Some examinations on body fatness of the western North Pacific minke whales

Tsutomu Tamura, Seiji Ohsumi and Yoshihiro Fujise

The Institute of Cetacean Research, 4-18 Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan

ABSTRACT

The body fatness of western North Pacific minke whales (*Balaenoptera acutorostrata*) was examined by use of 498 whales collected by JARPN surveys from May to September between 1994 and 1999. Three types of fatness index (*f(1), f(2)*and *f(3)*) were compared on their characteristics, and it was found Patterns of fatness are different by sexually immature and mature stages and by sexes. The *f(3)* of sexually mature whales was suitable as the fatness index for this study. A formula of W / L^b was used to represent *f(3)* by sex, where b is 2.0 and 2.5 for sexually mature males and females, respectively. The thickness of blubber is not so good indicator of the fatness. The girth length is more useful than the thickness of blubber for the indicator of fatness. Sexually mature females were little fatter than males. Fatness of pregnant whales increased with gestation period till the fetus grows to 120 cm in length, and then it may stop to increase the fatness, or fatter pregnant whales leave the feeding ground. The hypothesis of W Stock was not approved by the area difference of fatness. There is a possibility that the migration pattern of J and O Stocks is different. It was estimated that there are wintering whales and most individuals of O Stock arrive gradually into the feeding ground from the breeding ground. After July fat whales may leave the feeding ground, or they stp fo increase the fatness in the feeding ground. The maximum figure of *f(3)* was about 1.8 times of the minimum figure. The average increasing rate of *f(3)* from May to July was about 7 % of that in May in the research area. Yearly trend of fatness was not observed in research area during years 1994-1999.

INTRODUCTION

Baleen whales are generally known to migrate between the feeding ground in high latitudinal waters in summer and the breeding ground in low latitudinal waters in winter. Thus, the baleen whales become fat by storing large amount of fat in their body during feeding season, and they become slim conversely by consuming the stored fat during breeding season. The minke whale (*Balaenoptera* *acutorostrata*) is considered to belong to this type of behavior. Therefore, the knowledge on fatness of minke whales is important to understand their nutritional behavior on feeding, breeding and migration.

The index of body fatness of an animal is represented basically by ratio of body weight to body length. However, it was difficult to measure body weight of large cetaceans directly in the past. Recently, the study on the fatness of the minke whale has been developed by the direct measurement of its body weight by use of a large weighing machine for JARPA survey since 1988/89. Ohsumi *et al.* (1997) examined on the fatness by use of data on the body weight and body length of whales, which were collected by the JARPA from the Antarctic. The blubber thickness and girth lengths, which were easily measured and used as indicators of fatness of whales hitherto for long years, were also examined by Ohsumi *et al.* (1997) on their utility as the fatness indices comparing with the body weight.

In the JARPN survey which has been carried out in the western North Pacific since 1994, the body weight and body length have been measured with many other items on each minke whale sampled under the same manner as the JARPA survey. In this study, we examine on the body fatness of minke whales in relation to the stock identification and role of this whale in the ecosystem which are the two objectives of the JARPN survey.

MATERIALS AND METHODS

Research area, year and sample size

The research area of the JARPN was a part of sub-areas 7, 8, 9 and 11 which were set by the IWC/SC (IWC, 1994), excluding the EEZ of Russia. Furthermore, sub-area 7 was divided into east (7E) and west (7W) for the purpose of this research (Fig. 1). The survey years and sample size of minke whales by sex and by sexual maturity are shown in Table 1. A total of 498 minke whales, which were collected between 1994 and 1999 was used for this study. The male sex ratio of the samples is 84.1 %, and then most of the samples are males. Among male samples 88.3 % is sexually mature, and 57.0 % of female samples are sexually mature. Then, most of the data were collected from sexually mature whales.

Data analyses

Data collected and measured for this study include sex, body length, body weight, sexual maturity determined by reproductive organs, body length of fetuses, blubber thickness at the position of dorsal side and girth length at the position of umbilicus of each whale sampled. The position for the measurement of blubber thickness has been used traditionally in Japan as the most practical point as shown in Fig. 2, and the position for the measurement of girth length in this paper is at the umbilicus as shown in Fig. 2.

Three types of body fatness index are used as shown in following three equations:

$$f(1) = W / L^3 \quad \ldots\ldots(1)$$

$$f(2) = W / L^a \quad \ldots\ldots(2)$$

$$f(3) = W / L^b \quad \ldots\ldots(3)$$

Where, f is the body fatness index, W is body weight in kg, L is body length in m, and a and b are constant, but b is used for mature whales and different by sex.

These three types of index are examined on their relation with body length, sex and sexual maturity to select the most suitable index for this study.

Secondly, the blubber thickness as an indicator of fatness is evaluated. The fatness index of blubber thickness (bf) is calculated by the following equation (4):

$$bf = b / L \quad \ldots\ldots(4)$$

Where, bf is the index of body fatness in the case of blubber thickness, b is blubber thickness in cm and L is body length in m. Then, the relation between f value and bf value are examined.

Thirdly, the girth length as an indicator of fatness is evaluated. The fatness index of girth length is calculated by the following equation (5):

$$gf = g / L \ldots\ldots(5)$$

Where, gf is the body fatness index in the case of girth length, g is girth length at the position of umbilicus in cm, and L is body length in m. Then, the relation between f value and gf value are examined.

RESULTS

Selection of the most suitable fatness index

The index of body fatness ($f(1)$) which is calculated by equation (1) is commonly used for the study of fatness of wild animals, and dimension of L^3 is the same as W. This kind of fatness index was applied by Ohsumi *et al.* (1997) for the examination on fatness of the Antarctic minke whale. On the other hand, a-value of the index of body fatness ($f(2)$) is calculated as a-value of the body length and body weight relationship (W=cL^a.) where a and c is constant. In the case of *f(3)* b-value is calculated by use of (W=dL^b.) for mature males and females, separately. Then, we examine characteristics of these three kinds of index to select the most suitable fatness index for the present paper.

From the relationship between the body length and body weight of males and females combined, the a-value in equation (2) was calculated to be 2.7. The b-value in equation (3) is calculated to be 2.0 for mature males, and it is 2.5 for mature females.

