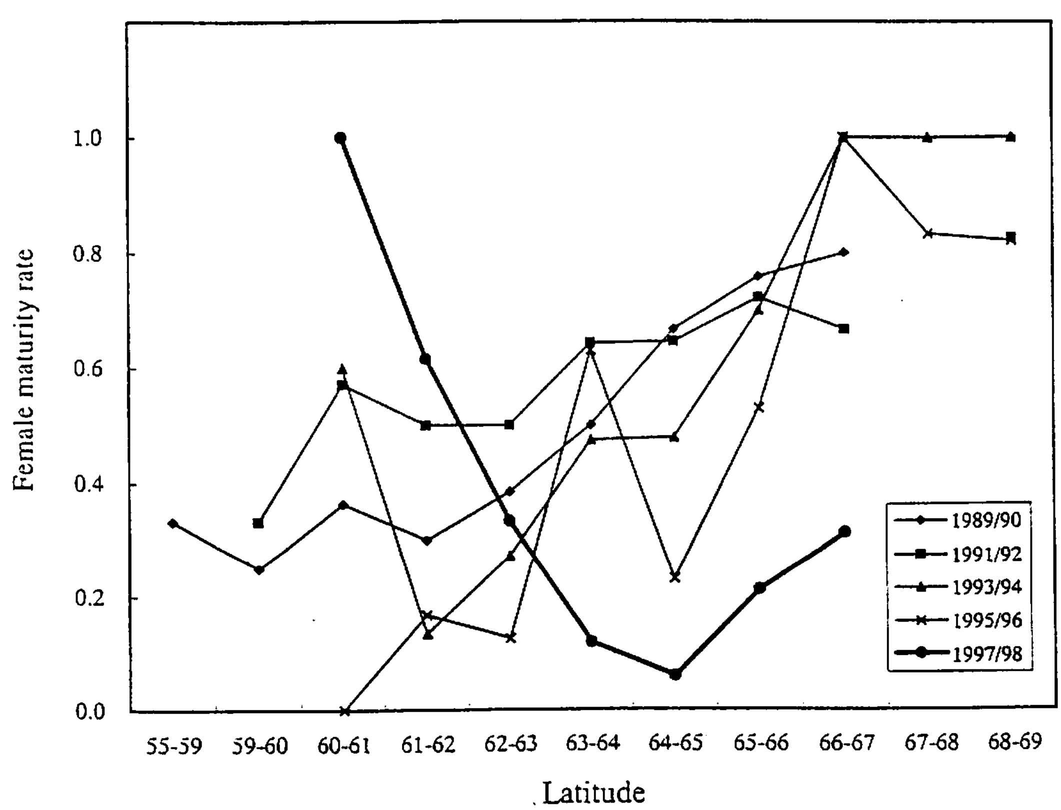

Fig. 2. Latitudinal changes of maturity rates for female minke whales in Area IV.

