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SEXUAL SEGREGATION OF THE SPERM WHALE IN THE NORTH PACIFIC*

SEIJI OHSUMI

INTRODUCTION

The whaling for the sperm whale (*Physeter catodon*) have been operating widely in the North Pacific. Sperm whales were killed by 7 Russian and Japanese whaling fleets chiefly in the Bering Sea, coasts of the Aleutian Islands and the Gulf of Alaska in 1964. And land stations were distributed in the coasts of California, Canada, Kuril Islands and Japan in the same year. Recently number of sperm whales caught have been gradually increasing, especially in the pelagic whaling ground in the northern part of the North Pacific. And regulation of sperm whale fishing has become to be need. However, for reasonable regulation of sperm whale fishing, we must have more ecological knowledges on the whale.

As one of well-known knowledges on the ecology for the sperm whale, so called " harem " schools distribute in low and middle latitude, and it does not move to high latitude even in summer season. On the contrary, males which separate from harem school distribute in high latitude in summer season (Matthews, 1938). But, this knowledge is mearly general, and there seems to be no study which deals the sexual segregation quantitatively. In present paper, I want to discuss on this problem.

Japanese whalers have been operating to catch sperm whales in the northern part of the North Pacific by factory ship whaling, and coastal whaling continues in the adjacent waters to Japan. And we have relatively many biological materials of the whale from both waters. I will discuss the sexual segregation of the sperm whale between high and middle latitudes dealing with the materials as a model. That is to say, I used the material from the Aleutian waters as a model which represent the whales distributed in the high latitude, and the material from coast of Japan as another model of the sperm whales distributed in the middle latitude. Of course, it is a problem that there are some possibilities that they belong to different sub-population by means of blood typing investigation (Fujino, 1963). However, I used the materials only as two models in the high and middle latitude, and I consider my discussion will adapt for each sub-populations.

MATERIALS AND METHODS

Upper teeth of the sperm whale are used for the age determination of the investigated individuals. Preparation and reading of upper tooth growth layers are the same as the paper of Nishiwaki *et al.* (1958). Age determination is based on the

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* Brief paper was read in the Meeting of Jap. Soc. Sci. Fisheries in Oct., 1965.

paper of Ohsumi *et al.* (1963), that is to say, one growth layer in the dentine is defined as one year.

As the materials, I used the biological data of the sperm whales which had been collected by the staffs of the Whales Research Institute in some whaling stations adjacent to Japan from 1960 to 1964 and in the Aleutian waters (Areas IV and V) in 1961 and 1962. The number of materials of which age were determined with upper teeth is as follows:

	Coast of Japan	Aleutian
Males	1,035	1,975
Females	2,237	—

For estimating the size distribution of the sperm whales which are really distributed in the Aleutian waters, I used data of the estimated body lengths which were observed by whale marking vessels in the northern part of the North Pacific. According to the data, almost of the sperm whales which distribute in the Aleutian waters are lone or small schools of few individuals, and the distribution of the females is considered to be very few. Then, I used a length-age key of the male sperm whale adjacent to Japan for exchange of the estimated size distribution by the marking vessels to estimated age distribution.

SEASONAL CHANGE OF THE SEX RATIO IN THE WHALING GROUND OF MIDDLE LATITUDE

Sex ratios of the sperm whales changes seasonally in the waters of middle latitude.

Clarke (1956) studied on the seasonal change of ratios of the male sperm whales in the catch in the Azores waters. The ratios are the highest in the winter and the lowest in August.

TABLE 1. NUMBER OF SPERM WHALES INVESTIGATED BY THE STAFFS OF WHALES RESEARCH INSTITUTE IN THE COAST OF JAPAN FROM 1960 TO 1964

Sex	Maturity	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Males	Immature	1	2	2	21	66	51	14	157
	Mature	19	47	81	297	347	160	22	973
	Unknown	7	5	14	58	57	16	3	160
	Total	27	54	97	376	470	227	39	1,290
Females	Immature	2	3	16	26	80	39	19	185
	Mature	11	51	88	372	941	578	99	2,140
	Unknown	4	25	24	127	201	116	18	515
	Total	17	79	128	525	1,222	733	136	2,840
Grand total		44	133	225	901	1,692	960	175	4,130
Sex ratio of males		61.4	40.6	43.1	41.9	27.7	23.7	22.3	31.3
% of immature	Males	5.0	4.1	2.4	6.6	15.9	24.2	40.3	16.5
	Females	15.4	5.6	15.4	6.5	7.9	6.3	16.1	8.0

In the coast of Japan, the male ratio is the highest in spring and the lowest in October in the seasons from 1946 to 1952 when the whaling operated throughout the year. According to the biological investigations by the Whales Research Institute from 1960 to 1964, the male sex ratios gradually decline from May to November as shown in Fig. 1, and the tendency is almost the same as that from 1946 to 1952. The seasonal changes are seemed to be different about two months each other between Azores and Japan. This is considered to be caused by the difference of the oceanographical construction between each waters.

Such seasonal changes of the sex ratio are considered to reflect the change of migration of sperm whale herds. In the late winter and spring seasons, the male sperm whales which are mainly mature lone bulls begin to migrate from lower latitude, and they leave from the middle latitude to higher latitude, after then, breeding herds mainly consisted with mature females and baby or juvenile individuals come to middle latitude waters. Mature male groups begin to migrate from higher latitude by the end of fall. According to Slepzov (1955), the large males appear in the migration season of spring and fall in Kuril waters. Japanese coastal waters are considered to be a northward migratory course of lone or male schools in the spring time.

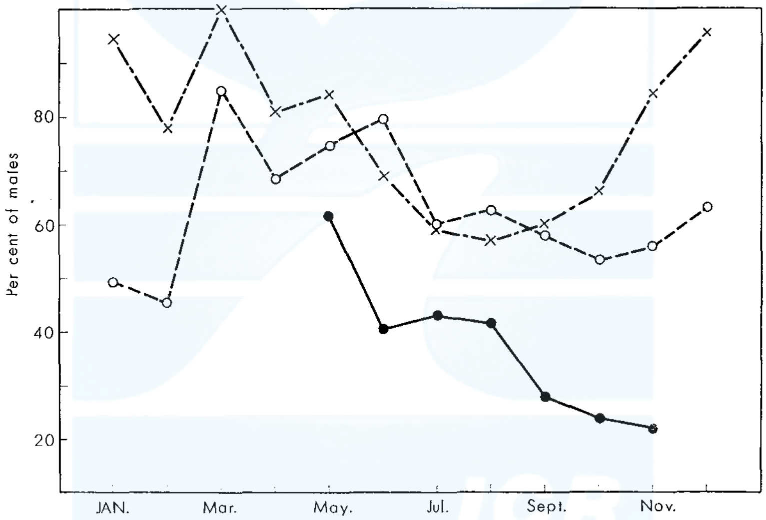

Fig. 1. Seasonal change of male sex ratios in the sperm whales in the northern hemisphere. Open circles and broken line: Coast of Japan, 1946–1952. Closed circles and solid line: Coast of Japan, 1960–1964. Closses and chain line: Azores, 1939, 1954.

Present materials were collected mainly in August, September and October for the case of coastal Japan, and in June, July and August for the case of northern Pacific respectively. Therefore, they seem to represent the optimum distributions of the sperm whale herds in each latitudal areas.

AGE DISTRIBUTION OF THE SPERM WHALES IN THE ADJACENT WATERS TO JAPAN

Table 2 and Fig. 2 show the age distributions of the male and female sperm whales caught in the waters adjacent to Japan from 1960 to 1964 in a semilogarithmic graph based on number of growth layers in the dentine of upper tooth. There is a remarkable difference between males and females. In younger age, the distribution of the males is almost the same as of the females, but from 12 years of age the total mortality coefficient in the females is lower than that in the males. Following three factors will be concerned with this phenomenon.

1. Difference of natural mortality rate between males and females.
2. Difference of fishing mortality rate between males and females.
3. Segregation of males.

Considering the age distribution of the male sperm whales in the Aleutian waters, the first factor will be abandoned, because the natural mortality rate of the males in this area is not so different from the females as shown in the next chapter.

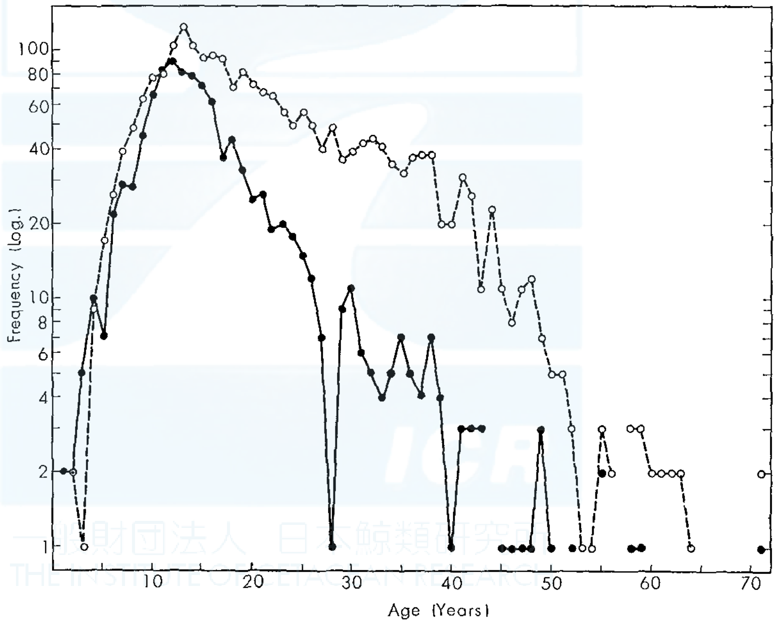

Fig. 2. Age distributions of male and female sperm whales from the waters adjacent to Japan in 1960–1964.
Open circle and broken line: Female. Closed circle and solid line: Male.

The second factor may be considerable, because adult males are larger than the females, and whaling efforts have been added more to the former than to the latter. But, I consider in the operation system for the sperm whale in the coastal waters the second factor is seemed to be not so affected on this phenomenon. The third factor must affect mainly to the difference of present total mortality rate in the middle latitudal waters. If not, we cannot explain the distribution of adult males in high latitudal waters.

TABLE 2. AGE DISTRIBUTIONS OF THE SPERM WHALES IN THE COAST OF JAPAN (1960–64) AND ALEUTIAN ISLANDS (1961, '62).

Age	Coast of Japan		Aleutian Males	Age	Coast of Japan		Aleutian Males
	Males	Females			Males	Females	
1	2	—	—	36	5	37	57
2	2	2	—	37	4	38	29
3	5	1	—	38	7	38	45
4	10	9	—	39	4	20	51
5	7	17	—	40	1	20	43
6	22	26	—	41	3	31	54
7	29	39	—	42	3	26	41
8	28	48	—	43	3	11	39
9	45	63	—	44	—	23	32
10	67	77	—	45	1	11	25
11	84	81	1	46	1	8	22
12	90	105	—	47	1	11	32
13	82	124	3	48	1	12	31
14	79	103	7	49	3	7	21
15	72	92	19	50	1	5	17
16	62	95	21	51	—	5	22
17	37	93	43	52	1	3	25
18	44	71	42	53	—	1	19
19	33	82	60	54	—	1	18
20	25	73	63	55	2	3	11
21	26	68	62	56	—	2	13
22	19	66	78	57	—	—	13
23	20	56	61	58	1	3	14
24	18	50	76	59	1	3	7
25	15	56	75	60	—	2	7
26	12	50	75	61	—	2	7
27	7	40	82	62	—	2	7
28	1	49	60	63	—	1	1
29	9	36	66	64	—	—	9
30	11	39	65	65	—	—	8
31	6	42	71	66	—	—	3
32	5	44	56	69	1	—	—
33	4	41	55	71	—	2	—
34	5	35	51	75	1	1	—
35	7	32	63	77	—	1	—
	(cont.)			Total	1,035	2,237	1,975

In present paper, I presume that natural and fishing mortality rates are respectively almost the same for the males and females in Japanese coastal waters, and the deviation of age distribution in the females minus those in the males presents the age distribution of the males segregated to the high latitude. And this hypothesis will be examined in the following chapters.

AGE DISTRIBUTION OF THE MALES IN THE ALEUTIAN WATERS AND COMPARISON OF IT WITH THE ASSUMED AGE DISTRIBUTION

In Fig. 3, solid line shows the age distribution of the male sperm whale caught by Japanese fleets in the Aleutian waters in 1961 and 1962 in a semi-logarithmic graph. In these years Japanese whalers caught 4,349 sperm whales, and males were 4,305 (98.9%) among them. According to Ohsumi & Nasu (unpublished), in the waters around the Aleutian Islands and Bering Sea, female sperm whales distribute very few, and they relate with the distribution of warm water mass.

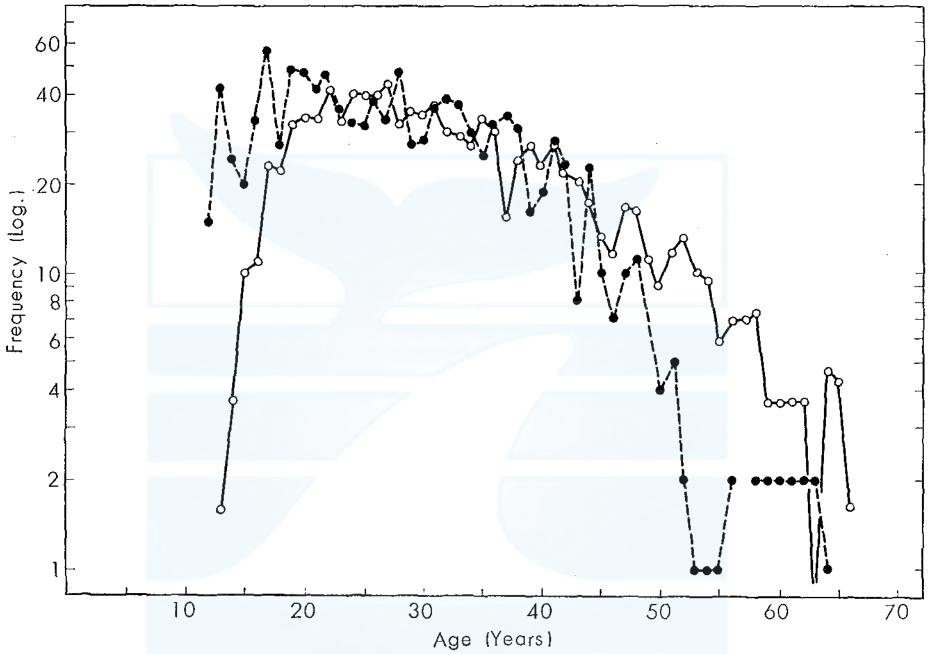

Fig. 3. Age distribution of the sperm whales in the North Pacific.
Closed circle and broken line: Females ninus males in the Japanese coastal waters.
Open circle and solid line: Males caught in the Aleutian waters (1961–1962).

Fig. 3 also shows the age distribution which was represented as the deviation of two age distributions between females and males (females minus males) in the Japanese coastal waters, assuming that the deviational part presents in the high latitude segregated from middle latitude.

Comparing above two age distributions, they are very fittable each other in the range of ages from about 25 to 45 years. But, in younger generations, the possiblly segregated males are more frequent than the males which were caught. I think this is caused by the size limitation in the catch by whalers. For the factory ship whaling, legal size is limitted as 38 feet or more. According to age-length key, the average age of the male sperm whales which are 38 feet long is 18.6 years. Therefore, in younger generations, the age distribution of the whales caught have a danger that it does not show the real population which distributes in the waters.

TABLE 3. SIZE DISTRIBUTION OF THE SPERM WHALES OBSERVED BY INVESTIGATION VESSELS AND CAUGHT BY CATCHER BOATS IN THE ALTUTIAN WATERS

Body length (feet)	Observed		Caught (1957-59)	
	Whales	%	Whales	%
33-34	1	0.4	—	—
35-36	11	4.3	—	—
37-38	17	6.6	87	1.7
39-40	61	23.6	527	10.5
41-42	43	16.6	719	14.4
43-44	30	11.6	772	15.5
45-46	43	16.6	776	15.6
47-48	26	10.0	812	16.2
49-50	17	6.6	719	14.4
51-52	2	0.8	447	8.9
53-54	4	1.5	125	2.5
55-56	3	1.2	12	0.3
57-58	1	0.4	—	—
Total	259		4,996	

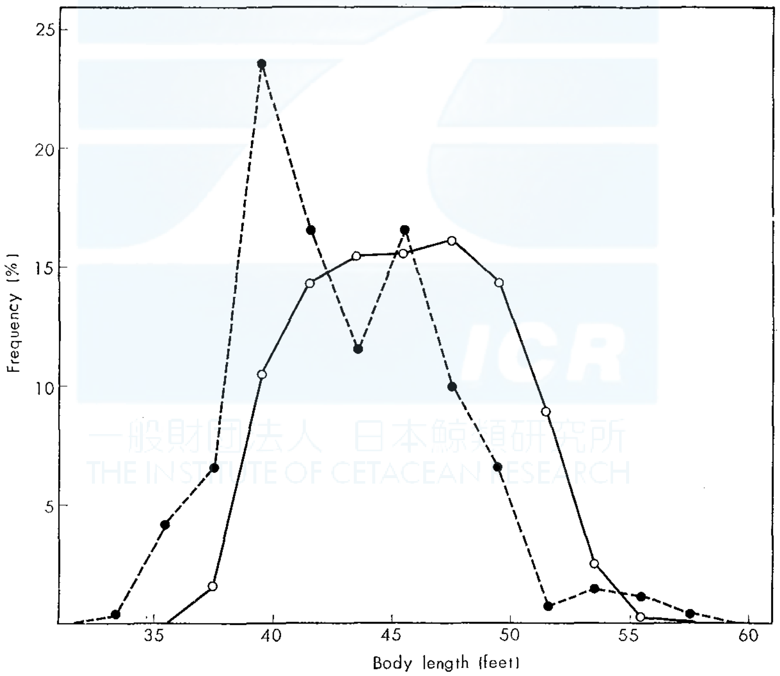

Fig. 4. Size distribution of the sperm whales observed and caught in the Aleutian waters. Open circle and solid line: estimated length by investigation vessels. Closed circle and broken line: caught whale.