Fig. 3 A and B show the relation between body length and *f(1)* in males and females, respectively. Fig. 3 C and D show the same kind of relation in the case of *f(2)* in which a is 2.7. And Fig 3 E and F show the case of *f(3)* in which values of b are 2.0 for males and 2.5 for females.

It is found that in all cases there is a transition phase at the body length of 6.5 m in males and 7.0 m in females. These figures are corresponded with the body length at sexual maturity in males and females, respectively. The body length at sexual maturity in both sexes were obtained in this paper on the minke whales taken by JARPN surveys from the relationship between body length and rate of sexual maturity as shown in Fig. 4. Although the body length at the transition phase is the same in three types of fatness index, the patterns are different each other. The values of *f(1)* and *f(2)* are almost constant in immature stage, and they tend to decrease with body length in mature stage of both sexes as shown in Fig. 3 A, B, C and D. On the other hand, *f(3)* values increase with body length in immature stage, and they become constant with body length after attainment of sexual maturity as shown in Fig. 3 E and F.

This comparison indicates that *f(1)* and *f(2)* are effected by body length of the whale in sexually mature stage, but *f(3)* is not effected by body length in the sexually mature stage. It will be useful to eliminate the effect of body length for the study on fatness of the minke whale. As the pattern of fatness indices of immature and mature whales are different each other, it should be better to omit the data of immature whales which are scarce in number for the present study. Furthermore, as the pattern of fatness index with body length is different by sex even in the sexually mature stage as shown in Fig. 5, it was found that the different formula should be used by sex to exclude the factor of body length. Then, the final selection was the use of equation (3), and different values of b should be used for mature males and females. Thus, values of b in equation (3) are 2.0 and 2.5 for sexually mature males and females, respectively, and the *f(3)* of sexually mature whales will be used as the fatness index in which b values are different by sex in later sections of this paper.

Comparison of fatness index by sex

Table 2 shows the maximum, minimum, mean and standard deviation for *f(3)* by sex on sexually mature whales. It is natural these values are different by sex, because different values of b are used by sex. Then, it will be safe to separate data by sex in examination of *f(3)*. There are some doubts that the present data on the minimum and the maximum figures can represent true values in the whole population, because the research ground for this study is estimated to be on the way of migration between the breeding and feeding grounds of the minke whale. Anyway, the minimum and maximum values of *f(3)* were 5.69 and 10.33 in mature males and 23.75 and 39.83 in mature females, respectively, and then the maximum values of *f(3)* in sexual mature whales are 1.8 and 1.7 times of the minimum values in males and females, respectively.

This means that it is possible for the sexually mature minke whale to become fat about two times at maximum during the feeding season.

Evaluatiou of blubber thickness as an indicator of fatness

Fig. 6 A and B show the relation between *f(3)* values and *bf* values in sexually mature males and females. The correlation coefficient of sexually mature males and females is 0.30 and 0.51, respectively. Therefore, the blubber thickness will not be regarded as a good indicator of the fatness of the minke whale, especially for mature males, although it has been used as a fatness indicator traditionally for long years in many kinds of whales.

Evaluation of girth length as an indicator of fatness

Fig. 7 A and B show the relation between *f(3)* values and *gf* values in sexually mature males and females. The correlation coefficient is 0.59 and 0.64 in mature males and females, respectively. Therefore, the girth length can be regarded as better indicator of the fatness than blubber thickness in the minke whale. Then, girth length can be used as an indicator of fatness, when the data on body weight are not available.

Change in fatness with gestation period

It is believed that baleen whales breed in lower latitudinal waters in winter without feeding, and mature females begin to migrate to the feeding grounds in higher latitudinal waters after conception. The gestation period of a pregnant whale is usually estimated by body length of its fetus, and *f* value is regarded as an indicator of staying period of a whale in the feeding ground.

Fig. 8 showed the relation between the body length of fetus and *f(3)* values of its mother. It is found that there is a trend of increase in *f(3)* values with body length of fetus till about 120 cm in body length of fetuses, although there are large individual variations of *f* values. It is estimated that the increase rate of body fatness of the pregnant minke whale was about 40 % in average from the conception (*f(3)* = 25) to the period in which a fetus grows to 120 cm (*f(3)* = 35).

However, it seems that the increase of fatness stops after the fetus grows larger than 120 cm in body length. This suggests us that a pregnant minke whale of which fetus grows more than 120 cm and become more fat than *f(3)* = 35 approximately may leave the feeding ground, or they do not become more fat in the feeding ground.

The body length at birth of the Northern Hemisphere minke whale is estimated to be 2.6 m

(Lockyer, 1984), and the pregnant whale of which fetus is larger than 220 cm has not collected by the JARPA surveys. Then, it has not yet reached to the conclusion whether the latest stage pregnant whale remains in feeding ground and it becomes more fat or not.

Area variation of the fatness index

Table 3 shows the sample sizes of sexually mature whales by sex, by sub-area and by month. As examined later, the fatness index changes seasonally, and it is need to compare the values in the same month to examine the area difference of the fatness index.

Table 4 A, B, C and D show *f(3)* values in the Pacific side of Japan (sub-areas 7, 8 and 9) and the southern Okhotsk Sea (sub-area 11) by month. In July and August minke whales were sampled both in the Pacific side and the southern Okhotsk Sea. In sexually mature males the mean value of *f(3)* in the Pacific side are smaller than those in the southern Okhotsk Sea both in July and August, but the difference is not so large (0.45 in July and 1.46 in August). In the case of mature females the mean value in the Pacific side in July and August combined (32.11) is almost the same as those in the southern Okhotsk Sea (33.28), although sample size is small in both sides.

Seasonal change in the fatness index

Table 4 and Fig. 10 show monthly values of the maximum, minimum, mean and standard deviation of *f(3)* of mature minke whales. The maximum values are almost constant in all months from May to September in mature males. This phenomenon suggests that there are some whales which spend the winter season in the feeding ground, and the minke whale will not become fat more than 101 of value of *f(3)* in males in the feeding ground.

On the other hand, the minimum values of mature males increase from May to July and they become almost constant from July to September. This indicates that the minimum value of *f(3)* of whales which arrive to the feeding ground will be less than 56 in mature males.

The mean values also increase with month almost parallel with the minimum values in males. This indicates that the minke whale becomes fat during the stay in the feeding ground, but it may leave the feeding ground after it becomes fat to a certain extent. Increase rate of mean values of *f(3)* from May to July was estimated to be about 107 % of that of May in mature males. However, we must recognize that the average increase rate does not represent that of an individual. Furthermore, this phenomenon is not confirmed as the result for a whale to stay within the research area in whole research season.