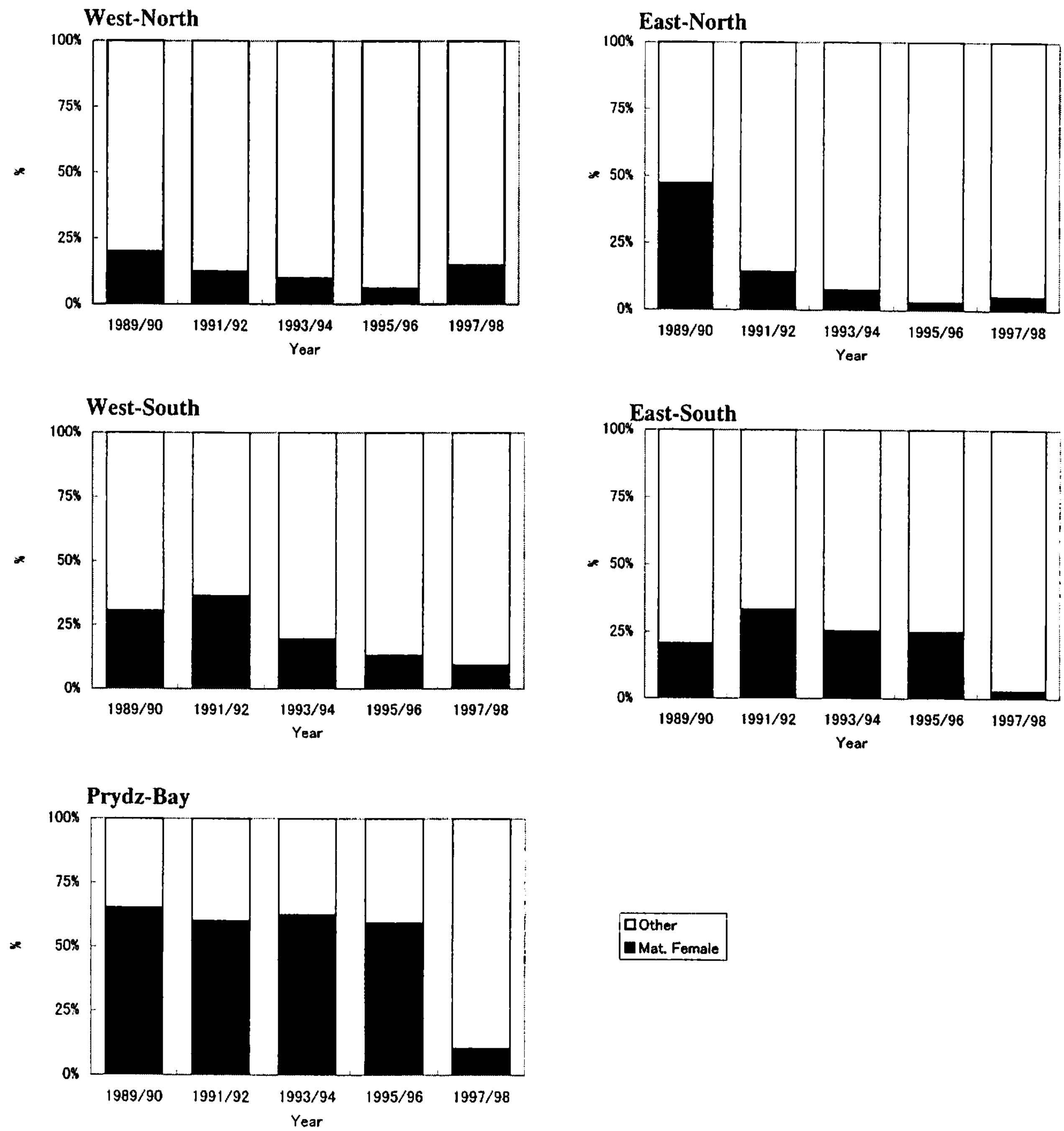

Fig. 3. Comparison of the proportion of mature females in the whales sampled in each survey stratum in the 1997/98 survey to other survey seasons.