For the solution of this problem, I used the records of estimated body lengths of the sperm whale which had been observed with Japanese research vessels in the course of whale marking in the northern part of the North Pacific. Research vessels recorded all whales which were found in the waters, so we may regard the records represent the whales distributed in the waters. Table 3 and Fig. 4 shows the size distributions of the whales observed and caught in Aleutian waters. The size distribution of the whales caught is like normal distribution and has a mode at about 45 feet, on the contrary, that of whales observed does not show a normal distribution, and there is a mode at about 40 feet. Fig. 4 also shows that there are many small sized sperm whales in high latitude, but they were not caught because of the size limitation. Of course, this size distribution was based on estimated body lengths, and they have some errors from true body length. According to the data of the sperm whales which were recaptured soon after marking, our estimation of body length of the swimming whales has a tendency of under-estimation from actual ones in the range of body lengths from 33 to 45 feet long. However, it will be true that

TABLE 4. AGE-BODY LENGTH KEY FOR THE MALE SPERM WHALES IN THE COASTAL WATERS OF JAPAN

Age	Body length (feet)													Total
	33–4	35–6	37–8	39–40	41–2	43–4	45–6	47–8	49–50	51–2	53–4	55–6	57–8	
6– 7	2	1												3
8– 9	13	3	1	1										18
10–11	33	29	2	2										66
12–13	38	36	16	—										90
14–15	18	42	21	5										86
16–17	10	29	24	8			1							72
18–19	11	19	8	5	5	1	—							49
20–21	8	10	11	2	2	—	1		1					35
22–23	1	6	4	4	4	1	4		—					24
24–25	1	6	6	2	3	1	2	1	1					23
26–27	3	3	2	2	—	1	3	—	—					14
28–29		1	—	1	—	1	1	—	1					
30–31		2	1	—	2	3	2	2	—					12
32–33		—	1	1	—	1	1	1	—					5
34–35		1	—	2	—	1	—	—	1		1			6
36–37		—	—	3	1	—	—	—	1		—			5
38–39		1	—		1	—	1	1	—	2	—			6
40–41			—			—		—	2	—	—			2
42–43			1			—		1		—	—			2
44–45						—		1		—	—			1
46–47						—				—	—			—
48–49						—				1	—		1	2
50–51						1				—	1			2
52–53										1	—			1
58–59										—	—	1		1
68–69										—	1			1
74–75										1				1
Total	138	189	98	38	18	11	16	7	7	5	3	1	1	532

more small sperm whales distribute in high latitude than the whales caught in the waters.

It is estimated that the observed sperm whales were almost males from the school composition of them, because they were almost lone or small numbers in a school, and it is seldom to find a large school like harem school in Aleutian waters.

TABLE 5. TOTAL MORTALITY COEFFICIENTS FOR THE SPERM WHALES BY AREAS, SEXES AND RANGES OF AGES

Area	Sex	Ages	Total mortality cœfficient
Coast of Japan	Males	12–25	0.165
		26–50	0.081
	Females	12–52	0.073
Aleutian	Males	24–66	0.071

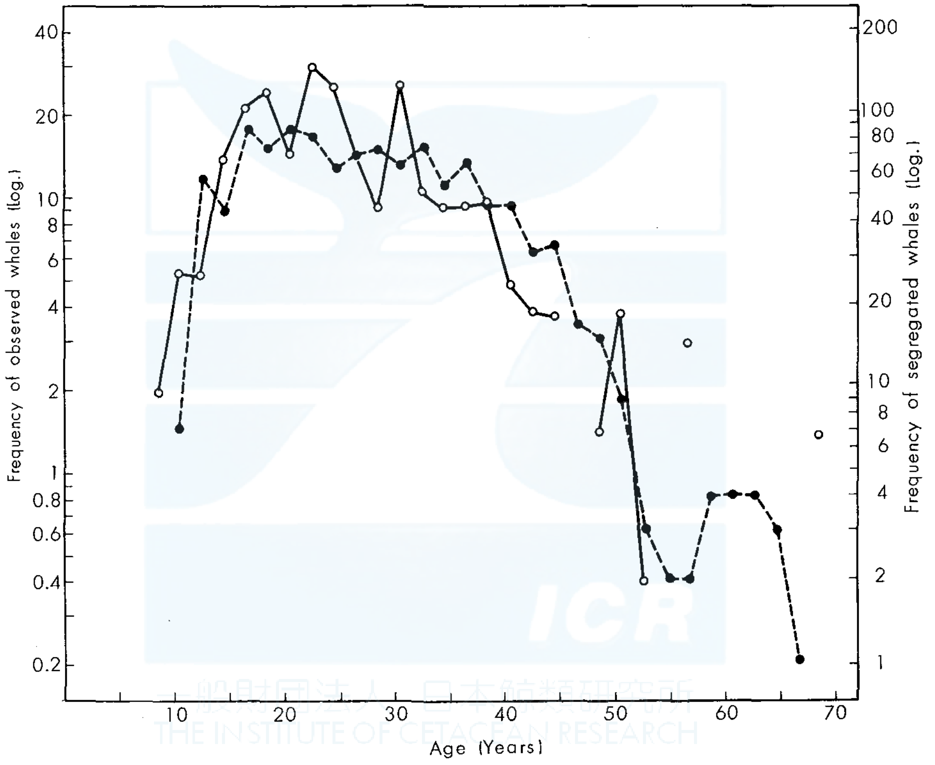

Fig. 5. Age distribution of the sperm whales.

Open circle and solid line: age distribution of the distributed sperm whale in the Aleutian waters calculated by size distribution and age-length key.

Closed circle and broken line: female ninus males in Japanese coastal waters.

To compare the age distribution of possiblly segregated males with that of observed sperm whales which were distributed in Aleutian waters, I calculated the estimated age distribution of the latter from estimated size distribution by means of age-length key of the male sperm whales from the coastal waters of Japan. I did not use the age-length key of the male sperm whales in the Aleutian waters, because it is different from that of distributed whales by size limitation.

Fig. 5 shows the age distributions of the sperm whales segregated from middle latitude and observed in the Aleutian waters respectively. From this figure, we can find that the both fairly fit each other. Estimation that the deviation of age distributions between females and males in Japanese coastal waters means the segregation of males from middle latitude to high latitude may be comfirmed from this examination.

There is another difference in the age distributions between the whales caught and segregated in the older generation (Fig. 3). There is an uncertainty in the latter distribution because of scarsity of number of samples in older ages. But, it is also considerable that whalers select large whales for their catch as possible, and the large sized or old whales apt to be caught by whalers than the actually distributed whales.

THREE MODELS OF AGEAL SEGREGATION AND COMPARISON OF REALLY AGEAL SEGREGATION OF MALE SPERM WHALES WITH THEM

When natural mortality coefficient (M) and fishing mortality coefficient are settled in constant throughout life span for the mother population, the age distribution of it is shown in Fig. 6A, having a total moritalty coefficient (Z_1). If individuals which are over age of *i* disperse with a constant dispersal coefficient, the age distribution changes into Fig. 6B. Fig. 6C shows age distribution of a population in which the individuals over *i* years old increase in their dispersal coefficients acceleratively year by year with constant acceleration rate. Fig. 6D is a age distribution in the third population in which individuals over *i* ages increase their dispersal coefficient with constant accelerate coefficient until the age of *j* and after then they disperse with constant dispersal coefficient.

Now, comparing with above three models of ageal segregation, the age distribution of males in the coastal waters of Japan resembles with Model D (Fig. 6D). Owing to size limitation of catch, the age distribution in young generation does not represent the true age distribution, but in this stage age distributions are almost the same in males and females. This means that in young stage males distribute in the middle latitudal waters in the same way as females. Age distribution of males changes at the age of about 12 years from that of females. This phenomenon will mean that segregation of males begins from about 12 years of age, and this age will correspond with *i*-age in Model D. According to Nishiwaki *et al.* (1958), the age at sexual maturity of the male sperm whale is considered to be about 10 tooth laminations. Then, the segregation of males will begins after sexual maturity.

The total mortality coefficient of males in the range from 12 ages to 25 ages is relatively high value, and after 25 ages the total mortality coefficient becomes lower and shows almost the same value of females. This means that in the ageal range from 12 to 25 years males segregate from middle latitude waters with the almost constant accelerated rate age to age, and after then individuals segregate with con-

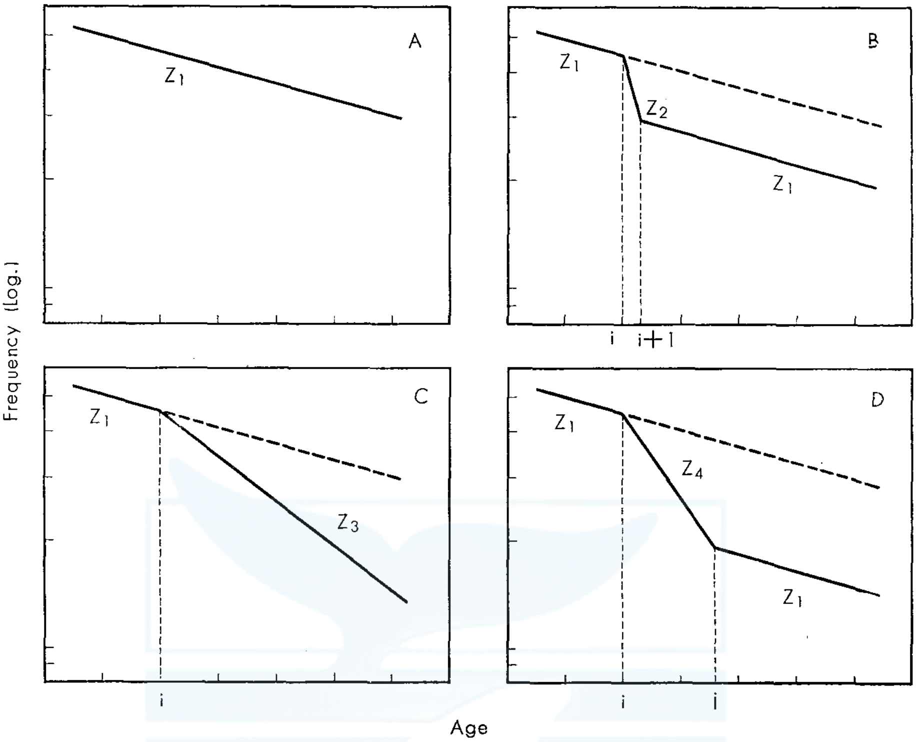

Fig. 6. Age distributions in the four cases of which various ageal segregation table plase.
A: Mother population
B: Segregated over i years old with the rate of Z_2—Z_1
C: Segregated over i years old increasing with the constant rates (Z_3—Z_1)
D: Segregated over i years increasing with constant rates (Z_4—Z_1) until j years old.

stant segregation rate.

Table 5 shows the calculated total mortality coefficients of the sperm whales in the coastal waters of Japan and in the Aleutian waters. In these values, the coefficient of males in the ageal range from 12 to 25 years (0.165) will correspond with Z_2 in Model D, and that of females (0.073) correspond with Z_2, respectively. The coefficient of Japanese water males in the ageal range after 26 years (0.081) is not so different with those of females in the Japanese coastal waters or males in the Aleutian waters. The deviation between Z_2 and Z_1 (0.092) will mean the accelerated segregation coefficient between one age and the next age until 25 ages. Age of 25 years corresponds with *j*-age in Model D. Average body length of males at 25 years is 45 feet according to the growth curve in the paper by Nishiwaki *et al.* (1958), and the weight of testis in larger side is 2.8 kg according to Nishiwaki *et al.* (1956).

In the sperm whale, although males attain at sexual maturity, it takes some years until they can join into the breeding activity. This problem is one of the important subjects in the ecology of the sperm whale, but I think that 25 years of age or the body length of 43–45 feet will be the minimum age or body length at attainment of full maturity in the male sperm whale. If so, the segregation of males will be concluded as follows: In the sexually immature stage, males remains in " harem " school, and after attainment of sexual maturity some of males begin to segregate from the harem. The rate of segregation of the males increases age to age until they attain at full maturity. After then the segregation rate becomes constant. For the proof of this assumption, investigation of school composition of the sperm whale will be need.

THE RATIO OF SEGREGATED MALES IN HIGH LATITUDE OF MOTHER POPULATION

In Model D population, the segregation rate of population size over *i* age (K) is shown in following formula:

$$K = 1 - \frac{(1-e^{-M_1})\,[1-e^{-(j-i)M_4}]}{1-e^{-M_4}} - e^{-[(j-i)M_4+M_1]}$$

When $M_4=0.073$, $M_2=0.165$, $i=12$ and $j=25$ are set into this formula, the segregation rate is calculated as 0.416. This means that about 42 per cent of sexually mature males disperse to high latitude from mother male population.

From Table 2, the actual segregation rate which calculated as the rate of deviation between females and males over 12 age is also calculated as 60.8 per cent.

If the sex ratio is the same for males and females in mother population, the population size of males which segregates from mother population and distributes in high latitude is about 21 to 30 per cent of mother population size.

However, as mentioned above, in the Aleutian waters the population size as the object for whaling must be smaller than the population size of whales which distribute in the high latitude, because the legal size is 38 feet for factory ship whaling. Comparing two age distributions in Fig. 3, the available rate as the object for whaling is calculated to be 86 per cent of the real population size of males in high latitude.

CHANGE OF SEGREGATION RATE OF MALE SPERM WHALE ACCORDING TO THE AGE

The segregation rates in each age were calculated smoosing the age distributions which were shown in Fig. 2. The change of segregation rates according to the age is shown in Fig. 7. After the age at sexual maturity, the segregation rate increases remarkably accompanying with increment of age until about 25 years of age. And it becomes maximum at the age of 40 years. After then it decreases accompanying with increase of age. In the middle ages ranging from 25 to 53 years, the segregation rates are over 75 per cent, and at the maximum it attains to about 90 per cent.

However, there are some males which are fully mature but not segregated to high latitude. Most of these males are considered to be so-called harem leaders.

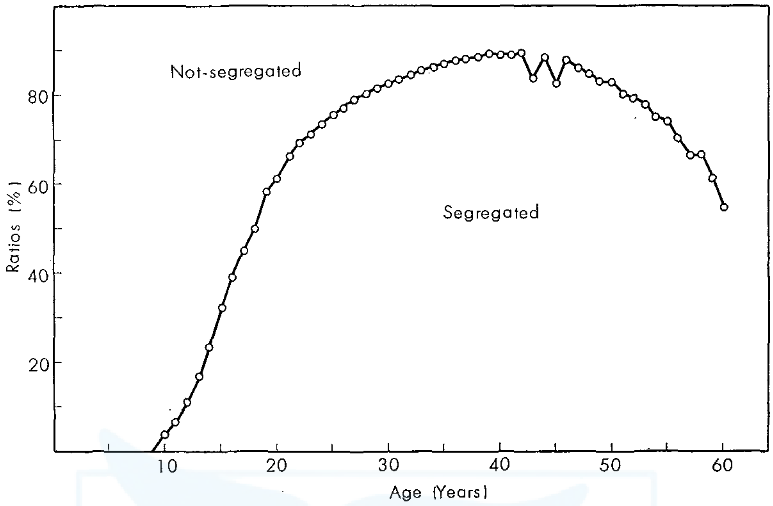

Fig. 7. Change of ratio of segregated sperm whale males according to age.

As mentioned above, after about 40 years of age segregation rates decrease accompanying with ages, although there is an uncertainty whether this result is true or not because of scarsity of number of samples in older age. If it is true, this phenomenon will mean that old bulls remain in the middle latitude as harem leaders.

DISCUSSION

One of the questions in the present paper is whether the materials from Japanese coastal waters represents the mother population from which males segregate to high latitude or not. Townsend (1935)'s laboring work on the distribution of sperm whales by means of logbook data in the American Whaling Age is considered to show seasonal change of distribution and density of the whales in the world. However, conserning with North Pacific Ocean, there is no catch records in the waters arround the Aleutian Islands Chain and Bering Sea. I think this means that American whalers chased chiefly " harem " schools and did not chased lone and large bull in the high latitude, because harem school was more easy to be caught than lone bull by them. If it is true, the distributions of the sperm whales which were shown by Townsend should represent chiefly those of harem school. Fig. 8 shows the latitudal frequency distributions of the sperm whales in the Pacific Ocean in summer and winter seasons drawn from the maps by Townsend. As mentioned by him, it is clear that there is seasonal movement in the sperm whale. In Fig. 8, A will be main distribution of sperm whales of northern hemisphere stock in summer, and it will move to A′ in winter. If so, the main stock of northern hemisphere sperm whale in the Pacific will distribute in the range from 20°N to 40°N in summer. Then my materials which were obtained from the adjacent waters to Japan will be able to represent the main population of North Pacific sperm whale.

For the solution of the sexual segregation in the sperm whale, we must investigate the composition of school in the sperm whale directly. Clarke (1956) described on the classification of sperm whale schools in Azores waters. According to his classification, there are three kinds of schools in the sperm whale. They are juvenile, bachelor and harem schools. Sex ratio, number of individuals in a school, age composition, sexual condition etc. are important subjects to study as well as the number and ratios of above three kinds of schools in the ocean.

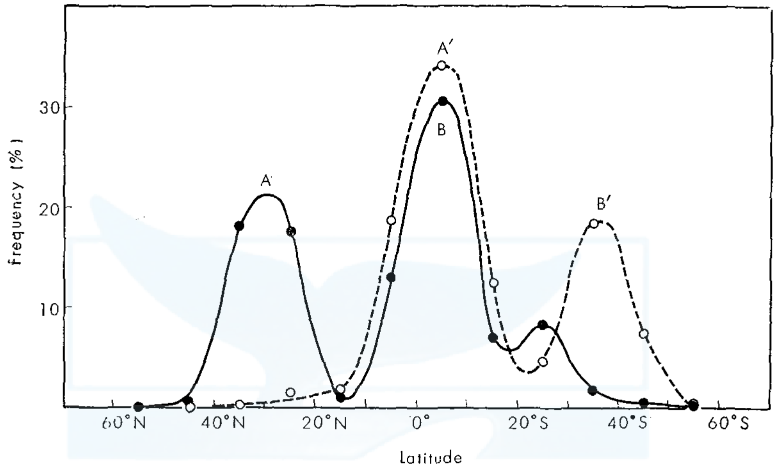

Fig. 8. Latitudal frequency distribution of the sperm whales in the Pacific in summer and winter season after the log-book records of American whaling ships. Drawn from maps by Townsend (1935).
Solid line: Summer (July to September). Broken line: Winter (January to March).