Comparison of fatness index between J and O Stocks

It has been proven that two stocks (J and O Stocks) are distributed and migrated in the Okhotsk side, and individuals of both stocks can be separated by the haplotype of mt-DNA (Goto *et al.*, 2000).

Table 5 compares *f(3)* values of J and O Stocks in sub-area 11 which were identified thus by Dr.

Goto. In the case of mature males the values of the maximum and mean values of O Stock are larger than that of J Stock. According to the result of the Mann-Whitney test, they are statistically significant in males (Mann-Whitney test: p=0.02).

This phenomenon suggests that the migration and feeding pattern may be different between J and O Stocks in sub-area 11, although data numbers are small to obtain the conclusion.

Comparison of fatness index between sub-area 7 and sub-area 9

An assumption that an independent stock (W Stock) from O Stock exists in sub-area 9 was made by the Working Group in 1993 IWC/SC meeting (IWC, 1994). Table 6 compares several kinds of *f(3)* values of sexually mature minke whales sampled from Sub-area 7 (O Stock) and those from sub-area 9. Statistical difference is not detected between both sub-areas by use of Mann-Whiney test in each month (Mann-Whitney test: May p=0.07, June p=0.12; August p=0.12). This means that minke whales in both sub-area groups migrate and feed in almost the same pattern. Anyway, the existence of W Stock cannot be detected by the examination of the fatness index.

The minke whale distributed in sub-area 7 is regarded to belong to O Stock. Then, comparing with the values in sub-area 7 in Table 6 with those of O Stock in Table 5, mean values of the latter are little larger than that of the former. This may be caused by the difference of migration pattern in sub-area 11 and sub-area 7, and the O Stock whales reached to sub-area 11 earlier than those in sub-area 7.

Yearly change in fatness index

Table 7 shows yearly change in the maximum, minimum, mean and standard deviation of *f(3)* values of the sexually mature minke whales in JARPN research area from 1994 to 1999. Although yearly variation was observed, any trend is not detected in these figures. Therefore, it is estimated that nutritious condition of the western North Pacific minke whale has not changed so markedly in recent six years. However, as examined in the section of seasonal change in these figures, there is a seasonal change in the values of the minimum and mean values and research season has varied year by year in these years. Then, these factors should be considered in the evaluation of this phenomenon.

DISCUSSION

Value of blubber thickness as traditional indicator of fatness of whales

Blubber thickness was regarded as practical index of fatness of whales for long years from the pioneering work of Mackintosh and Wheeler (1929) on the Southern blue and fin whales. The blubber thickness at the body side under the dorsal fin as shown in Fig. 2 has been measured routinely on each whale caught by Japanese commercial whaling from 1946. In the North Atlantic, both the fin and sei whales were demonstrated to exhibit seasonal variation in body condition and relative amounts of body fat (Lockyer *et al.*, 1985). For the North Atlantic minke whale, fatness index based on blubber thickness was found useful, because blubber thickness increases during the feeding season both on the ventral and dorsal sides of the whales (Næss *et al.*, 1998). However, Ohsumi *et al.* (1997) who examined on several parts of whale body found that the blubber thickness was not so good indicator for the Antarctic minke whale. This finding was obtained by comparison of the fatness index by use of blubber thickness with the fatness index by use of body weight. In this paper we confirmed the conclusion of Ohsumi *et al.* (1997) by a double check on the North Pacific minke whales which were collected by the JARPN survey.

This kind of study can be done by use of weighing machine which is able to measure body weight of a minke whale directly, easily and plentifully in a short time. Before then the body weight of large whales must be obtained by weighing many pieces of a body parts which was took apart by dissection and sum up these measurement data. Therefore, it was laborious and difficult practically to measure body weight on many individuals.

The minke whale is suitable as the material to study on the fatness of baleen whales, because its body weight is not so large and able to measure it directly by use of a weighing machine.

Consideration on the migration from body fatness

We supposed that there is not so large individual variation of body fatness in females which have the same class of fetal body length. However, this assumption was not real as shown in Fig. 8. This phenomenon was already found by Ohsumi *et al.* (1997) on the Antarctic minke whale. It is thought that the starting date of migration from the breeding ground may not directly affected by the conception or there is individual variation in the ingesting of nutrient after start of migration from the breeding ground.

From analysis of seasonal change in the fatness index, the existence of wintering whales and delay of arrival of whales into the feeding ground were confirmed in the North Pacific as similar to that in the Antarctic (Ohsumi *et al.*, 1997). It was estimated from this study that some lean minke whales reach to the feeding ground by July, and the individuals which become fat at enough level may leave from the feeding ground gradually after August. It is a problem to be considered that the research area of the JARPN surveys is a feeding area or a passage ground of migration of the minke whale. By each of such cases, the interpretation on the migration from body fatness will become different. On this connection, there is large sexual and age segregation in the distribution of minke whale, and males are abundant in the research area of the JARPN surveys through the research season (Zenitani *et al.*, 2000). Considering from the fact that similar phenomena were observed in the Antarctic, which is the typical feeding ground of the minke whale, it can be considered that the JARPN research area is a feeding ground for at least adult males.

Consideration on nutrition from fatness

The increase rate of fatness index of sexually mature males was about 7 % in average during 3 months from May to July, and apparently it does not increase after August. It is clear from the result that the minke whale accumulated the nutrient rapidly during 3 months, but it may be estimated that fat whales leave feeding ground after they reach to a certain level of fatness. Lockyer (1981) investigated the seasonal change in body mass of the larger rorquals in the Antarctic and estimated that the total increase in the body mass over the summer feeding was 30 to 100 % and noted the hibernating mammals often doubled their mass. Although the present result does not represent the increase of nutrient of an individual but the average including individual variation of intake of nutrient and difference of arrival of the whale into the feeding ground, value of 100 % may be too large, because the ratio of the maximum figure of *f(3)* to the minimum was 1.8. This means the increase rate of body fatness should be less than 80%.