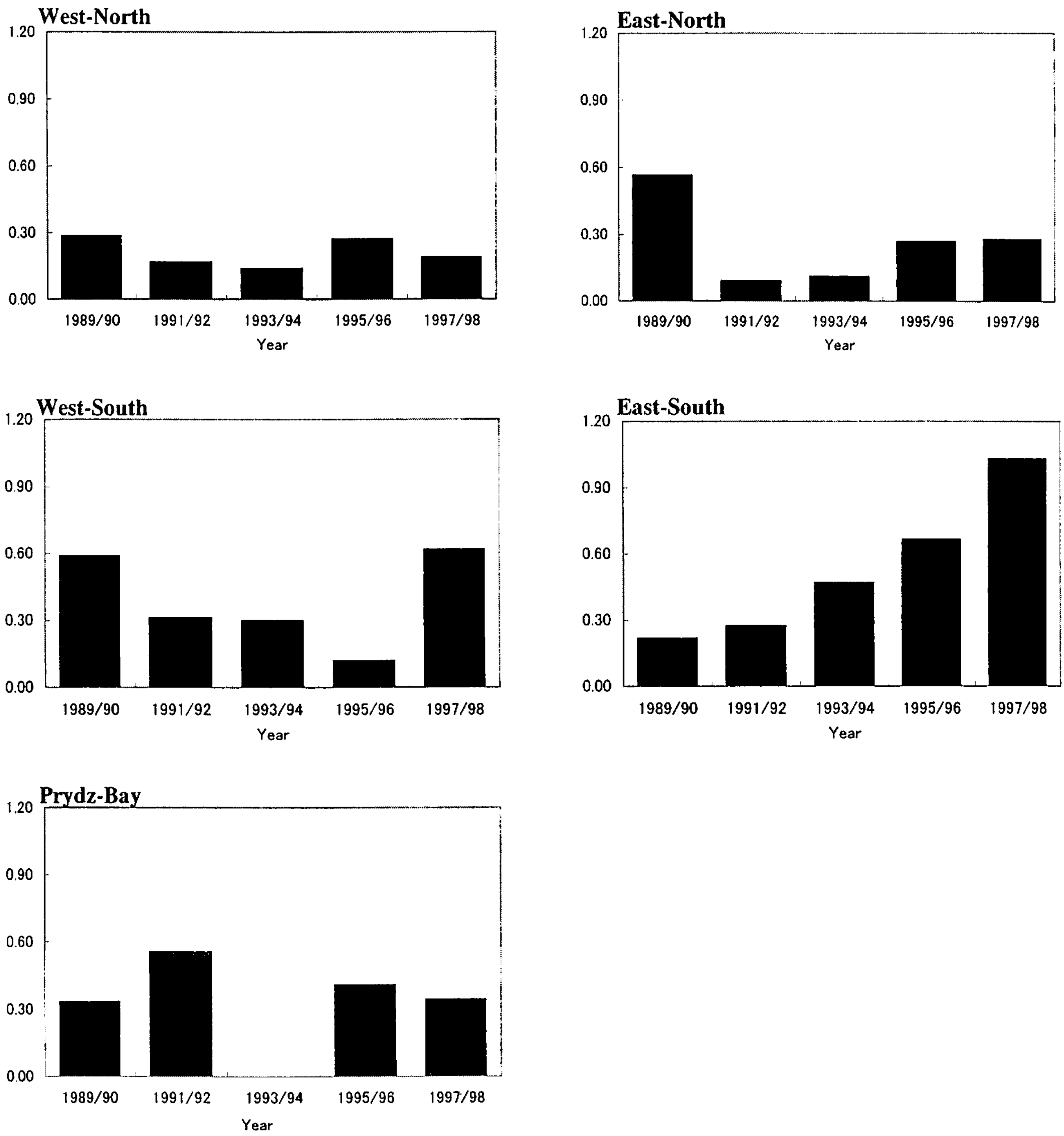

Fig. 4. Comparison of the ratio of immature females to the males (immature + mature) in the samples in each stratum in the 1997/98 survey to other survey seasons.

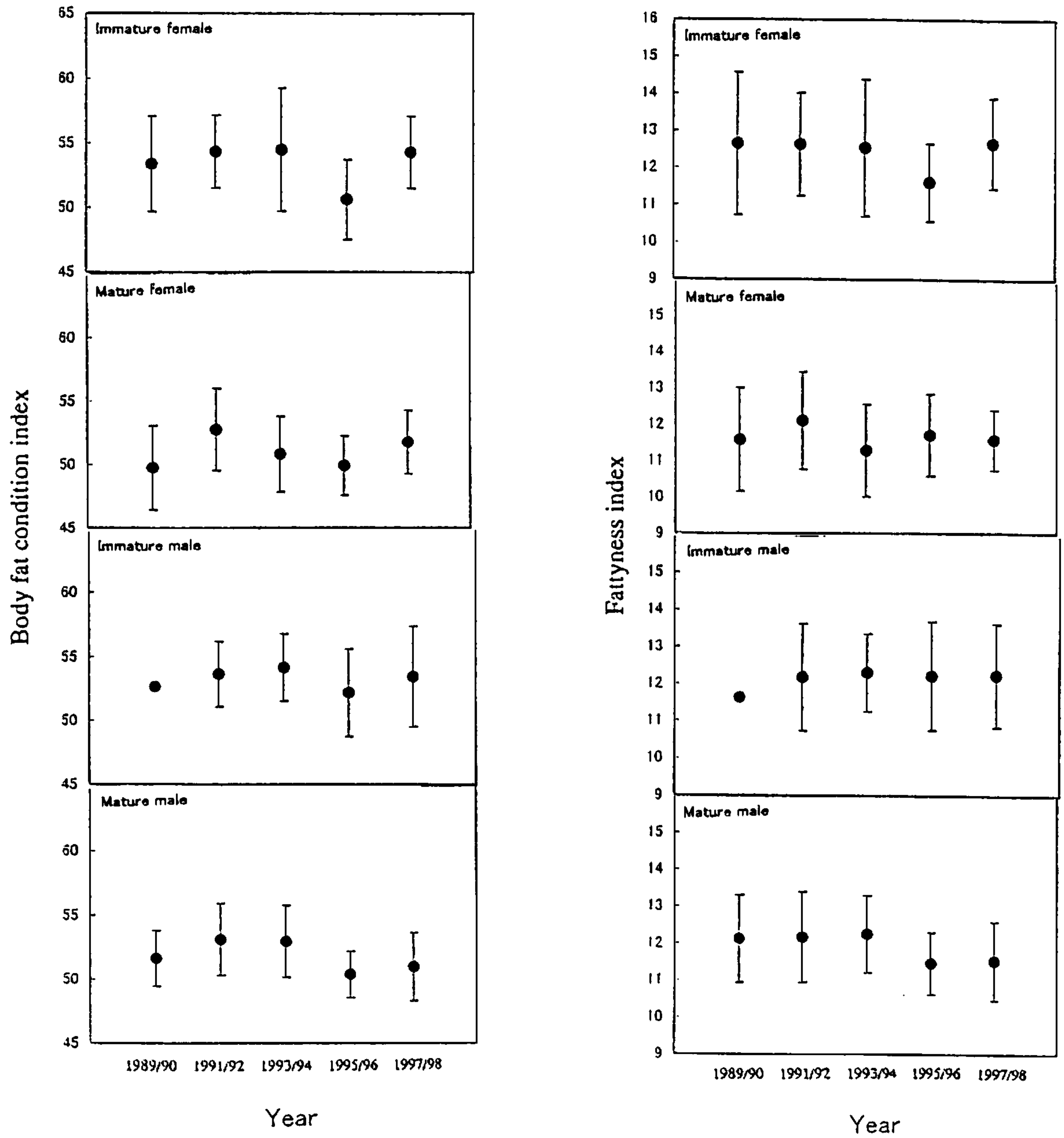

Fig. 5. Interannual changes in body fat condition index and fattyness by reproductive class in February in a part of Area IV (63°– 69°S, 70°– 100°E). Mean +/- S.D. are shown.

Appendix I. Defined lines from the nearest point of ice edge to the whale at sighting for 1989/90 First period.