Concerning with sexual segregation of the sperm whale, it is practically need for the regulation of whaling how many adult males are need at least for the meintainance of reproduction in the sperm whale population. If 25 years is the age when join into breeding activity in the male, using the age distribution of sperm whale from the coast of Japan, the tentative ratio of needful adult males can be calculated, when we assume that harem males remain in middle latitude even in summer- autumn season.

The result is that one adult male leads about 16 mature females. However, it will not be solved, unless we have knowledges on the sexual behavior of the sperm whale.

SUMMARY

Sexual segregation of the sperm whale from middle latitude to high latitude was discussed chiefly by means of the age distributions of the sperm whale caught in coastal waters of Japan and in the Aleutian waters.

1. There is a seasonal change of sex ratio in the sperm whale caught in the coast of Japan. The sex ratio of males is the highest in the spring and the lowest in

October and November. This phenomenon is considered to be caused by change of the seasonal migration of males in this waters.

2. The age distribution of the male sperm whales is different from that of the females in the coastal waters of Japan. And this phenomenon is considered to represent the sexual segregation according to the age in the middle latitude.

3. By means of estimated body lengths of the sperm whales which were observed in Aleutian waters by marking vessels and age-length key for the male sperm whales, an age distribution was obtained. This age distribution closely fits with the deviation of age distributions between females and males in the coastal waters of Japan. This is considered to proove the assumption that the deviation of two age distributions between females and males in middle latitude segregate to high latitude waters.

4. Owing to the size limitation for sperm whale catch, the age distribution of the male whales in the Aleutian waters does not represent the real age distribution of the whales which distribute in the high latitude.

5. Segregation of male sperm whales from middle latitude begins soon after the age at sexual maturity. And until the age of 25 years, the segregation rate increases with the ages. After then, the segregation rate becomes nearly constant. The age of 25 years in suggested to be the age at full maturity when males become to have breeding activity.

6. About 40–60 per cent of mature males of mother population are suggested to segregate to the high latitude waters. Therefore, the population size of males which distribute in high latitude will be about 20–30 per cent of mature sperm whales in mother population.

7. Rates of segregated males in each generation increase rapidly from 12 to 25 years, and it attains to about 90 per cent in maximum at the age of 40 years. After then, the segregation rates decrease gradually with the age.

ACKNOWLEDGEMENTS

The materials used in the present paper were collected by the efforts of biologists and inspectors who had investigated the whales in the whaling grounds. My sincere thanks are due to them. I am much indebted to many members of the Japanese Whaling Companies for the help in investigation and collection of the materials.

Dr. M. Nishiwaki and Mr. T. Kasuya kindly read the number of growth layers in the dentine of many maxillary teeth with me for the age determination of the materials. I should like to thank them.

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CRITERION FOR DETERMINING AGE OF FIN WHALE WITH REFERENCE TO EAR PLUG AND BALEEN PLATE

TADAYOSHI ICHIHARA

INTRODUCTION

The age determination is an important problem for the fisheries science as well as for the development of whale biology. In the fisheries science it is a basic study contributing to the human management for natural resources through the stock assessment. In order to estimate the age of the fin whale (*Balaenoptera physalus*), various methods have been developed since the early in this century and they are represented by the regular accumulation of corpora in ovaries (Wheeler, 1930., Laws, 1961), the periodical occurrence of baleen plate ridges (Ruud, 1940), the colouration of crystalline lens (Nishiwaki, 1950a) and the ear plug laminae accumulated in the external auditory meatus of the baleen whale (Purves, 1955). Among these age material, the ear plug laminae which is accumulated throughout the life of whale in both sexes is the most valuable. The report by Purves who found the ear plug an important age indicator for the first time has fascinated me but simultaneously induced me to have some doubts on the formation mechanism of ear plug.

My study in a series began in 1959 from the examination on structure which is essential for interpreting the ear plug proper. The alternation of the dark and the bright layer in the ear plug indicates the complicated aspects in most cases. The alternation of layers was counted only by the naked eye and there was no objective measuring method. In order to examine the biological meaning of two different layers, the photometric apparatus* recording the laminae had to be devised in 1963. In 1964, the prenatal development of ear plug and its feature in the structure was examined in relation to its formation in the adult whale.

It is necessary to estimate the annual increment rate of laminae to determine the age of whale by means of the ear plug. Since Purves' report, many scientists have estimated the annual increment rate of laminae, assuming factors effecting on the alternation of the ear plug layers. These works, in relation to the ages of the fin whale and the humpback whale (*Megaptera novaeangliae*), have resulted from the comparison of the ear plug with the other age indicator, particularly from the interrelation between the annual ridge on the baleen plate and the ear plug laminae for the young whale (Laws & Purves, 1956) and between the annual increment of corpora in female ovaries and the ear plug laminae (Laws, 1961). With regard to this point, no work concerning the ear plug proper has been reported and only the elapsed time from fire to recovery in the marking experiment checked the increment rate of laminae in a year (Dawbin, 1959., Chittleborough, 1960.,

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* Grant-aided by the developmental research in the ministry of education in Japan.

Ohsumi, 1962). There are many instances of recaptured fin whales which were marked in the unknown age at fire, in the Antarctic and the North Pacific. All previous papers are grounded on the estimation that the increment of laminae is annually regular throughout the life of whale. It means that the alternation of two different layers does correspond to the calendar time.

My question on the regular formation of lamina arised from plotting the thickness of each lamina according to the Walford graphic method (1946). This examination was carried out in the ear plugs of male fin whales captured in the 1957/58 season in the Antarctic, because the occurrence of layers in the male is clearer than that in the female. In the present study, I propose my opinion that the annual increment rate of laminae is slightly different in the growing stages of the fin whale and hence that the ear plug is rather a relative age indicator representing the physiological time related to the life history of whale.

It was necessary to examine the structure of baleen plate in relation to the age determination and new findings are given for it as well as a new devised method to study it. The material of this study was brought by the Japanese expeditions in the Antarctic and supplemented by the North Pacific expedition. The biological examination in October and November in 1964 at South Georgia in addition to 4 months period from December to March on board the pelagic whaling factories enabled me to cover 6 months periods in the Antarctic. The material from fin whales in the breeding season probably is indispensable to examine the biological meaning of the ear plug layer, but no Japanese Whaling Company operated for the catch of the fin whale at the land station in the winter season.

The future experiment of either the time-marking to the ear plug or the marking for the calf accompanied by the cow will confirm the proposed annual increment rate of ear plug laminae in this paper.

PHOTOMETRIC APPARATUS RECORDING EAR PLUG LAMINAE

The idea recording the alternation of layers in the ear plug of baleen whale was presented and the first trial to take successful records was made through construction of the simple apparatus (Ichihara, 1963).

The primary purposes to develop the photometric apparatus exists in not only taking the objective record for the dark and the bright layer in the bisected ear plug, but also grasping the biological significance of the occurring each layer through the record. In order to attain the latter purpose, the biological research for the individual possessing ear plug should be combined with the photometric records. This biological meaning will be discussed later in this paper. To answer the former purpose, the apparatus in the first step was improved in detail, although the principle of recording is almost the same. The main improvement is in the points that the automatic recording was developed to some degree and the the compensated recording became possible in addition to take the natural colour change on the surface of bisected ear plug. In Fig. 1, the schematic diagram of the recording apparatus is given and the photograph for the set of photometric apparatus is indicated in Fig. 2. The same notation (A, B) is used both in the upper diagram indicating the optical mechanism and in the lower diagram showing the electrical mechanism in a set. The bisected ear plug submerged in 10% formalin solution is illuminated by a 8 mm cine-lamp and the glass vessel containing the plug is moved horizontally in a constant speed by a 8 mm-cine motor. As two prisms composed of BaK_4 (ZnS) are included in a tube, the refleced light on the surface of the ear plug is divided into two components in the first prism where the ratio of reflection to transmission (R/T) is 70 percent. Through the view finder (C), we can observe the movement of ear plug. At the next prism, the value of R/T is

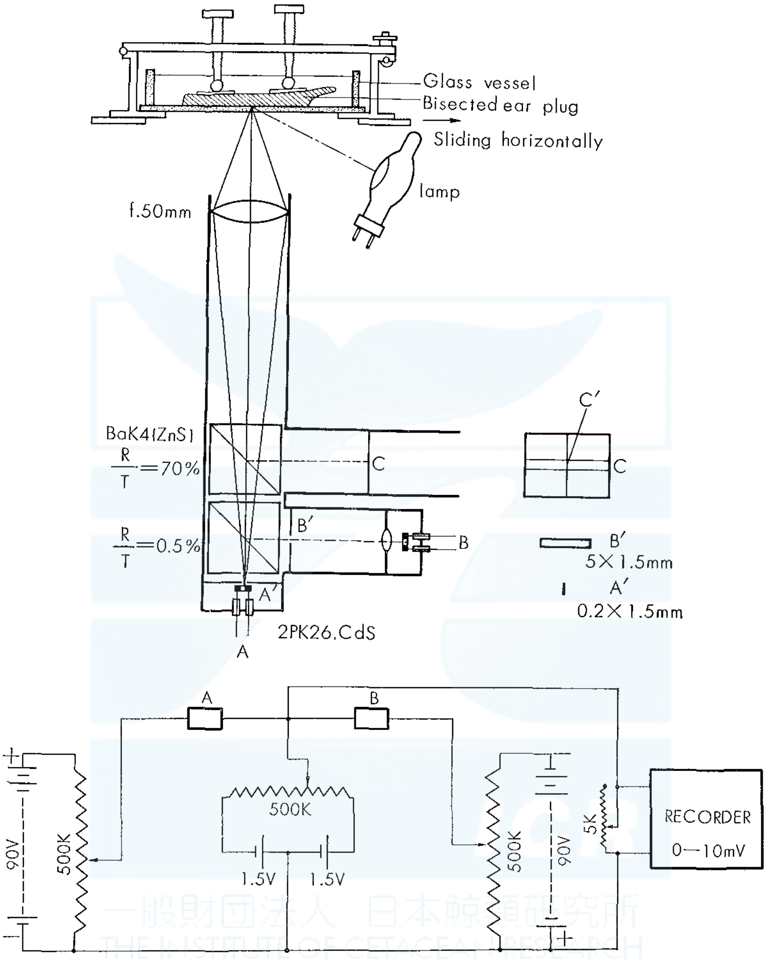

Fig. 1. Schematic diagram indicating mechanism of the photometric recording apparatus for the ear-plug laminae. Optical mechanism is shown in the upper and electronic mechanism in the lower. See notations in the text.

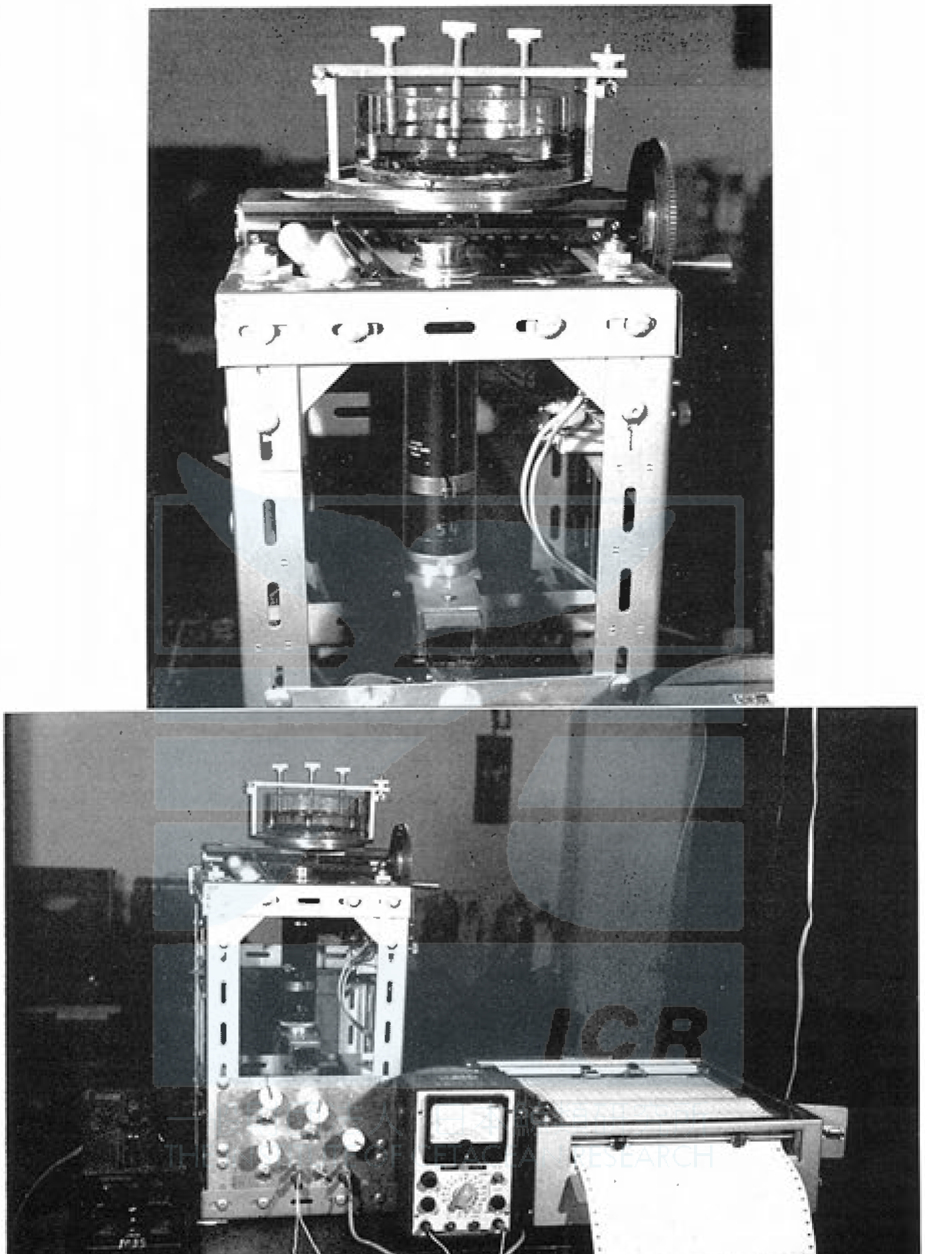

Fig. 2. Photographs indicating a set of photometric apparatus recording the ear-plug laminae.

0.5 percent and most of light reaches to CdS (2PK26) on A through A' slit (0.2 × 1.5 mm). The light which reaches to CdS on B through B' slit (5.0 × 1.5 mm) is used for compensating the original photometric record. The pen writing recorder is able to follow the change of current till 0.2 second. Under this condition, we can control voluntarily the rotation of 8 mm cine motor and the movement of re-

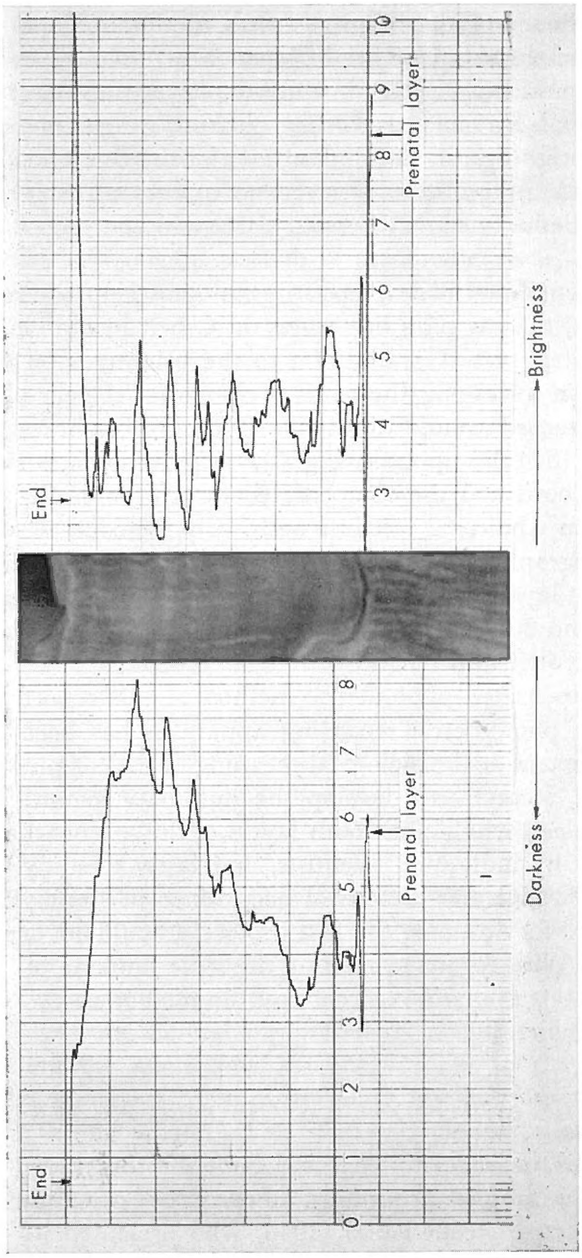

Fig. 3. Photometric record for a ear plug from a young fin whale, 62 feet long female in the North Pacific. 18.8 mm core in length shows 7 laminae already formed and the 8th lamina under formation. The record by compensated method is indicated in the upper and the ordinary record in the lower. The photograph of bisected ear plug is indicated in the middle.

cording paper, and hence several kinds of record is obtainable for a single specimen.

When B is switched off, the photometric record depends on the light reaching to A and only the ear plug image on C' line in the view finder is recorded. In this case, the record reflects the natural colouration on the bisected ear plug and indicates the general change of the brightness as a mountain slope as well as the alternation from the dark layer to the bright layer (See the lower in Fig. 3). The alternation of the dark and bright layer in the ear plug is important as an age indicator of baleen whales. By such a recording method, we can not exaggerate the change of alternating brightness in the limited area of the recording paper. Considering this point, furthermore, it is desirable to undurate the record around a standard level. This desire is closely related to obtain the record satisfying the human eye-sense.