Ichii *et al.* (1998) examined the inter-annual changes in body fat index of minke whales in the Antarctic, and they cleared the body fat index linked to food availability and sea-ice extent during the austral summer in the Antarctic. Ohsumi *et al.* (1997) showed that the fatness index represented by blubber thickness decreased gradually from 1979 to 1996. On the other hand, yearly trend was not found in the fatness index of the western North Pacific minke whale, although data were available for only six years from 1994 to 1999.

The alternation of abundant fish species is large and food species of the minke whale have changed remarkably in the north-western region of the North Pacific (Kasamatsu and Tanaka, 1992; Tamura *et al.*, 1998, Tamura and Fujise, 2000). The present result suggests that the minke whale maintain food availability at least in recent year in spite of yearly change in food species in the area.

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Table 1. Number of the western North Pacific minke whales sampled by JARPN surveys used for this study.

Year	Male		Female		Total
	Immature	Mature	Immature	Mature	
1994	1	17	2	1	21
1995	2	89	2	7	100
1996	9	54	4	10	77
1997	14	73	7	6	100
1998	13	76	6	5	100
1999	10	61	13	16	100
Total	49	370	34	45	498

Table 2. Comparision of *f (3)* by sex.

	Males	Females
Number	370	45
Maximum	10.33	39.83
Minimum	5.69	23.75
Mean	8.04	32.20
S. D.	0.78	3.99

Table 3. Sample sizes of sexually mature whales by sex, by sub-area and by month from 1994 to 1999.

	Mature male						Mature female					
Month / sub-area	7W	7E	8	9	11	Total	7W	7E	8	9	11	Total
May	0	41	7	17	0	65	0	3	0	2	0	5
June	35	1	28	39	0	103	2	0	2	3	0	7
July	0	0	38	62	26	126	0	1	1	5	14	21
August	14	0	5	27	17	63	0	0	0	3	7	10
September	9	0	0	4	0	13	2	0	0	0	0	2
Total	58	42	78	149	43	370	4	4	3	13	21	45

Table 4. Seasonal change in fatness index *f (3)* from 1994 to 1999.

A. Mature males in sub-areas 7, 8 and 9

Month	May	June	July	August	September
Number	65	103	100	46	13
Maximum	94.26	100.49	99.41	99.09	100.02
Minimum	56.87	59.87	66.25	62.44	64.96
Mean	76.35	79.97	81.89	81.40	82.12
S.D.	7.55	7.77	7.05	8.09	11.51

B. Mature females in sub-areas 7, 8 and 9

Month	May	June	July	August	September
Number	5	7	7	3	2
Maximum	32.61	38.80	37.13	33.71	33.66
Minimum	27.52	24.97	29.36	29.12	33.52
Mean	29.20	31.13	32.87	31.35	33.59
S.D.	2.09	4.27	2.61	2.30	0.10

C. Mature males in sub-area 11

Month	May	June	July	August	September
Number	0	0	26	17	0
Maximum			103.29	94.05	
Minimum			72.97	71.78	
Mean			82.44	82.86	
S.D.			6.74	6.58	

D. Mature females in sub-area 11

Month	May	June	July	August	September
Number	0	0	14	7	0
Maximum			39.32	39.90	
Minimum			23.75	29.50	
Mean			31.69	34.86	
S.D.			5.12	3.54	

Table 5. Comparision of *f (3)* values between J stock and O stock in sub-area 11.
(J and O Stocks which were classified from genetic analyses by Dr. Goto)

	Mature males			Mature females	
	J stock	O stock	Mann-Whitney	J stock	O stock
Number	12	31		9	12
Maximum	86.70	103.29		39.55	40.03
Minimum	71.78	73.17		24.63	24.06
Mean	78.64	84.14	0.02	33.09	33.06
S. D.	5.48	6.43		5.71	4.25

Table 6. Comparision of *f (3)* values between sub-areas 7 and 9 in each month.

May	Mature males			Mature females	
	Sub-area 7	Sub-area 9	Mann-Whitney	Sub-area 7	Sub-area 9
Number	38	17		3	2
Maximum	92.42	94.26		29.71	32.61
Minimum	64.36	56.87		27.52	28.33
Mean	74.76	79.05	0.07	28.34	30.47
S. D.	6.17	9.88		1.19	3.02

June	Mature males			Mature females	
	Sub-area 7	Sub-area 9	Mann-Whitney	Sub-area 7	Sub-area 9
Number	34	39		2	3
Maximum	95.96	100.92		38.80	32.07
Minimum	64.98	59.87		29.35	24.97
Mean	80.28	82.97	0.12	34.07	29.69
S. D.	6.84	8.56		6.68	4.09

July	Mature males			Mature females	
	Sub-area 7	Sub-area 9	Mann-Whitney	Sub-area 7	Sub-area 9
Number	0	61		1	5
Maximum		99.41			37.13
Minimum		66.25			30.79
Mean		80.75	No test	29.36	33.60
S. D.		6.79			2.55

August	Mature males			Mature females	
	Sub-area 7	Sub-area 9	Mann-Whitney	Sub-area 7	Sub-area 9
Number	14	26		0	3
Maximum	93.49	99.09			33.71
Minimum	70.43	71.73			29.12
Mean	79.36	83.52	0.12		31.33
S. D.	5.95	8.04			2.30

September	Mature males			Mature females	
	Sub-area 7	Sub-area 9	Mann-Whitney	Sub-area 7	Sub-area 9
Number	8	4		2	0
Maximum	98.97	100.02		33.66	
Minimum	64.96	77.77		33.52	
Mean	77.58	91.02	No test	33.59	
S. D.	10.43	10.73		0.10	

Table 7. Yearly change in fatness index *f (3)* from 1994 to 1999.

A. Mature males

Year	1994	1995	1996	1997	1998	1999
Number	17	89	54	73	76	61
Maximum	10.00	9.94	9.90	10.09	9.24	10.33
Minimum	7.00	5.99	6.24	5.69	6.35	6.50
Mean	8.43	8.12	7.92	8.41	7.56	8.08
S.D.	0.81	0.78	0.73	0.79	0.62	0.70

B. Mature females

Year	1994	1995	1996	1997	1998	1999
Number	1	7	10	6	5	16
Maximum		37.13	39.83	32.74	34.01	39.32
Minimum		30.79	29.36	24.97	27.52	23.75
Mean	29.12	33.27	33.95	30.46	30.55	31.99
S.D.		2.27	3.38	3.15	3.13	5.13

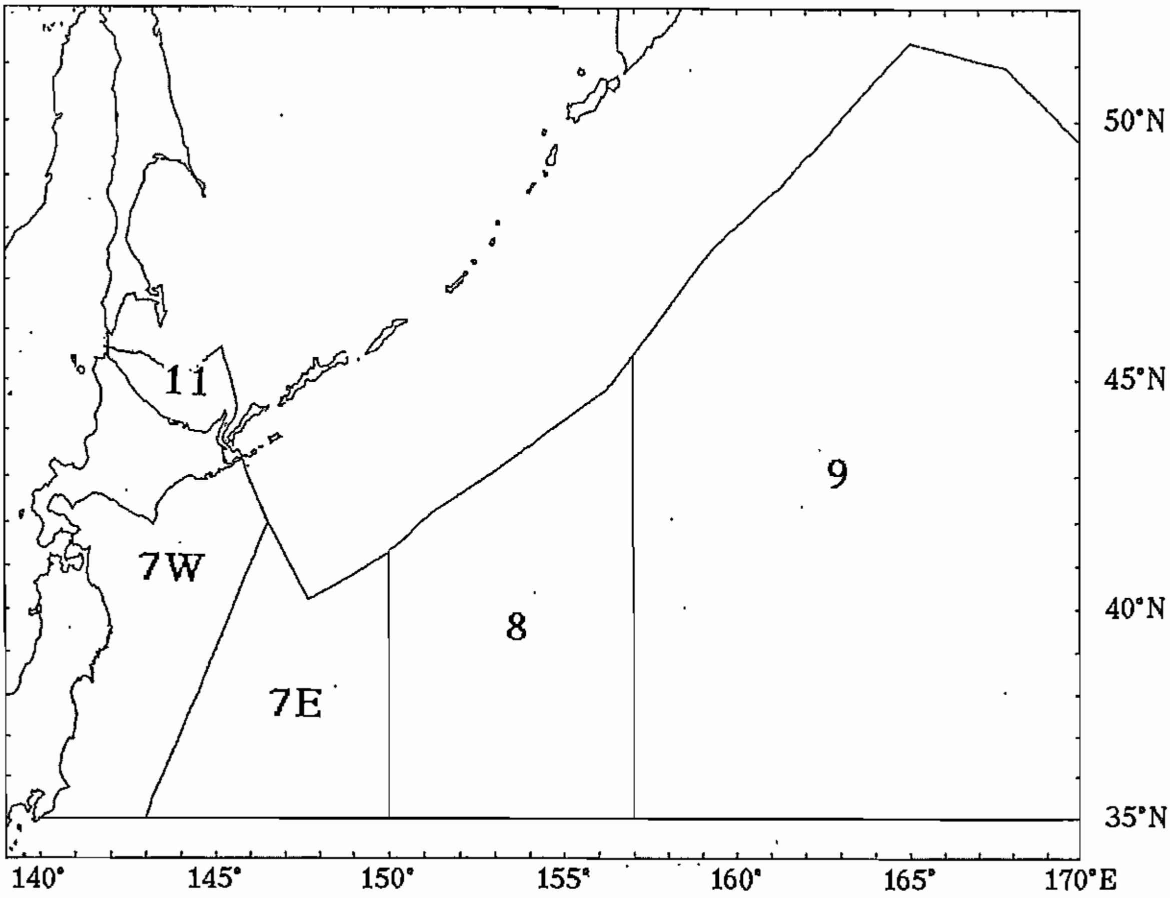

Fig.1. Sub-areas surveyed by the JARPN from 1994 to 1999. Sub-areas were based on IWC (1994), excluding the EEZ of Russia. Furthermore, sub-area 7 was divided into east (7E) and west (7W).

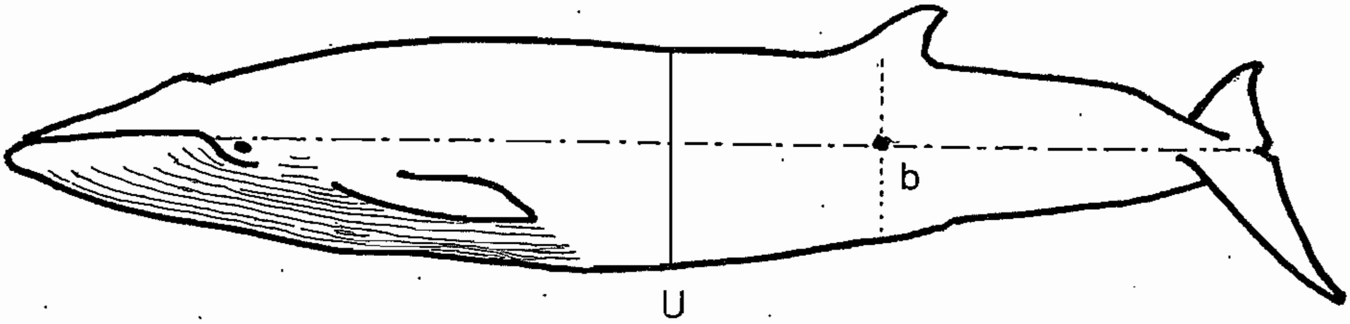

Fig.2. The positions of blubber thickness (b) and girth length (U) measured.