The compensation method is developed by the kind help of Prof. M. Hirata. When B is switched on, the ear plug brightness on C belt in the view finder is included in the photometric record in addition to the brightness on C' line. This method has an effect on averaging the general change of the ear plug brightness. It is possible to take a record around the standard level of brightness, with gradual sliding of the specimen (See the upper in Fig. 3). Fig. 3 indicates the comparison between the original record and the compensated record for the ear plug from the North Pacific female fin whale, 62 feet in length. By the contrast of two kinds of records with the photograph of ear plug, the significance will be clarified. In this ear plug, the 8th bright layer is now under formation. In the original record (the lower figure), the 7th and 8th bright layers are not recorded clearer, compared with the compensated record (the upper figure).

I applied the compensated photometric method to this report instead of the original method. The photometric recording apparatus has been developed for three projects, firstly to examine the biological meaning of the ear plug layer through the accurate recording, secondly to develop the automatic counting for the ear plug laminae of the baleen whale and tooth layers of the sperm whale in order to avoid subjective counts by individual scientists, and lastly to study the racial difference of population through the pattern of occurrence in the layer. As a long time had been expended for attaining the first project, I could not expand my study in other two projects. With regard to reading the scale laminae of fish, Kuroki *et al.* (1965) devised a semi automatic recorder and applied it to the scale of chum salmon in the North Pacific.

PHOTOGRAPHIC METHOD FOR SECTIONED BALEEN STRIP

Since the baleen plate is an important age indicator for the young baleen whale, its structure should be examined accurately. Few paper concerning structure of the plate has been reported except Ruud (1940) who presented its significance in detail. Although he indicated photographs of longitudinally sectioned plate in order to examine the thickness of two components; the cortical layer and the medullary layer, these photographs for a fin whale plate were divided into three parts.

By the normal photographic method, it is difficult to examine the general structure of the long plate, because the thickness of plate is much thinner compared with the length of plate. If the devised photographic method to enlarge the width and shorten the length in a long strip is developed, it is very convenient to study the structure of plate. Prof. Hirata developed the special photographic method to attain this object in 1959. By his courtesy, I applied this method to the baleen plate from the very young fin whales killed in the North Pacific and the Antarctic. The mechanism is indicated in the diagram of Fig. 4, and the devised structure of camera is of importance to understand the mechanism.

A slit of 5 μ in width is placed just before the film plan in a 35 mm camera. The winding lever is exchanged by a gear which contacts with another gear in smaller diametre. At the tip of stem of the smaller gear, there is a pulley which a piano wire winds. A piano wire is stretched by a lead as indicated in Fig. 4.

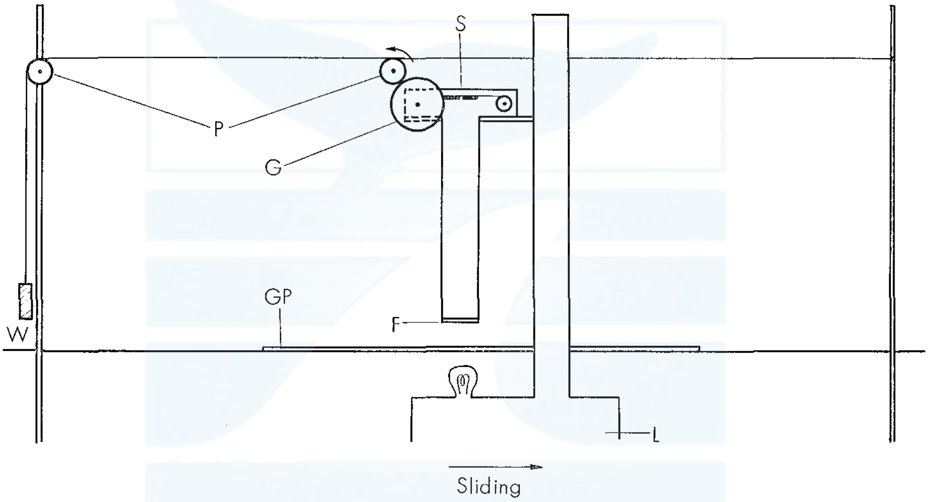

Fig. 4. Diagram indicating the mechanism of photographic apparatus recording the baleen strip. F: filter, L: lathe, G: gear, GP: glass plate, S: slit, P: pulley, W: weight.

A support of a copy apparatus which is equipped with the camera shifts in a constant speed with an old lathe operated by a motor. The film is wound in a slower speed than the movement of camera. The long strip in the thickness of 0.2–0.3 mm was taken off by a plane along the outside curvature of the longest baleen plate of the fin whale. This strip was placed on the glass plate and illuminated from underside. Photographs of the devised apparatus is shown in Fig. 5 in which the left figure indicates the general view and the right the enlarged part of camera.

Fig. 6 is a photograph for the long strip of the baleen plate from the immature fin whale, 60 feet long female, killed in the Antarctic. In the longitudinal section of the baleen plate, the length of about 64 cm is shorten and the thickness of about 4 mm is enlarged. The horizontal scale has cm unit and the vertical scale does mm unit. In the left side, there appear clearly the end of cortical layer as well as the end of tube in the medullary layer and so the right side indicates the tip of baleen plate. In this figure, the anterior part of plate is indicated at the upper border and the posterior part at the lower border. It seems that there are many inflections in the longitudinal direction of plate and large 8 inflections are remarkable. Near the tip of plate, the length from inflection to inflection is shorter than near the base of plate. The border line between the cortical layer and the medullary layer is clearly discriminated in the photograph. It is recognizable that the thickness of plate varies from tip to base in the cortical layer as well as in the medualllry layer and that the changing thickness in the anterior cortical layer does not correspond

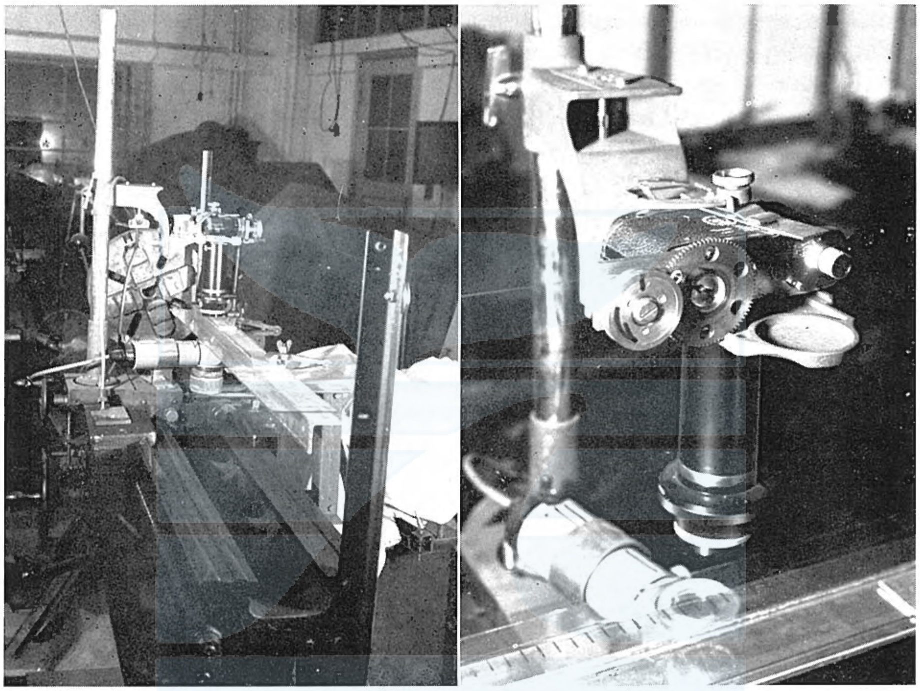

Fig. 5. Photographs of the apparatus taking a continuous picture of sectioned baleen strip. Left: The general view of the apparatus. Right: The part of the reconstructed camera.

Fig. 6. Photograph of a longitudinally sectioned baleen strip. The proximal end of plate is indicated in the left and the distal end in the right. The horizontal scale in cm unit and the vertical scale in mm unit. This strip was obtained from a longest baleen plate of a 60 feet long fin whale in the Antarctic.

to that in the posterior layer. This suggests that the growth of the anterior layer is independent of that of the posterior layer.

STRUCTURE OF BALEEN PLATE

Eshricht and Reinhardt (1866), Tullberg (1883) and recently Utrecht revealed the structure of the baleen plate from the adult fin whale. The each baleen plate consists of an inner, medullary layer (horny layer) built up of horny tubes arranged in a flat sheaf. The medullary layer is covered by the outer layer, cortical layer which is pushed out by the continuous cornification of the gum cell. A diagrammatic sketch of the structure of the baleen plate was drawn by W. L. van Utrecht and

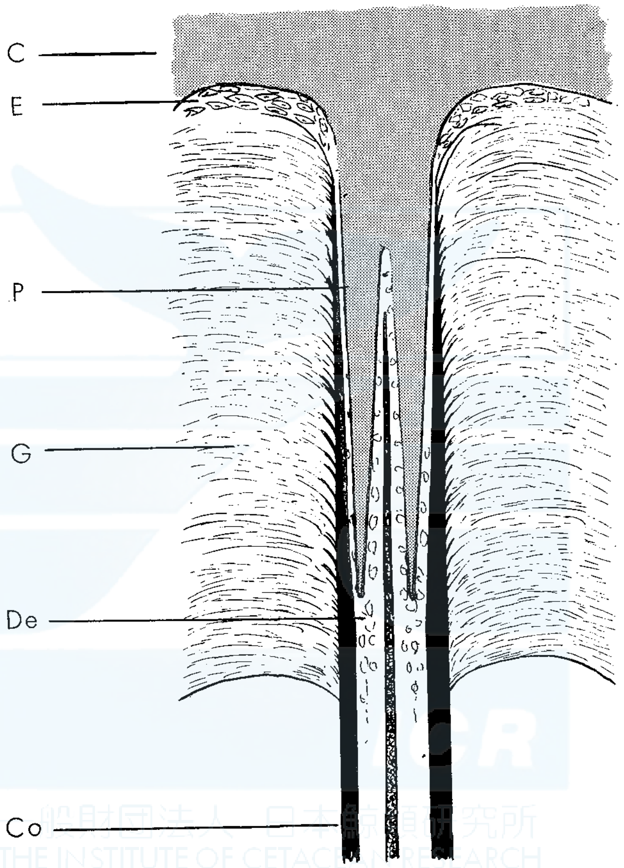

Fig. 7. Diagrammatic sketch indicating the base of baleen plate, modified from the original (Utrecht, 1958)
C: Connective tissue of palate. E: Epithelium. P: Papillae covered with epithelium. G: Gum. De: Dead epithelial cells in the hollow part of horn tube. Co: Cortical layer.

included in the paper by Slijper (1958). In Fig. 7 I indicate a diagrammatic sketch, modified slightly from the original, to confirm the structure of the baleen plate and to help the understanding for my interpretation.

The gum composed of non-cornified epidermal cells undergoes constant cell division by which worn off material is continually replenished from the basal layer. Two descriptions are cited here with regard to the formation mechanism of the cortical layer and the horny layer, because such two parts are necessary to understand the baleen plate as an age indicator of the fin whale.

' Because of this cell division and the consequent outward migration of cells, tensions are set up in a specific spot close to the wall of the baleen. These tensions cause cornification of the gum cells. The resulting cornified layer is pushed out with the tubules and the gum, and emerges as the cortical layer of the tubules. The gum itself contributes no further material to the baleen, new material being added exclusively by the cell covering the walls of the baleen where they face the gum. The cells of this intercalated layer shift outward with the horn tubules and the cells of the gum, and gradually become cornified. Hence the thickness of the cortical layer is determined by the thickness of this special intercalated layer——. Difference in thickness may be produced in these regions ' (Slijper, 1958). In the skin or epidermis external to the papillae the horny tubes are formed and it is the free ends of these which make the baleen fringe (Burne's cetacean dissection, 1952). These two descriptions suggest us that two parts of each baleen plate derive from the different phases of the epithelium of the upper jaw.

Examining the longitudinal and transverse sections of the baleen plate from the full grown fin whale, Ruud (1940) concluded that one medullary tissue is formed gradually from one papilla and probably keep the same thickness from the young to the old. This finding supports his method for the age determination from the baleen plate. Tomilin (1945) reported independently the significance of baleen plate as an age indicator. The proposal that the variation of the thickness in the baleen plate must be due to variations of the thickness of the cortical layer was accepted also by Nishiwaki (1950b) who examined the age of the blue and the fin whale in the Antarctic by the same method as Ruud.

Considering the structure of the baleen plate, I had some doubts on this proposal supported by the previous workers. The horny layer is formed gradually onwards by the movement of the keratinized cell in the epidermis of the projected papillae. If the speed of keratinization is constant and no physiological factors accelerates or reduces the keratinized degeneration of the epidermal cell, the thick ness of the horny layer seems to be constant. But it is generally difficult to accept these conditions in the animal tissue.

As indicated in Fig. 8, the part of the outer margin of the baleen plate was planed down on the glass plate as a long strip from 0.2 mm to 0.3 mm thickness. It demands a kind of technical skill to obtain the perfect material along the outer curvature of the plate. After the smooth long strip was obtained successfully, the remains was used for recording the baleen sculpture.

Taking the photograph of the long strip through the same method already described, I measured the total thickness of the plate, the thickness of the cortical layer and the horny layer respectively from the tip to the end of the horny tube in the baleen plate. The measurements are made by the 10x shadowgraph. Fig. 9 indicates the measurements for three parts and the photograph of the long strip for this baleen plate. Both in parts of the tip and of 30–40 cm from the tip, the measurements was impossible, because of the vague border mainly based on the thick section. In an example of Fig. 9, the horny layer fluctuates between 1.0 mm and 2.2 mm thickness, indicating three or more peaks, whereas the thickness of the cortical layer increases from the tip to the base of the plate, varying from 0.4 mm to 2.3 mm.

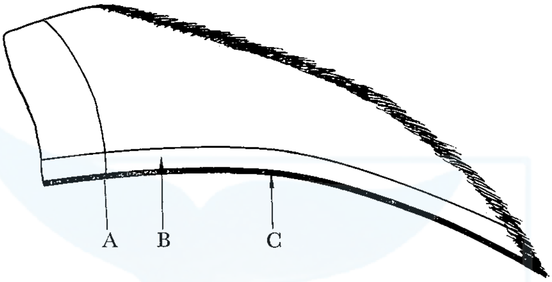

Fig. 8. Outline of a longest baleen plate of fin whale.
A: Gum line.
B: Portion used for recording sculpture.
C: Portion used for the photographic method.

Nevertheless the total thickness is expressed as a sum of both thickness in the cortical and the honry layer, its fluctuation is mainly affected by the varying thickness of the honry layer. Four arrows in Fig. 9 indicate positions of discrepancy in the thickness between the horny and the cortical layer. In spite of the lower value in the cortical layer, the higher value or the peak is given in the horny layer at the position indicated by arrows. At the first arrow, the total thickness is comparatively thinner but does not indicate the trough in its fluctuation. This figure shows that the fluctuation of the thickness is out of phase between the cortical and the horny layer.

The photograph of this specimen indicates that the growing direction of the baleen plate is not uniform but has several changes. At the points shown by arrows, there are remarkable inflections in the growth direction of the plate. In the photograph, the anterior surface of the plate is taken in the lower side. I found the inflection point of the plate correspond to the increasing part or the peak in the fluctuating thickness of the horny layer, in the examined specimens. This fact suggests that the active keratinization of the epidermal cell on the remarkably projected papillae determines the growth direction of the baleen plate. During the active formation, the growth of plate become rapid in thickness as well as in length. The inflections result from the alternation of the active and resting formation. Such inflections often exist in the accumulated layer of keratinized cells. In the course of the histological study on the ear plug of baleen whales, I have pointed that the inflection of the longitudinal bright layer is affected by the

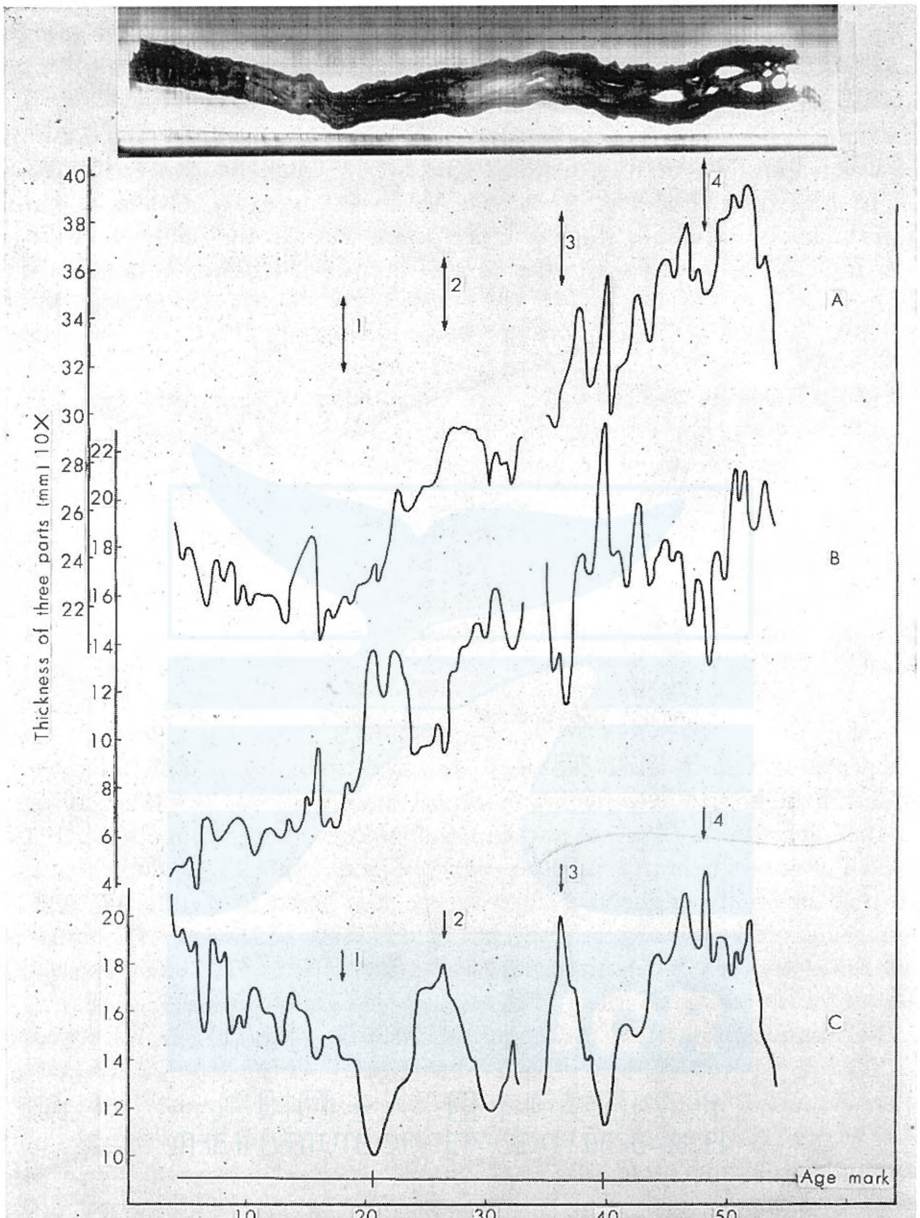

Fig. 9. Fluctuation of thickness for three parts of a baleen plate from a 60 feet long female fin whale in the Antarctic.

A: Total layer thickness. B: Cortical layer thickness. C: Horny layer thickness.

physical force during the accumulation of keratinized cell in the glove-finger epidermis (Ichihara, 1959). Numbers of varying vectors are related to the age unit of the baleen plate.

As indicated in Fig. 9, the age mark in the trace of the baleen sculpture lies in the position between two inflection points of the photographic section. In the baleen plate from the grown fin whale, an age unit generally includes two or four changes of vectors in the longitudinal growth of the baleen plate.

Ruud (1940) has also described that the medullary tissue varies little in the thickness longitudinally in the plate and that there remain the possibility of new papillae gradually formed. It should be noted that the thickness of the medullary tissue varies much than Ruud reported.

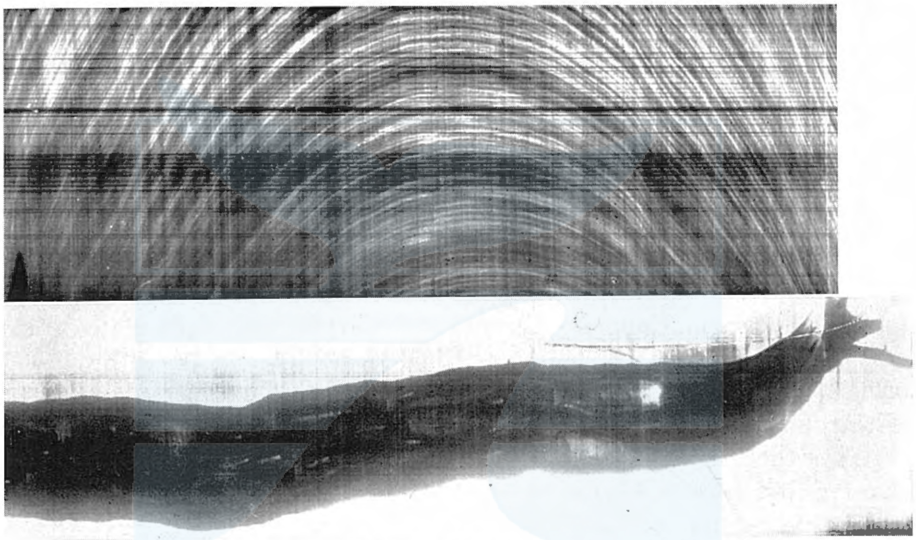

Fig. 10. Comparison between the longitudinal sculpture on the surface of a baleen plate and the changing vectors in the longitudinal section of the same plate. This photograph was obtained from a longest baleen plate of a 54 feet fin whale in the Antarctic.

Yablokov and Andreyeva (1965) found the ring-like structure in the walls of large and small tubules composing the medullary layer. They state that there is possibly a positive relation between the tubule stratification and the age of the baleen whale, however, the great variation in the thickness of the medullary tissue throws doubt upon the increasing stratification with the advancing age of the whale.

Each horny tube running longitudinally is embossed on the surface of the plate. Its embossment runs as parallel lines at a glance, but there are several periodical inflections in detail on a plate. In Fig. 10, the photograph of the surface structure in the plate is compared with the photograph of the longitudinal section.

The surface structure of the plate is taken in photograph by the devised method already mentioned. The inflection of running lines occurs simultaneously on the growing plate, that is, these inflections appears at the same position on the plate.

The fact that these inflections are coincident with the inflections in the longitudinal section of the plate, indicates that the baleen plate bends periodically not only from the anterior to the posterior but from the left to the right direction. All these bendings are influenced by the periodic growth in the thickness of the medullary tissue of the plate.

GROWTH OF BALEEN PLATE AND ITS VALIDITY AS AN AGE INDICATOR

In this chapter, I present a historical review for previous works concerning the growth of baleen plate and its validity as an age indicator. Mackintosh and Wheeler (1929) states that the first rudiments of the two blocks of baleen plate are found after the blue whale foetus reaches a length of 2 metre or more and then two plain strips of a soft whitish material appear, one on each side of the upper jaw. They state, furthermore, that at the 2.5 to 3 metres, minute transverse ridges appear on these strips and later develop into whalebone plates. They refer to the prenatal development of the baleen plate in the fin whale, reporting that the development of the baleen plate in the blue whale foetus applies equally to its development in the fin whale foetus. Ohsumi (1960) found the first rudiments of the baleen plates at the length of 1.75 metre in the antarctic fin whale foetus. These foetal lengths corresponds to the 7th pregnancy months for both species, according to the reasonable foetal growth curves indicated by Laws (1959). The initial baleen plate develops in the latter half of foetal stage, and after birth its length and width grow with the increasing length of whale as the filter organ of the swallowed zoo-planktons.

There are two stages in the development of the baleen plate in the postnatal growth. For the antarctic fin whale, Mackintosh and Wheeler (1929) have pointed out that the first growth of the lengths in plates is followed by the sudden spurt in the early life.

The baleen plate is exposed in the month of the baleen whale, and rubbed by the entrance and exit of the water and food during feeding. If the influence of these continuous frictions to the thickness of the plate is intensive, besides, it is different at the locality of the plate, the traces of the surface sculpture in the plate will be disturbed in the periodicity. In the fin whale, Ruud (1940) describes that the surface sculpture of the plate appears to be unaffected by wear from the base up to very near to the tip.

Ruud (1945, p. 35) indicated the tracing records for the baleen plate sculptures from 8 calves taken in the coast of Norway. All of these young fin whales were accompanied by cows and hence they are in the sucking or the weaning stages. The characteristics of these tracing records lies both in the presence of the prenatal plate and in the uniform thickness of the plate from the birth to killing. In addition to these valuable records, many traces are shown by him for fin whales from the young to the old age. It is important that the great similarity is found in these traces from fin whales of the same growing stage. In the personal communications, Mr. G. C. Pike indicated me very valuable records of baleen plates from young fin whales captured in the North Pacific. The clear similarity in tracing pattern is found for these 17 records from British Columbia fin whales. Taking notice the similar tracing pattern for baleen plates, Chittleborough (1959) determined ages of Australian humpback whales. He indicated typical records of baleen plate sculptures from a 1-year old individual to 6 year and more old individuals. Finding the similar pattern or the periodicity in the fluctuating thickness of the plate, Ruud proposed the theory of the age determination by means of the baleen sculpture in the baleen whale. He estimated that the different levels in the thickness of the plate are associated with annual alternations of a storing metabolism in the cold water and a consumptive metabolism in warm waters and that every period would then represent a year in the whale life. Nishiwaki (1951) has estimated that the inter val zone between the successive two main ridges on the baleen plate corresponds to the annual growth of the plate, by the statistical treatment of the baleen length formed in the antarctic feeding period. These indirect estimations concerning the annual formation were checked by the marking experiments. Dawbin (1959) and Chittleborough (1960) reported the validity of such estimations, examining the baleen plate sculpture of young humpback whales which were recaptured off New Zealand and Australia. These whales were marked at the known age in the early life.

PERIOD OF SUCKLING

Determining the age of very young whale by sculpture records needs the accurate knowledge about the periods of lactation and weaning. Scouting catcher ships were often dispatched to various localities in the Antarctic to observe distributions and the movements of fin whales. In the Japanese expeditions I requested experienced captains of these ships to take records of calves accompanied by fin whale cows. Besides, in the voyages for the whale marking under the International Cooperation, body lengths of calves were estimated from the ships. A pair of cow and calf is discriminated from the other fin whales in the following swimming habits. The thin cow accompanying the calf always rises to the surface of water at every spout of the calf even if she does not respirate at that time. All scouting ships took records, confirming this habit during the chase of fin whales. In the 1964/65 season in the Antarctic, 40 voyages were tried to examine the distribution of the fin whale. Monthly frequencies of these cruises are shown in Table 1.

The peak of the frequency in the scouting voyage was in February among the examined period from October 23 and March 24. Ten ships which worked for the whale observation in a total of 817 days covered the area of 30°S–65°S and of 90°E–0–170°E in the Antarctic. In such vast areas, only 63 pairs of fin whales were observed mainly in Area III (0°–70°E). Table 2 shows the latitudinal localities of swimming cows accompanying calves during the observation by ships.

Except two pairs in January, most of pairs were observed far north than 60°S. The mode of basic numbers is in the range of 45°–50°S in December and in the range of 50°–55°S from January to February. From a few records in November and March, there is no definite finding. However, Table 2 shows a trend that cows and calves remain in warmer sea far north than the antarctic convergence in the early of the summer and enter gradually in the southern waters with advance of month. The low frequency of the observed sucklings is mainly based on the recent depletion of the stock in the antarctic fin whale. The recent overfishing to the mature stock of the fin whale has reduced numbers of new born calves.

Simultaneously, it is impossible to neglect the ecological feature of sucklings. Discussion on this point will be made later. The occurrence of the pair is indicated in a broken line curve in Fig. 11 as the monthly percentage frequency.

TABLE 1. FREQUENCY OF THE 1964/65 RESEARCH VOYAGE BY MONTH FOR OBSERVING FIN WHALE COWS AND CALVES IN THE ANTARCTIC

Month	Frequency of voyage
October	2
November	5
December	6
January	9
February	12
March	6

TABLE 2. LATITUDINAL DISTRIBUTION OF OBSERVED 63 PAIRS COMPOSED OF COWS AND CALVES IN THE ANTARCTIC FIN WHALE.

Range of latitude	October	November	December	January	February	March	Total
40–45°S	—	1	5	—	—	—	6
45–50°S	—	—	13	2	1	—	16
50–55°S	—	1	9	12	4	1	27
55–60°S	—	2	—	6	3	1	12
60–65°S	—	—	—	—	—	—	—
65–70°S	—	—	—	2	—	—	2
Total	—	4	27	22	8	2	63

The mode of this curve is in the middle of December and the mean is in the third week of December. The shape of the curve for the antarctic fin whale has a slightly positive skewness indicating a resemblance to the shape of the curve of calving frequencies indicated by Mackintosh & Wheeler (1929) and Laws (1961). The occurrence of the lactating female which was examined by biologists on board the recent Japanese expeditions in the Antarctic, is shown in a full line curve in Fig. 11.

Since the catch of the fin whale is prohibited after April 8 in the Antarctic by the International Whaling Convention, the mean month for the occurrence of the lactating fin whales is not accurately determined by this figure. From the analogous shape between two distributions, it is estimated that the peak influx of the lactating female is in the middle of February and the mean occurrence is in the end of February. If the extrapolation for the decline of the curve is permitted, this figure suggests that there may be the occurrence of the lactating female until the coming May and June.

In the past pelagic antarctic whaling, generally speaking, there were records that fin whales were captured near to the ice-pack line. Before the depletion of the whale stock became remarkable, fin whales distributed widely in the area where *Euphausia superba* raises as the main food. After the 1959/60 season, the pelagic whaling ground has inclined towards the northern part than in the past. This tendency has been remarkable from year to year and the recent catch of fin whales has taken place far north than the antarctic convergence. Numbers of fin whales captured by the Japanese expeditions from the 1959/60 season to the 1961/62 season are shown in Table 3, in which the captured locality is summarized by 5 degree of latitude and by the whaling area. In the 1959/60 season, 69.2 percentage of the total was captured from 55°S to 60°S, 50.1 percentage in the 1960/61 season from 55°S to 60°S and 51.8 percentage in the 1961/62 season from 50°S to 55°S.

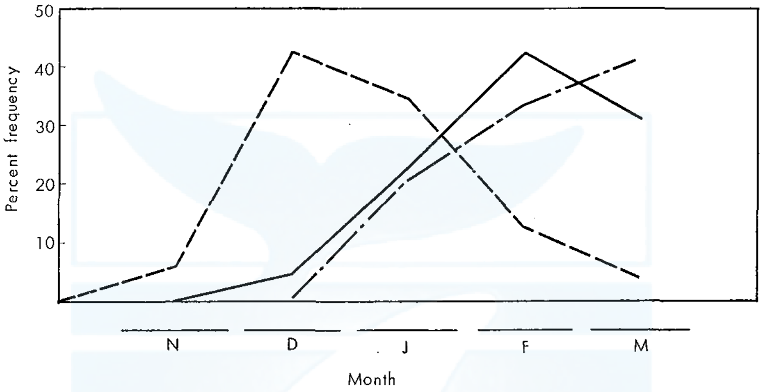

Fig. 11. Occurrence of cows accompanied by calves and of lactating females in the Antarctic fin whales.

- - - - -: Observed cows and calves. ———: Examined full lactating females.

— - —: End of lactating stage.

According to the International Whaling Statistics, the Japanese whaling fleets took 33.7 percentage of the total pelagic catch for fin whales in the 1959/60 season, 32.5 percentage in the 1960/61 season and 44.8 percentage in the 1961/62 season. In spite of the recent bias of locality in the whaling ground, much food composed primarily of *Euphausia superba* has been found from the examined fin whale, in particular far south than the antarctic convergence. Because of the extreme concentration of the whaling ground, it was rare to observe fin whales even in more southern areas near the ice pack where patches of krills were often observed in the sea. One of resonable causes which account for the recent bias of the whaling locality seems to be the extreme depletion of the fin whale stock in the An tarctic. There is no remarkable difference in the antarctic sea condition between the past and the recent days (Mackintosh, 1946., Nasu, 1966). Most of fin whales entering to the Antarctic remains recently the feeding area near the antarctic convergence (about 50°S) through the summer season and do not migrate so far south. This habit is neither observed nor reported in days when fin whales were abundant. On the basis of the figures for the period 1927–35 for South Georgia and 1945–47 for the pelagic catch, Laws (1961) reports that the month of occurrence of the lactating female is slightly different between two whaling localities. The mean month of the catch for the lactating female is in January for the South Georgia waters and in February for the pelagic whaling grounds.

TABLE 3. LOCALITIES OF THE FIN WHALE CATCH BY THE JAPANESE EXPEDITIONS FROM THE 1959/60 SEASON TO THE 1961/62 SEASON IN THE ANTARCTIC

1959/60 season

	Area						
Latitude	II	III	IV	V	VI	Total	%
45°–50° s	—	1	11	47	—	59	0.7
50°–55°	—	—	27	154	—	181	2.0
55°–60°	—	—	5913	238	—	6151	69.2
60°–65°	—	601	526	674	195	1996	22.4
65°–70°	—	195	—	190	123	508	5.7
70°–75°	—	—	—	—	2	2	0.0
Total	—	797	6477	1303	320	8897	
%		9.0	72.8	14.6	3.6		100.0

1960/61 season

	Area						
Latitude	II	III	IV	V	VI	Total	%
40°–45° s	—	86	—	—	—	86	1.0
45°–50°	—	1096	259	—	—	1355	15.2
50°–55°	—	954	276	—	—	1230	13.8
55°–60°	—	2395	1493	—	574	4462	50.1
60°–65°	—	231	16	236	1282	1765	19.8
65°–70°	—	—	—	—	5	5	0.1
Total	—	4762	2044	236	1861	8903	
%		53.4	23.0	2.7	20.9		100.0

1961/62 season

	Area						
Latitude	II	III	IV	V	VI	Total	%
45°–50° s	—	940	69	—	—	1009	8.5
50°–55°	226	5269	643	—	—	6138	51.8
55°–60°	—	1956	2052	—	—	4008	33.8
60°–65°	—	547	—	—	—	547	4.6
65°–70°	—	153	—	—	—	153	1.3
Total	226	8865	2764	—	—	11855	
%	1.9	74.8	23.3				100.0

Remark: Area II (60°W–0°), Area III (0°–70°E), Area IV (70°E–130°E), Area V (130°E–170°W), Area VI (170°W–120°W)

He suggested that the influx of lactating females to the whaling grounds might begin when sea surface temperatures rose above about 0°C and that it occurred about 5–6 weeks earlier in the South Georgia waters than in the pelagic whaling ground. The locality of the pelagic whaling ground in the 1945/47 season which Laws reported, could be estimated to be near 62°S from his descriptions. As mentioned above, the recent Japanese catch of fin whales has taken place mainly the same latitude or in the slightly southern area in the South Georgia (about 54°S, 37°W) waters (See Table 3), however, the peak influx of lactating females occurs in February in my data. From the 1959/60 to the 1964/65 season, the monthly percent frequency of lactating females is almost constant in the Japanese expeditions. If cows accompanying calves were killed at random from January to March, the shape of the full line should be different from that indicated in Fig. 11 and show the peak in December. In this meaning, it seems to me that Laws emphasized extremely the incidence of the lactating females in the South Grorgia catch for estimation of weaning date. The shape of frequency distribution curve of the lactating whale in the South Georgia waters is different from that of the calving curve. The earlier influx of lactating females in the South Georgia waters may be dependent on the habit in subpopulations of fin whales which both the recovery of the whale mark (Brown, 1954) and the examination on the blood type (Fujino, 1964) revealed. My data for the lactating females primarily come from area III (0°–70°E).