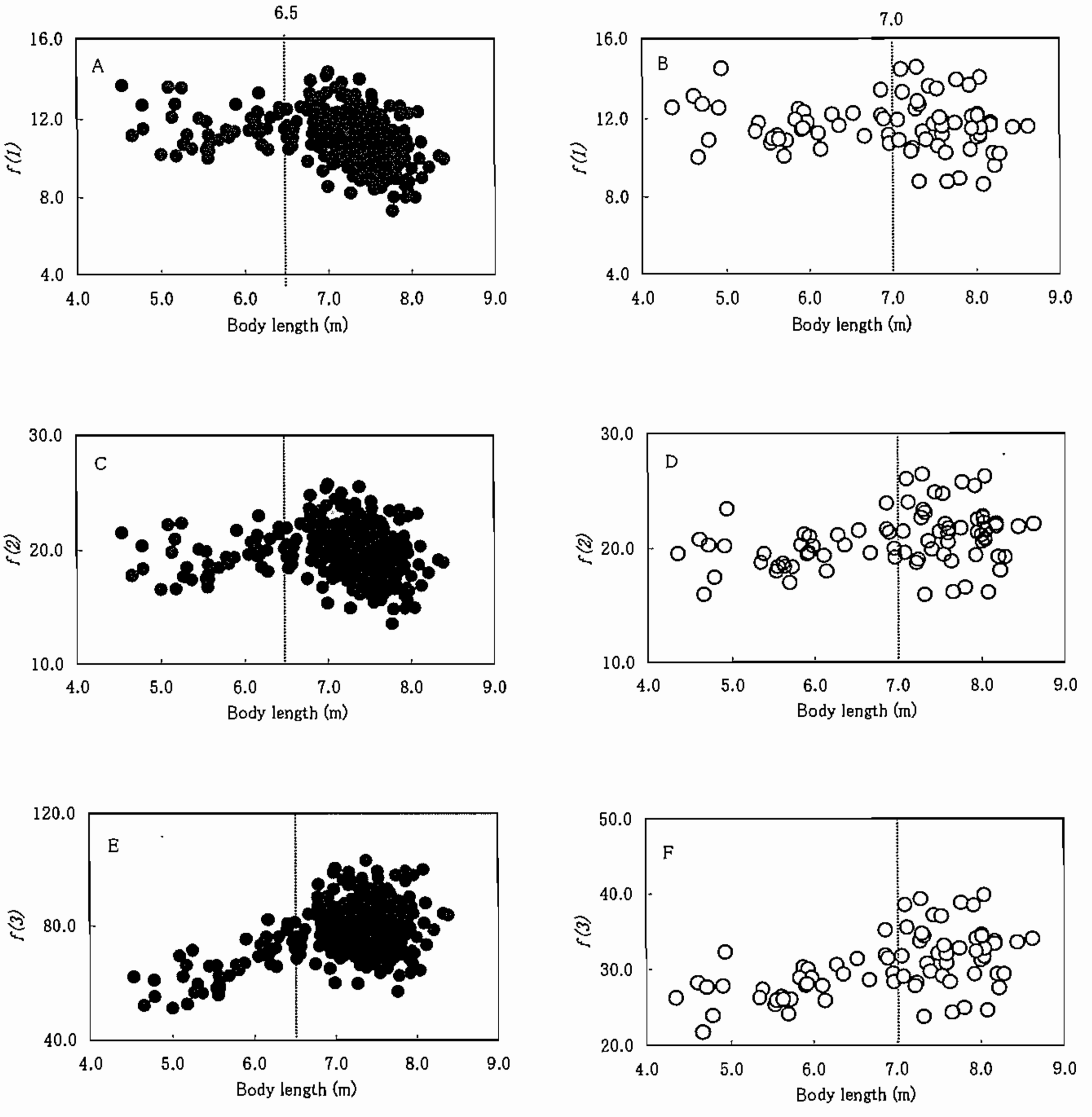

Fig.3. Relation between body length and two types of fatness index.

A and B: $f(1) = W / L^{3.0}$, C and D: $f(2) = W / L^{2.7}$, E and F: $f(3) = W / L^{2.0}$ (male), $W / L^{2.5}$ (female).
Open circle: females, Closed circle: males.

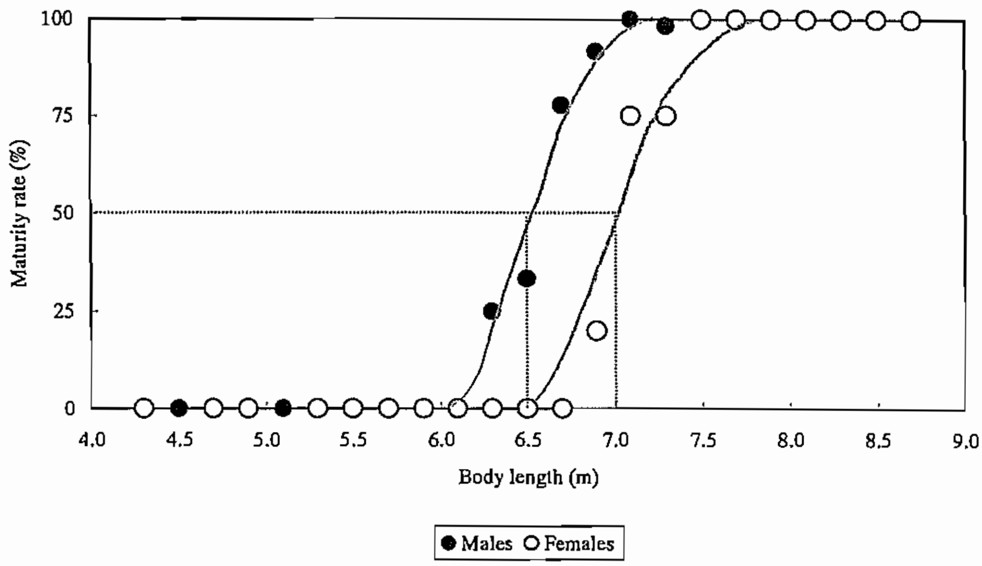

Fig. 4. Relation between body length and rate of sexual maturity of minke whales taken by JARPN surveys.