Both from the field observation on calves accompanied by cows and the frequency of the lactating females in the pelagic whaling, I conclude fin whales wean calves in the end of January when 50 percentage of weaning occurs in the sucking calf of the fin whale. Since the mean calving date for fin whales in the southern hemisphere is determined in the end of May (Laws, 1959), the period of suckling is about 8 months for the antarctic fin whale. Mackintosh & Wheeler (1929) suggested that the lactation period was about 6–7 months for the antarctic fin whales and estimated that the average length of the calf at weaning was probably about 12 metres, on the basis of an apparent increase in the rate of growth of the baleen plates at weaning and on the sizes of the largest sucking calves and the smallest independent calves. Ash (1956) also estimated the weaning date using the blubber thickness of the lactating female fin whale. The average blubber ratio (blubber thickness in cm/length of whale in feet) of five lactating females given by Ash is 0.279. If these lactating female are very near to weaning, the fatness curve for non-pregnant female is extrapolated backwards in time to a value of 0.279. In the non-pregnant female, this value correspond to the third week of December. Laws (1961) also confirmed the period of lactation that was proposed by Mackintosh and Wheeler. In these previous papers, the period of lactation is slightly underestimated. Fig. 11 indicates that the peak occurrences in pairs of cows and calves is in the third week of December, 7 months from the calving date.

The Japanese catcher ships engaged in the whale marking under the International Cooperation estimated the body length of cow and calf from the deck. From the 1954/55 season to the 1964/65 season, body lengths of 18 fin cows and calves were estimated by experienced gunners and captains in the Antarctic. Table 4 shows estimated lengths for cows and calves from November to January. Numbers of observed calves listed in this table are excluded from Table 2 and hence not used for estimating the occurrence of cows and calves. Because the data on the marking voyages do not include all records of observed cows and calves. The mean length for the fin whale calf is estimated as 44 feet in December and 45 feet for three months period.

In order to check whether the estimation is correct or not, I utilized the result of marking experiments. At the whale marking, lengths of all swimming whales have been estimated by gunners and captains from the ship. If the hit mark is recovered during the same whaling season, the estimated length would be checked at the flensing. I pick these whales up from the marking records reserved at the Whales Research Institute. From the 1956/57 to 1962/63 season, the numbers of fin whales in this case amounted to 46 and no case from the 1963/64 to 1964/65 season. Estimated lengths from the catcher ships are plotted against the measured lengths on the floating factories in Fig. 12. When the estimation is correct, the estimated value should be given on a line of 45°. Fig. 12 indicates, however, that there is a bias for the estimation. Over 63 feet in length, the length of the swimming whale is underestimated, whereas it is overestimated for the whale under 63 feet. This tendency may be a characteristics for the Japanese estimation. Kawakami (1956) presented a note on this problem for the fin, sei and sperm whales in the North Pacific, but the conclusive tendency was not examined on account of a few material. Although it is resonable that the young whale grows faster than the old whale between the marking and the recovery, the human bias overestimated the length of the young at the sea. This bias may come from the size limit, 57 feet in length, imposed on the fin whale and reflect the human desire in the whale catch, but the principal reason for underestimating of large whales probably lies in the relative shortness of tail region. With the growing body length of balaenopteriid whale, the percentage of tail region to total length gradually decreases. This trend of estimation is applied for the suckling but the extrapolation in Fig. 12 is not appropriate.

TABLE 4. ESTIMATED LENGTH OF FIN WHALE COW AND CALF, BY RESEARCH SHIP IN THE ANTARCTIC.

November		December		January		Total
Cow	Calf	Cow	Calf	Cow	Calf	Calf
67	45	71	30	68	40	30×1
67	45	68	35			35×1
69	47	60	40			40×3
?	54	65	40			45×6
		65	45			47×2
		?	45			50×4
		67	45			54×1
		72	45			
		65	47			
		67	50			
		68	50			
		70	50			
		70	50			

It is safe to say that the length of the fin whale suckling also is overestimated on the sea and a calf of 54 feet in length (Table 4) is too large. The actual length of the calf in December seems to be under 44 feet (13.4 metres) in length.

Mackintosh and Wheeler (1929) stated that in the growth of the baleen plate of the fin whale no spurt took place after the calf had reached much more than 13.0 metre and that one might expect it occurred between 12.0 metre (39 feet) and 13.0 metre (43 feet). According to their Fig. 96 it is reasonable to think the rapid growth of the baleen plate occurs at 43 feet in the length of the calf. Because the growth curve of the baleen plate is discontinuous at 43 feet of the whale length.

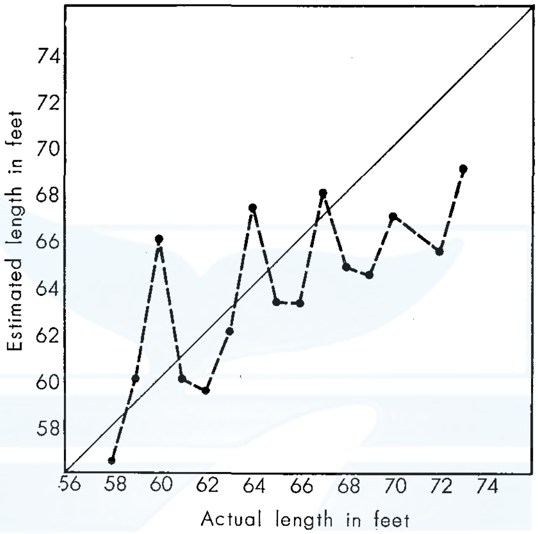

Fig. 12. Bias in the estimated length for the antarctic fin whale, checked from the recapture of marked whales in the same whaling season.

Measuring the longest plates from very young fin whales captured off the norwegian coast, Ruud (1945) testified that the growth curve of the plate, estimated by Mackintosh and Wheeler was valid. The rapid growth of the plate at 43 feet of the whale length suggests the shift from sucking milk to swallowing krill in the feeding habit. The growth of the plate is followed by the elongation of fringes which consist of the exposed horny tubes in the medullary tissue of the plate. There is a important relation between the feeding habit of the baleen whale and the size of the fringe in the plate (Tomilin, 1954). Besides this finding, Nemoto (1959) pointed out that the young fin whale has finer and shorter fringe than the old.

As in the case of the terrestrial mammal, there is also a weaning period for the fin whale. In this period, the fin whale calf will suck milk from the cow as well as feed on the plankton. It is difficult to determine the accurate period of weaning. It is possible, however, to assume that a short period in the end of sucking stage is occupied by such a weaning period. Tavorga and Essapian (1957) observed such a weaning period in *Tursiops truncatus* kept in the aquarium. In the fin whale, the weaning period is estimated to be not so long as in the bottle-nosed dolphin because of limited distributions in food. On the basis of 27 females in the recent Japanese expeditions, the frequency in the end of lactating stage is illustrated in the chain-line curve of Fig. 11. Laws (1961) reported that the thickness of mammary gland decreased under 17 cm in the end of lactation in the antarctic fin whale and Chittleborough (1958) noted in the Australian humpback whale that after lactation has ended, when involution of the gland is well marked, there may be liquid in the lacteal ducts, which is usually a whitish or turbid yellowish thin fluid. From examined lactating females, I picked up individuals satisfying two findings by Laws and Chittleborough. My small samples show that the peak frequency occurs in March and suggests that the fin whale calf becomes independent of the cow in the antarctic summer.

In conclusion, it is estimated that the sucking period including the weaning period is about 8 months from late-May to late-January for the antarctic fin whale and that around the antarctic convergence the calf is weaned from the cow at 43 feet in length.

Accurate estimation is indispensable to determining the formation period of the dark and bright layer in the ear plug.

RELATIONSHIP BETWEEN RECORD OF BALEEN SCULPTURE AND PHOTOMETRIC RECORD OF EAR PLUG

The tip of the growing baleen plate is gradually worn off by the friction with the lower jaw. This is the fatal defect for the age determination by means of the baleen plate. Strictly speaking, only the age of very young whales, of which baleen plates possess the neonatal marks on their tips, is determined by this method. The conspicuous convergence of the horny tubes is present from the gum towards the tip on the baleen plate from the sucking calf. It is important for the age determination by the baleen plate to decide whether or not the neonatal mark remains until any age.

It is essential to obtain very young baleen plate in order to examine the formation of ear plug laminae in the early life. 22 baleen plates were collected from fin whales during several years. One of these longests plates comes from a stranded young fin whale in the Okhotsk Sea. It is estimated that this male strayed apart from its mother in the weaning stage, judged from the body length of 42 feet. 21 baleen plates come from the antarctic whaling and include those from the weanlings misshot by the gunner of the catcher ship. Perfect ear plugs were collected from 20 fin whales and the photometric recording was applied to them. In individual from which imperfect ear plug is taken, only baleen sculpture was recorded and compared with others. Table 5 lists these samples and biological data.

The estimated lengths of Nos. 3. 4 and 6 seem to be too high, compared with the growth curve of the baleen plate, the broken line, given by Mackintosh & Wheeler (See Fig. 13). The length of the longest baleen plates from each whale is plotted in Fig. 13 where the open circle indicates the plate with neonatal mark on its tip and

TABLE 5. LIST OF EXAMINED YOUNG FIN WHALES

Sample No.	Locality	Date killed	Body length in feet	Sex	Diatom infecticn	State of ovaries	Diametre of largest follicle (mm)	Weight of Testes (kg)
1	Okhotsk Sea	Aug. 11	42	Male	None			not measured
2	Antarctic	Mar. 16	48	Female	,,	Immature		
3	,,	Feb. 12	49*	Male	,,			0.2, 0.2
4	,,	Feb. 11	50*	Male	,,			0.4, 0.3
5	,,	Mar. 27	57	Female	,,	Immature		
6	,,	Feb. 26	55*	Female	,,	Immature		
7	,,	Jan. 8	54	Male	,,			0.4, 0.4
8	,,	Feb. 10	57	Male	,,			0.2, —
9	,,	Feb. 17	57	Female	,,	Immature		
10	,,	Dec. 28	57	Female	Incipent	Immature		
11	,,	Feb. 11	57	Female	None	Immature		
12	,,	Feb. 5	57	Female	,,	Immature	5	
13	,,	Jan. 3	57	Male	,,			0.4, 0.4
14	,,	Mar. 6	57	Male	,,			0.5, 0.5
15	,,	Feb. 7	58	Male	,,			0.3, 0.4
16	,,	Dec. 28	58	Male	Incipent			1.0, 1.0
17	,,	Jan. 14	58	Female	None	Immature		
18	,,	Mar. 7	58	Male	,,			0.9, 0.8
19	,,	Dec. 15	60	Female	,,	Immature		
20	,,	Jan. 13	60	Female	,,	Immature	8	
21	,,	Jan. 10	61	Female	Incipent	Immature	7	
22	,,	Jan. 3	74	Female	Incipent	Mature 24 corpora albicantia	20	

* Estimated length

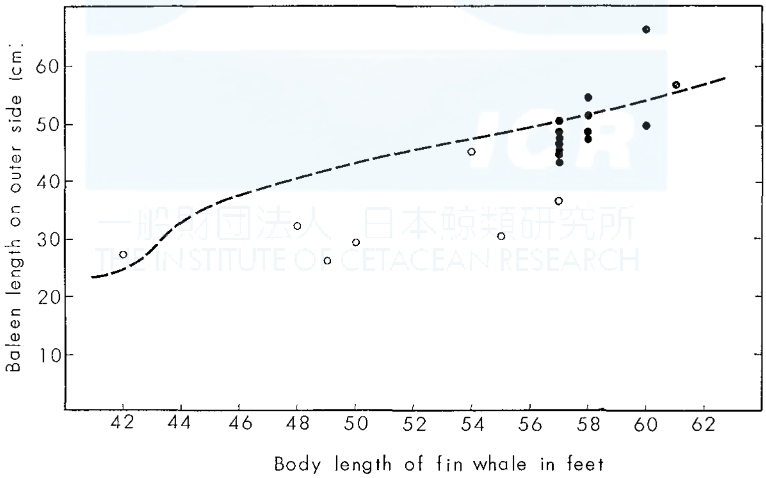

Fig. 13. Growth of baleen plate in the young antarctic fin whale. A 42 feet long male from the North Pacific is included. Broken line is cited from Mackintosh and Wheeler (1929). Open circle: plates with neonatal mark.

the closed circle shows the plate of which the neonatal mark is worn off. Most of my samples distributes along the broken line and the neonatal mark remains only in the baleen plate under 45.0 cm in length along its outer side. No whale over 57 feet, the size limit imposed on fin whales captured by the antarctic whaling, has baleen plates indicating the neonatal mark. Fig. 14 shows frontal views of the longest plates from Nos. 6 and 17 whale. The shape of gum lines is different between two specimens; the gum line of the plate possessing the neonatal mark is more protrudent than that of 58 feet fin whale.

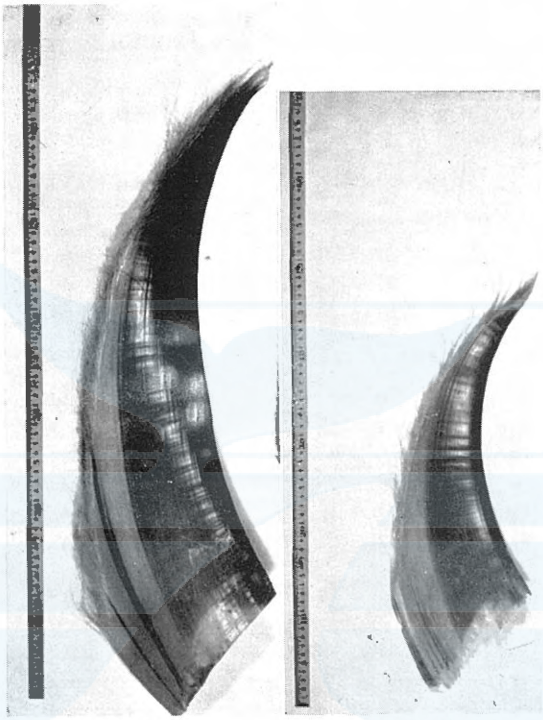

Fig. 14. Longest baleen plates from two fin whales. Sample No. 17 in the left and sample No. 6 in the right. Gum line is remarkably projected in the right plate. Scale unit is cm.

The photometric records were taken on longitudinally bisected ear plugs collected from Nos. 2, 3, 4, 5 and 7 whales. Since the baleen plates of these whales have the neonatal marks, it is possible to contrast the photometric records for ear plugs with the sculpture records for baleen plates. Observing the view finder of the photometric apparatus, we can check both the prenatal point and the proximal point of plug-core on the recording paper. The bright prenatal layer exists always in the distal end of the core in the ear plugs (Ichihara, 1964) and the last formation of ear plug is seen above the epidermis of the glove-finger. In the careful collection, the epidermis of the glove-finger remains on the proximal end of the ear plug and looks like white layer.

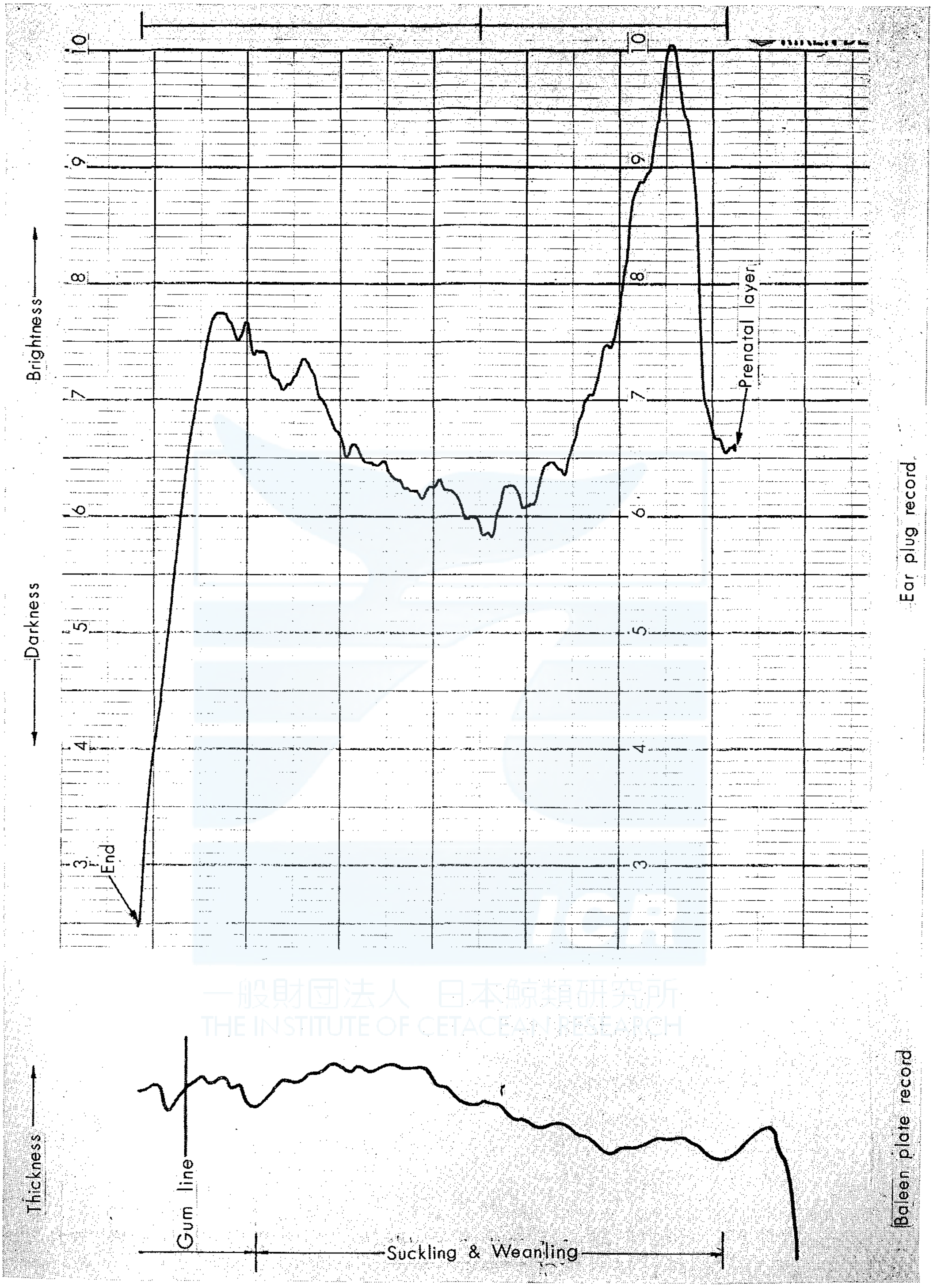

Fig. 15. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 2 fin whale. Core length of the ear plug is 8.4 mm and the length along the outer side of the baleen plate is 32.0 cm. Counts for both age characters are indicated.