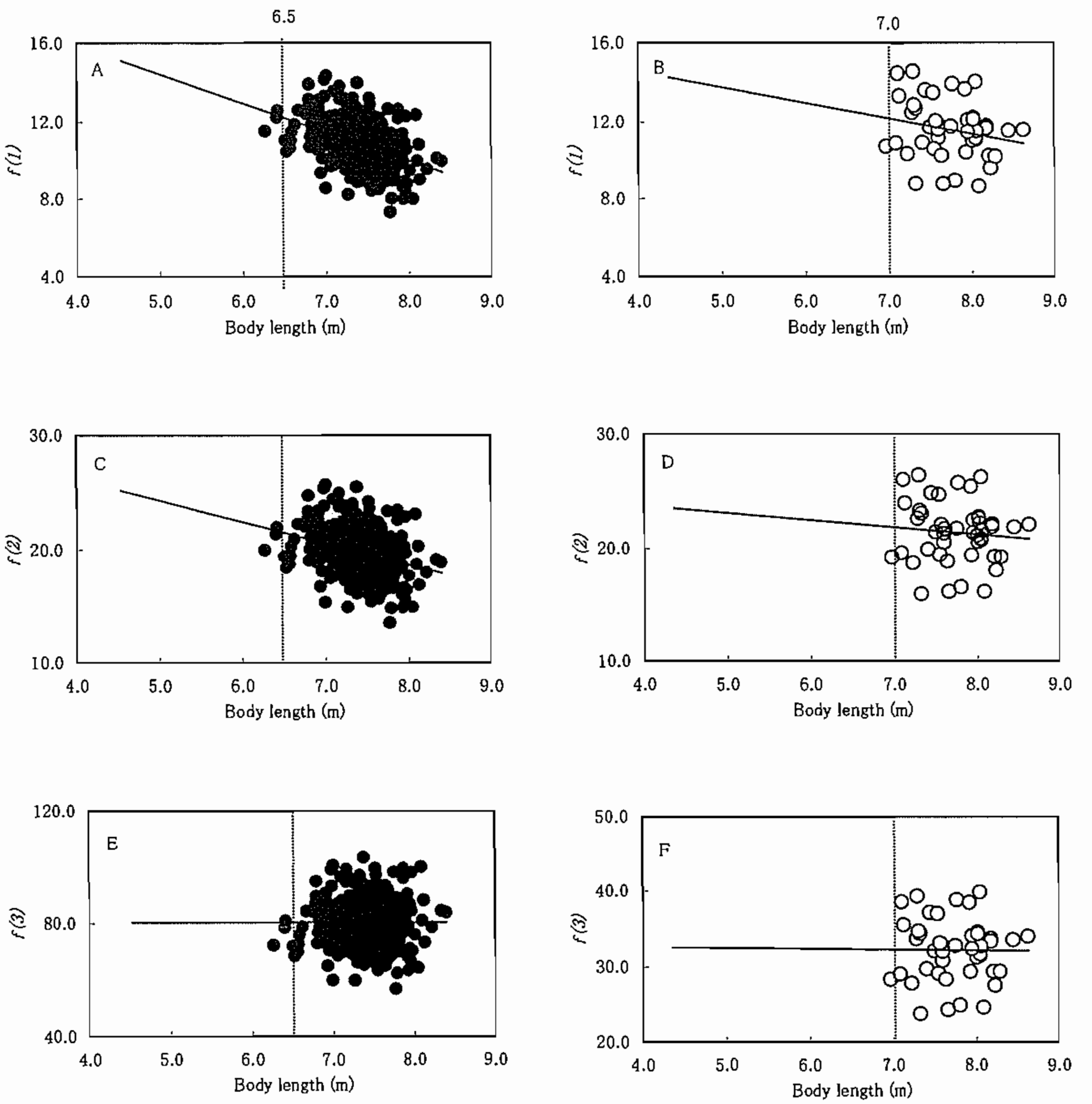

Fig.5. Relation between body length and two types of fatness index.
A and B: $f(1) = W / L^{3.0}$, C and D: $f(2) = W / L^{2.7}$, E and F: $f(3) = W / L^{2.0}$ (male), $W / L^{2.5}$ (female).
Open circle: females, Closed circle: males.

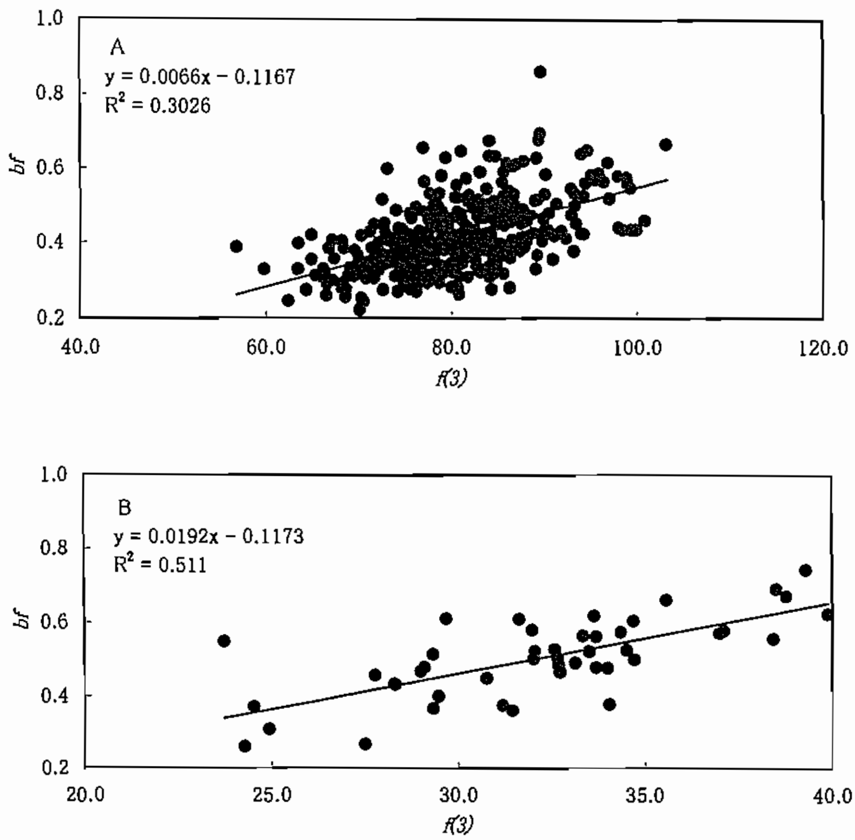

Fig.6. Relation between *f (3)* and *bf* in the sexually mature minke whales.
A: Males, B: Females

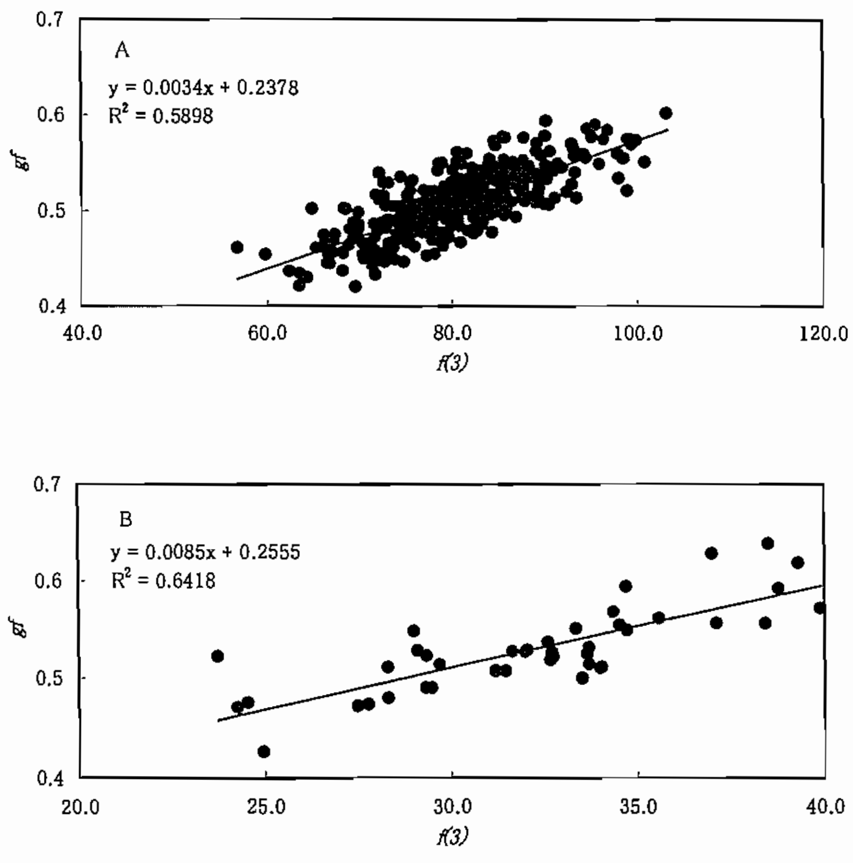

Fig.7. Relation between *f (3)* and *gf* in the sexually mature minke whales.
A: Males, B: Females

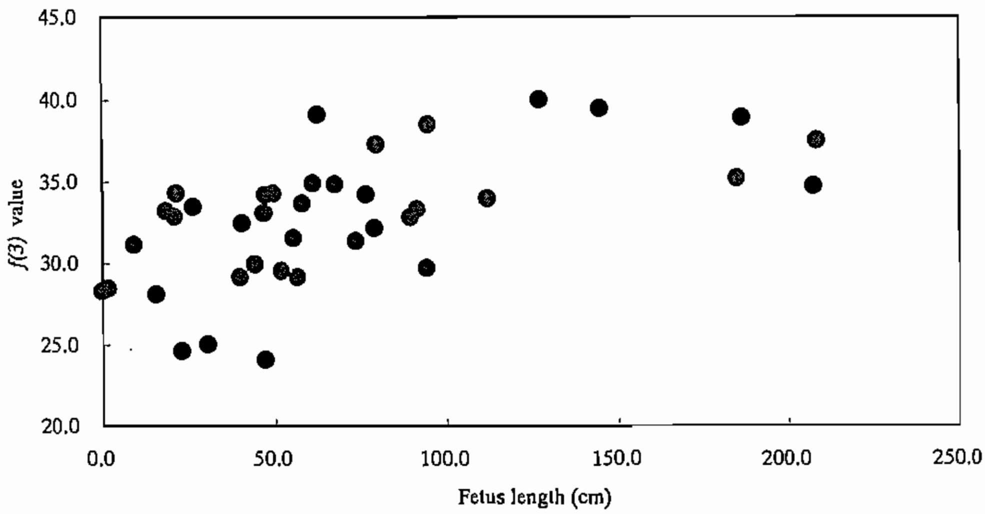

Fig.8. Change in *f (3)* values of mother whale with the growth of their fetuses.

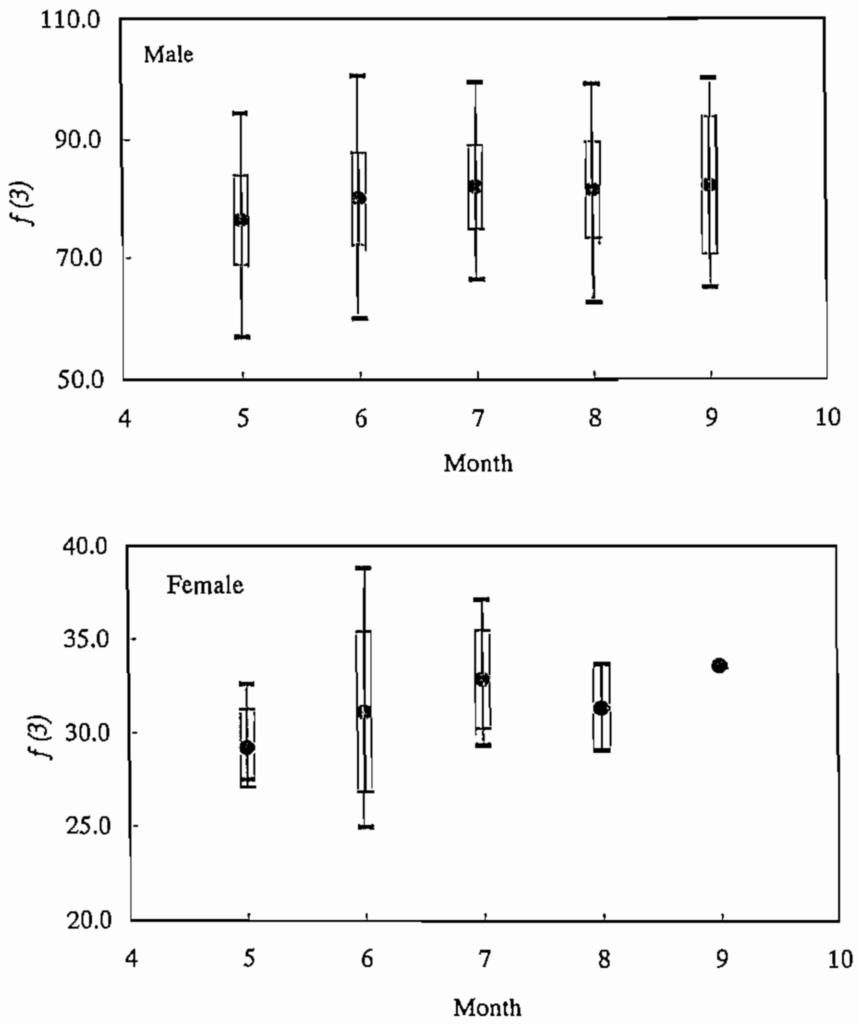

Fig.9. Seasonal change in mean ± *S.D.* values of *f (3)* for sexualy mature whales in sub-areas 7, 8 and 9.