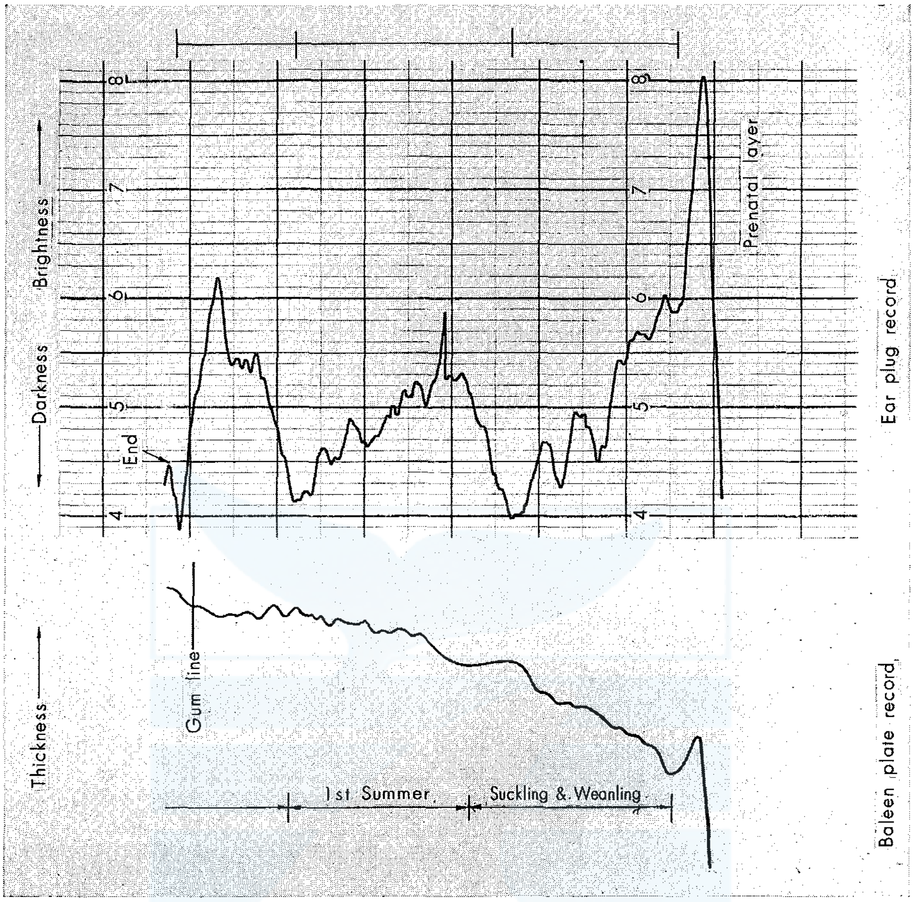

Fig. 16. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 3 fin whale. Core length of the ear plug is 8.4 mm and the length along the outer side of the baleen plate is 26.0 cm. Counts for both age characters are indicated.

These contrasts of records between two age charactors are illustrated from Fig. 15 to Fig. 19, in which age counts for such charactors are also indicated. The count for laminations in the ear plug is made between successive two maximum dark points, because the first dark layer is formed just after birth according to my previous study. There are no clear alternation of dark and bright layers in the photometric records for Nos. 5 and 7 whales. Ear plugs from these two whales indicates the complicated formation of keratinized and fatty degeneration in epidermal cells of the glove-finger. Even for Nos. 5 and 7 photometric records, however, it is easy to count the alternation of dark and bright layer, if we turn the positions of these figures. This is a practical method to interpret the photometric record. Two or three adjacent layers should be counted as one lamina, as in the case of the naked eye count. In many case of young ear plugs, the vague laminae are often

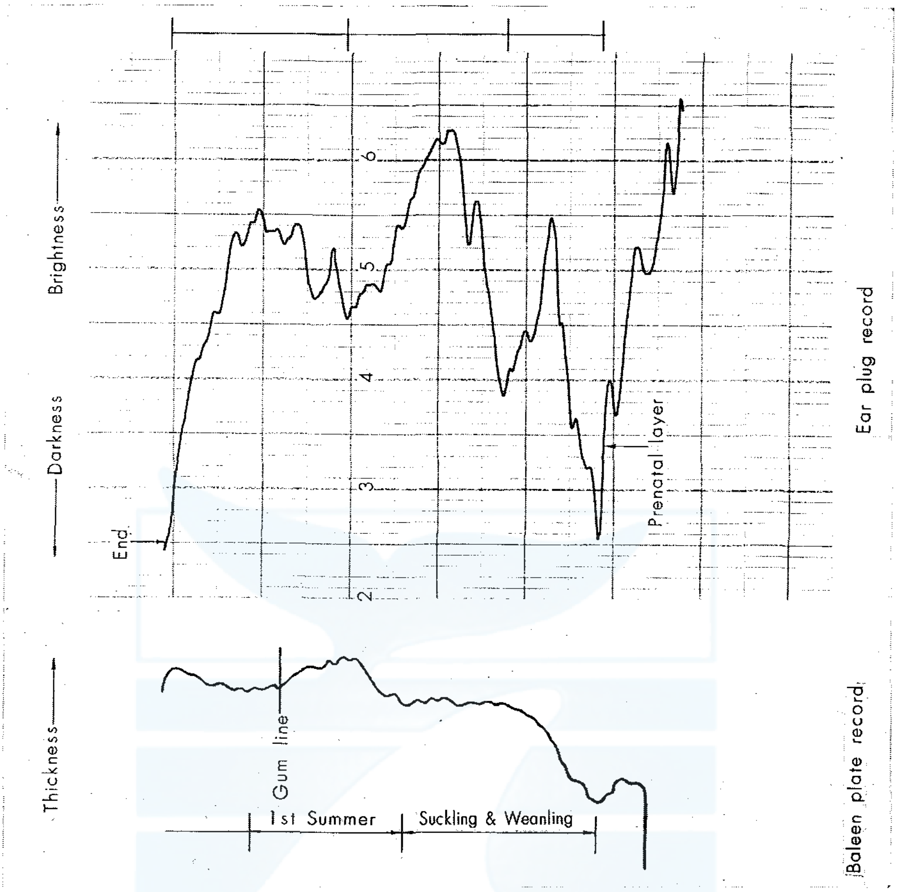

Fig. 17. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 4 fin whale. Core length of the ear plug is 4.3 mm and the length along the outer side of the baleen plate is 29.7 cm. Counts for both age characters are indicated.

present and becomes an obstacle to standardize the naked eye count. Since the sensibility of the photometric apparatus records accurately the vague occurrence of colour, it is possible to check the position of vague laminae. Strictly speaking, each lamina length to be counted as one lamination includes three undulations in the record for No. 5 whale and the situation is more complicated in the record for No. 7 whale than in other records. How to interpret a unit in the photometric record is a way to standardize counting for the alternation of laminae. Since Purves (1955) found the validity of ear plug laminae as an excellent age indicator, many scientists have reported the relation between other age materials and the number of laminae in the ear plug. In these previous reports, the basis of counting is dependent on the naked eye. Even for the young ear plug indicating the occurrence of vague laminae, this simple method has been applied for and whether or not the counting is agreeable has been reported. On the basis of the experienced counting for many

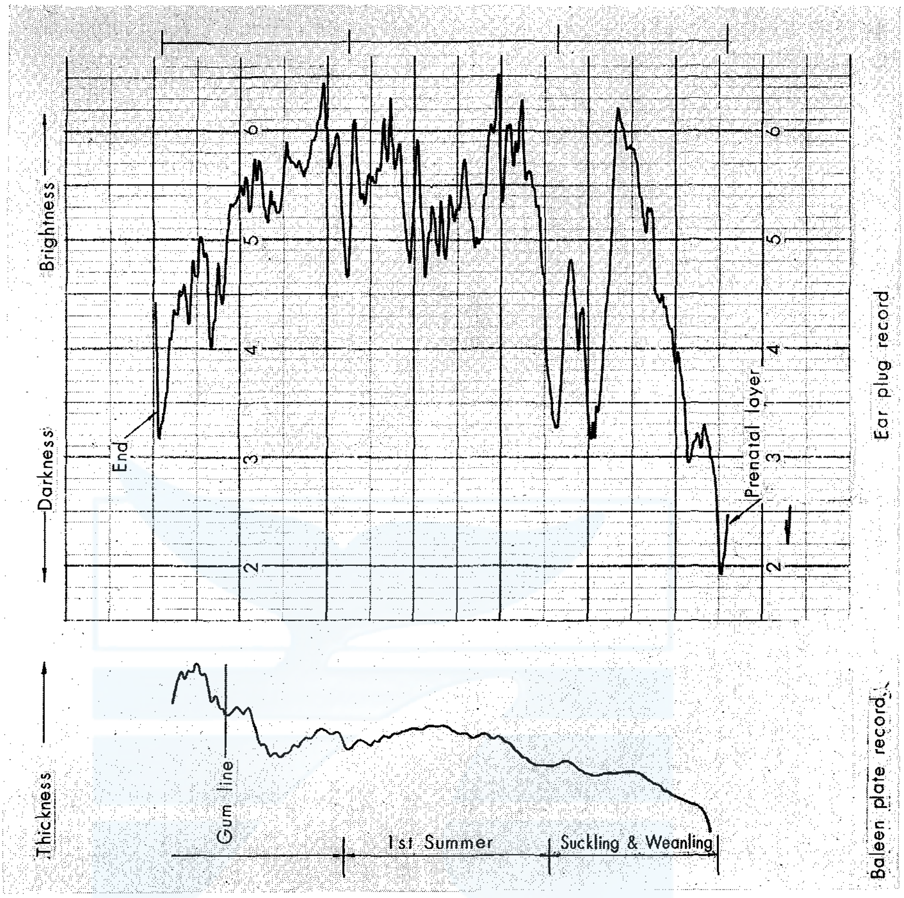

Fig. 18. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 5 fin whale. Core length of the ear plug is 18.2 mm and the length along the outer side of the baleen plate is 45.2 cm. Counts for both age charactors are indicated.

ear plugs collected from the Antarctic and the North Pacific fin whale, I compared the photometric records with the count by the naked eye, particularly for the young ear plug. Counting by two methods is made independently and checked each other. The comparison between two kinds of counting has not been clear until the compensation method of the photometric recording is devised. The all records on Figs. 15–19 are written by this devised method, through which every gradual change of colour on the bisected ear plug can be reproduced.

The traces on the sculpture of baleen plates was made through the improved apparatus by courtesy of Mr. Pike. The end of the record indicates the end of horny tubes in the plate existing in the more proximal portion than the gum line. From the sucking stage to the weaning stage, the trace is very smooth showing a characteristics in the early life of the whale. After weaning, the thickness of the plate

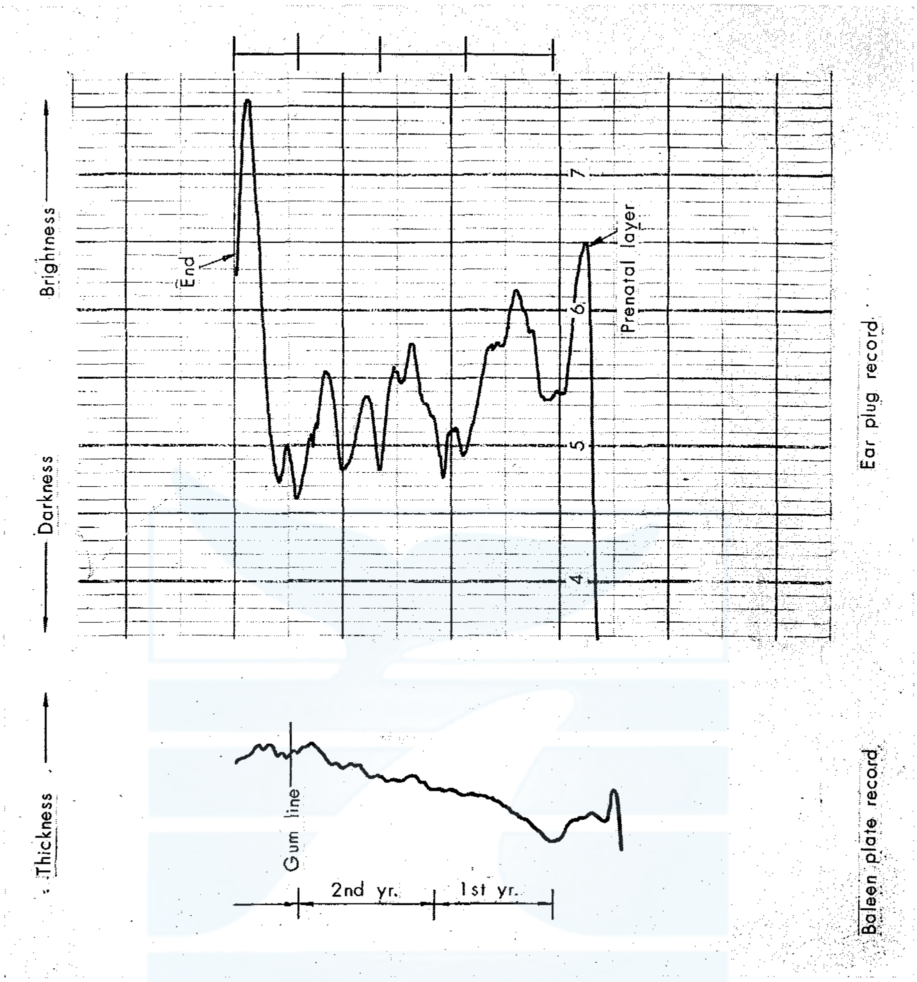

Fig. 19. The photometric record of the ear plug laminae against the record of the baleen plate sculpture. No. 7 fin whale . Core length of the ear plug is 4.6 mm and the length along the outer side of the baleen plate is 36.0 cm. Counts for both age characters are indicated.

undulates at fixed distance. Here, the count is made according to Mr. Pike's suggestion and written in Fig. 15–19. Two kinds of records deriving from different materials are contrasted by the way that both the neonatal mark and the end of records corresponds with each other. The photographs of bisected ear plugs from 5 very young fin whales are shown in Fig. 20. In the plates, there are comparisons between the photometric records and the baleen sculptures from 8 antarctic fin whales. The longest baleen plates from Nos. 10, 11, 12, 13, 14, 17, 18 and 19 whales have no neonatal mark and hence it is impossible to compare two kinds of records in the way applied for whales in the early life. When two undulating records are observed carefully, however, analogous patterns are found in the phase. If we arrange end

Fig. 20. Photographs of ear plugs from very young fin whales. Sample Nos. 2, 4 and 7 from the left of the upper. Sample Nos. 3 and 5 from the left of the lower.

points and suitable trough between two records, it is possible to find a correspondence between rhythmical waves deriving from different material. This interesting fact that at first was noticed in No. 13 records is applied for the other records and indicated in the plates. It is either difficult or nonsense to examine fine waves in two records, because not only the recording mechanism is different between the photometric method for the ear plug and the method measuring the thickness of the plate, but also records is more sensitive in the former than in the latter. The fact that the undulating similarity is found in the case arranging both the end of horny tube and the end of the ear plug, supports the finding that the thickness of horny layer is primarily related to age determined by the baleen plate. As metnitioned already, the fluctuating thickness of the horny layer affects the total thickness of the baleen plate. If the waving thickness of the cortical layer effects on the determined age, it is necessary to try to trace the plate till the end of cortical layer which is divided into two parts at the proximal end. (See Figs. 6 and 9). This try is impossible through the apparatus recording the thickness of plate and unnecessary for the age determination.

There is a slight discrepancy of phase between two records, since the last layer of ear plug is composed of the fresh keratinized or fatty degenerated cells deriving from the glove-finger epidermis and hence it shows the extraordinary thickness in comparison with the other layer formed in the past. Measuring the thickness of each lamina in the fin whale ear plug, Purves (1955, Tex-Fig. 2) reported such a extreme thickness in the last layer. Considering this resonable finding in the formation of the ear plug, the width of the photometric record for the last layer should be shorten. When this revision is applied for No. 11 record in the plates, we can interpret the discrepancy of phase at the end of two records. When this revision is applied for other records in the plates, the importance of the honry tube end is closed up in determining age through the baleen sculpture.

In the early life of the whale, particularly in the suckling and weanling stages, there is no clear similarity between two undulating records. It is difficult from records to discriminate and evaluate the smooth trace corresponding to the first lamination in the ear plug, however, the following estimation is helpful to do so.

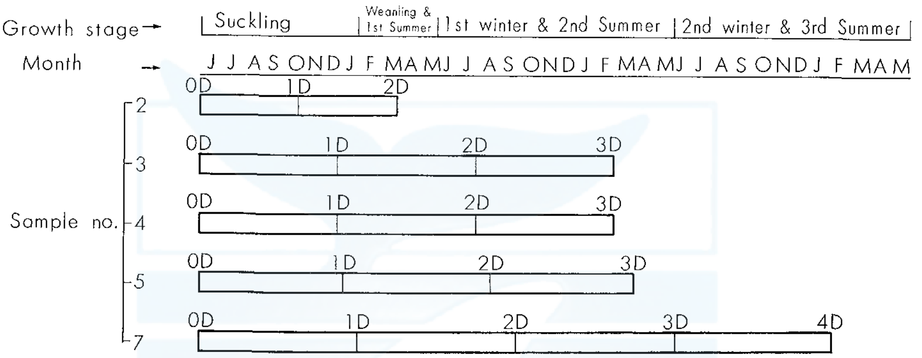

Fig. 21. Relationship between the growth of early life in the fin whale and the occurrence of dark layer in the ear plug. D: Peak of the dark layer formation.

In Fig. 21, the birth months for Nos. 2, 3, 4, 5 and 7 whales are arranged in the end of May. On the basis of both the age determined by the baleen plate sculpture and the captured month, the time when the last dark layer is formed is written. The peak of the dark layer formation is only given in the figure. Assuming that the formation of laminae in the ear plug is regular, the time when dark layers were formed in the past can be put down. Therefore, 0D indicates the birth time and 1D, 2D, 3D and 4D do the occurrence of the each dark layer after birth. According to this schematic figure, the 1st dark layer occurs from the end of October to the end of January for five specimens. As a mean, the peak formation of the 1st dark layer exists in the period from the end of December to the early of January. This means that the first lamina after birth is formed in the suckling stage. Laws and Purves (1956), examining ear plugs from very young fin whales taken in the coast of Norway, reported that the first lamination after birth was regarded as the combined nursing and first free feeding period in the life of whale, representing a total period of approximately one year. Although they do not give any comment on the formation of ear plug whether or not the dark layer is made just after birth, the estimation of one year is too long for the initial formation of laminae.

Besides it is estimated from Fig. 21 that the peak formation of the bright layer is present in different months except May and June, in the young stage of whale after weaning. This problem, probably concerning the feeding habit of the young fin whale, will be discussed later in this paper.

TABLE 6. COMPARISON BETWEEN THE AGE DETERMINED BY BALEEN PLATE SCULPTURE AND THE NUMBER OF EAR PLUG LAMINAE. DATA OBTAINED FROM 5 FIN WHALES FROM THE ANTARCTIC.

Sample No.	Age determined by baleen plate record (A)	Number of laminae in ear plug (B)	Period of one lamina formation (A/B)	Annual accumulation rate of ear plug laminae
	month		month	
2	10	2	5.0	2.4
3	21	3	7.0	1.7
4	21	3	7.0	1.7
5	22	3	7.3	1.6
7	32	4	8.0	1.5
Total	106	15	7.1	mean 1.7

TABLE 7. CORRESPONDENCE OF THE NUMBER OF LAMINAE IN THE EAR PLUG TO THE AGE DETERMINED BY THE BALEEN PLATE RECORD. DATA OBTAINED FROM 8 FIN WHALES FROM THE ANTARCTIC. (SEE PLATES.)

Sample No.	Number of lamine in ear plug	Age determined by baleen plate record	Correspondence		Annual accumulation rate of ear plug laminae (A/B)
			Number of laminae (A)	Number of age mark on baleen plate (B)	
19	3.0	3+	3	3	1.0
11	3.5	2+	2	2	1.0
18	3.5	3+	3	3	1.0
12	4.5	2+	3	2	1.5
17	4.5	2+	3	2	1.5
13	5.5	3+	2	2	1.0
10	6.5	2+	4	2	2.0
14	8.0	2+	2	1	2.0
					mean 1.4

The presence of the 1st bright layer during the sucking stage suggests a positive relation between the growth of whale body and the nutritious level. It is reasonable to think that the growth ratio of body in the fin whale decreases for a time after birth and at the weaning period, and that this trend is related to the change of food, as in the case of other mammals. Considering that the calf adapts itself to the mother's milk and shows the rapid growth in the early stage of suckling, the slope in the photometric record is interpreted. Generally speaking, the rising slope is steep while the falling slope is gentle in the first lamina of the photometric records (See Fig. 15–19). Accordingly, the peak occurrence of bright layer is not present in the middle between the neonal mark and the 1st trough of the compensated undulating record.

Through two kinds of records, it is possible to estimate the period of one lamina formation and annual accumulation rate of ear plug laminae. According to the growth stage, examined young whales are divided into two groups. Specimens in Table 6 has the neonatal mark on the tip of baleen plate while the neonatal mark is worn off in the blaeen plate of the specimens in Table 7. Although the ageing basis lies in the baleen sculpture in this examination, the method of estimation is slightly different between two groups. In Table 6, the age determined by the baleen sculpture is shown as the month age. In the early life of whale, the annual accumulation rate of ear plug laminae is larger than in the older whale. As a mean the ratio for the first group is 1.7 and 1.4 for the second group.

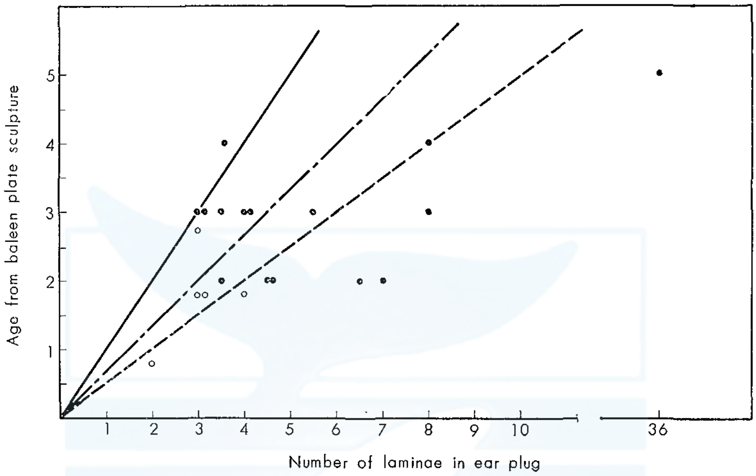

Fig. 22. Relation between the number of laminae in the ear plug and the age determined by baleen plate from 20 antarctic fin whales. Open circle: The prenatal mark remains on the tip of baleen plate. Closed circle: The tip of baleen plate was already worn and hence the age of whale exceeds the dotted position. Solid line: annual formation of laminae. Broken line: bianual formation of laminae. Chain line: 1.5 laminae formation per year.

The rate for the second group is estimated on the basis of the corresponding unit in two kinds of records. Since the ageing unit is entered respectively for the two kinds of records in the plates, it is easy to select the correspondence from them. This examination shows no rule that one laminae in the ear plug corresponds to one ridge on the baleen plate or two laminae do to one ridge. In particular, the value of the annual accumulation distributes widely for the first group.

The comparison between the age determined by the baleen plate and numbers of laminae in the ear plug is indicated for examined all specimens in Fig. 22. Open circles in the figure show the first group and closed circles include the second group. The tip of baleen plate begins to be worn off in the early life of the whale and there is no neonatal mark for the baleen over three ages.

When the same kind of figure is drawn by the data given by Laws and Purves (1956, Table 1), the distribution of each dot is agreeable with my finding. They have concluded that the laminae formation is biannual, although each dot distributes around both solid line (annual formation) and the broken line (biannual formation). Nishiwaki (1957) supported the biannual formation of laminae, comparing the baleen plate with ear plug laminae from the antarctic fin whale. On the other hand, Ohsumi (1964) emphasized extremely the correspondence of one lamina to one ridge of the plate, examing the North Pacific and the antarctic fin whales. I disagree with the regular formation of laminae throughout the life of whale. Open circles in Fig. 22 distribute along both the broken line and the solid line. Discrepancy from the conclusion by Laws and Purves, is derived from the interpretation of ageing by the baleen plate. There are controversies on the question when the tip of baleen plate begins to wear off. Utrecht (in Slijper, 1958) examined that the age determination was only reliable up to an age of four years and Nishiwaki (1957) also supported this finding. From the sculpture records in this paper, I disagree with Ruud's estimation that six to seven years will be represented on the baleen plate. The age estimated by him and colleague is only on the low side.

FORMATION TIME AND PERIOD OF EAR PLUG LAMINAE

It is essential to know when the alternation of the dark and bright layer occurs in the plug core, in order to examine whether or not the occurrence of layer is regular with advance of the whale age. I raised this problem as an approaching method to examine the increment rate of laminae. (Ichihara, 1959). It is impossible to determine the formation time and period of layers in the ear plug by means of the observation by the naked eye or the microscopic examination on the unstained material, because the last lamina under formation is very soft tissue indicating no clear border and its accumulated length is longer than that of the previous lamina. In the otolis and scale of fishes, the ratio of the length of the last ring under formation against the length of the previous ring is useful for the estimation of annual increment of ring. These age material belongs to the hard tissue as well as the tooth of the aquatic mammals. Ohsumi et al. (1963) estimated the annual accumulation rate of dentinal growth layer in the tooth of the sperm whale, adopting the same method, but it should be noted that there were a great variation among length of already formed layer. Sergeant (1962) presented the same method for estimating the annual increment of teeth layer in the Newfoundland pilot whale. For the careful examination, I developed the following method for the ear plug. Ear plugs collected from the flensed whale were preserved in 10% formalin solution and sent to our Institute. After the bisected specimens were presented to the counting by the naked eye, the proximal part of the ear plug-core was cut off as a small block. After then this block was longitudinally sliced in the frozen section in the thickness from 10 to 15 μ. These specimens were collected by myself in the 1961/62 whaling season in the Antarctic and hence they could be preserved as perfectly as possible. For the present purpose, the preservation of the proximal end in the ear plug was essential. Sectioned tissues from 857 fin whale were stained by SUDAN III and partly by Haematoxylin and Eosin. The fatty degenerated cell layer was stained by SUDAN III and the keratinized cell layer by Eosin. As the histological structure of the ear plug has been clarified in my paper (1959), I don't repeat it here. At first, I used Haematoxylin-Eosin together with SUDAN III for the continuous sections from the

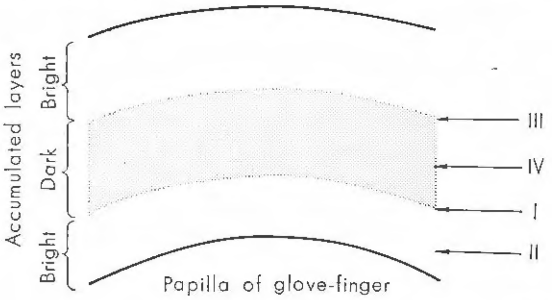

Fig. 23. Diagram indicating the progressive stages in degeneration of the epidermal cells at the base of ear plug. Each stage was determined at the most proximal end of ear plug.

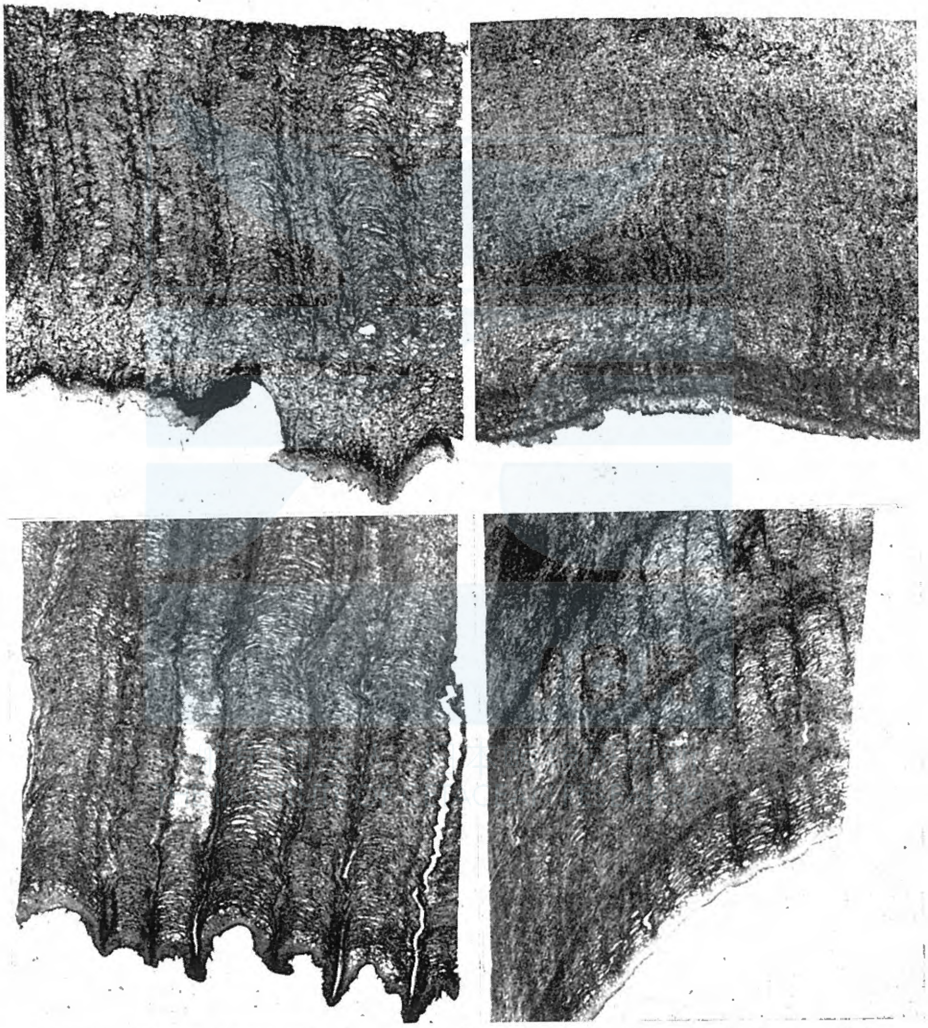

Fig. 24. Progressive stages in the ear-plug base of the fin whale. Each photograph indicates the frozen section stained by SUDAN III. Black parts show bright layers and the most proximal part do the glove-finger epidermis. From the upper left to the right: I and and II stages. From the lower left to the right: III and IV stages.

same ear plug. As the result, however, only SUDAN III staining, was enough to examine the state of base of the ear plug. As the aim of this examination principally lies in observing the degenerated cell above the basal layer of the glove-finger epidermis, I classified the progressive degenerations into several stages and examined what kind of stages the present degeneration corresponded to. Fig. 23 is a diagram showing kinds of stages to be determined and Fig. 24 indicates the photograph of the ear plug base stained by SUDAN III.

Discrimination of each stage needs the presence of the epidermis of the glove-finger from which the tissue of the plug-core is derived. Confirming the presence of the epidermis at the base of the stained ear plug, I selected 464 specimens (54.1%) from 857 samples. The shadowgraph of 20x or 50x was used for this examination.

Four stages from I to IV are divided into further four stages by the help of the following idea. The peak occurrence of the bright layer, stained by SUDAN III is in stage II while that of the dark layer is in stage IV. Observation on cells under degeneration at the germinal layer supports this finding. The germinal layer is fully occupied by the fatty degenerated cells in stage II, on the other hand, by the keratinized cells in stage IV. Two kinds of degenerated cells occurs at 50 percentage level in both stages I and III, judging from the shadowgraphic observation. It is permissible to draw Fig. 25 on the basis of such a histological examination.

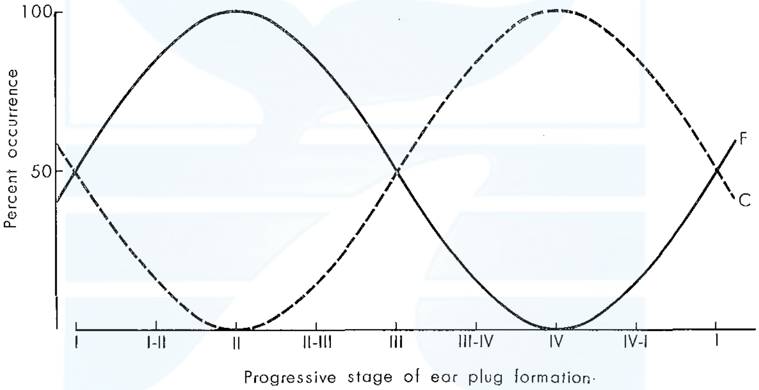

Fig. 25. Occurrence of the fatty degenerated cells (F) and the keratinized cells (C) at each stages in the germinal layer of the glove-finger epidermis.

In addition to 464 specimens from the pelagic whaling, 35 specimens from the South Georgia whaling also were examined in the same way. The material from the Japanese pelagic whaling were collected from Dec. 12 to the end of March in Area III (0°–70°E), therefore, they covered about 4 month by periods in the antarctic summer. The material from South Georgia were taken from the sexually immature fin whales captured between Oct. 1 and Dec. 8 in 1964. Although the size of South Georgia sample is scarce, the aggregated material amounts to 176 ear plugs from the sexually immature whales captured during 6 monthly periods from October to March. A slight anxiety remains for the sampling from the different races existing in the population of the antarctic fin whale (Brown, 1954, 1962), however, it is permissible if the material from the pelagic whaling is examined with reference to the material from South Georgia.

By the light penetrating the material through the shadowgraph apparatus, the proximal end of all meterial was classified into 8 stages.

Table 8 shows the monthly percentage frequencies at each stage, for the ear plug from 141 immature fin whales taken by the pelagic whaling. In tabulation,

TABLE 8. PERCENTAGE FREQUENCIES BY MONTH OF DEGENERATING STAGES IN THE BASE OF EAR PLUG. SEXUALLY IMMATURE MALE AND FEMALE FIN WHALES FROM THE ANTARCTIC.

Stage	Dec.	Jan.	Feb.	Mar.
III	0			
III-IV	8.1	0		
IV	5.4	8.6		
IV-I	21.6	8.6	0	0
I	8.1	2.9	3.4	15.0
I-II	13.5	14.3	6.9	17.5
II	13.5	22.9	24.2	17.5
II-III	21.7	22.9	3.4	10.0
III	8.1	20.1	6.9	12.5
III-IV	0	0	20.7	0
IV			13.8	22.5
IV-I			20.7	5.0
I			0	0
Total	100.0	100.0	100.0	100.0
Size of sample	37	35	29	40

TABLE 9. PERCENTAGE FREQUENCY BY MONTH OF DEGENERATING STAGES IN THE BASE OF EAR PLUG. SEXUALLY MATURE MALE AND FEMALE FIN WHALES FROM THE ANTARCTIC

	Male				Female			
Stage	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.
III								
III-IV	0	0			0	0		
IV	5.3	2.7	0		7.4	6.8	0	0
IV-I	21.1	2.7	5.1	0	14.8	9.1	11.3	14.3
I	10.5	18.9	20.5	8.7	18.5	15.9	16.1	12.2
I-II	26.2	16.2	10.3	17.4	18.5	20.5	17.7	8.2
II	10.5	29.8	20.5	21.8	18.5	31.8	27.4	26.5
II-III	15.8	18.9	20.5	13.1	22.3	9.1	9.7	20.4
III	5.3	10.8	12.9	6.5	0	6.8	9.7	8.2
III-IV	5.3	0	5.1	4.3		0	4.8	2.0
IV	0		5.1	15.2			3.2	8.2
IV-I			0	13.0			0	0
I				0				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Size of Sample	19	37	39	46	27	44	62	49

the gradual advance of stage with the passage of time was taken into account. For the mature whale as well as for the immature whale, the similar tabulation is practised in Table 9, based on 141 males and 182 females taken by the pelagic whaling.

From the basic figures in these tables, Figs. 26, 27 & 28 are presented. The black portion in these figures indicates the occurrence of the dark layer under formation and the white portion does that of the bright layer under formation in the proximal end of the ear plug. There is the characteristic bimodal peak for the immature group, while there is the unimodal peak rather than otherwise for the mature group. The frequent occurrence of the dark layer in the South Georgia specimens supports such a feature in the immature group. In the early summer of the Antarctic, the occurrence of the dark layer is predominant but the bright layer is frequently present during December and January and the dark layer is frequent in February again.

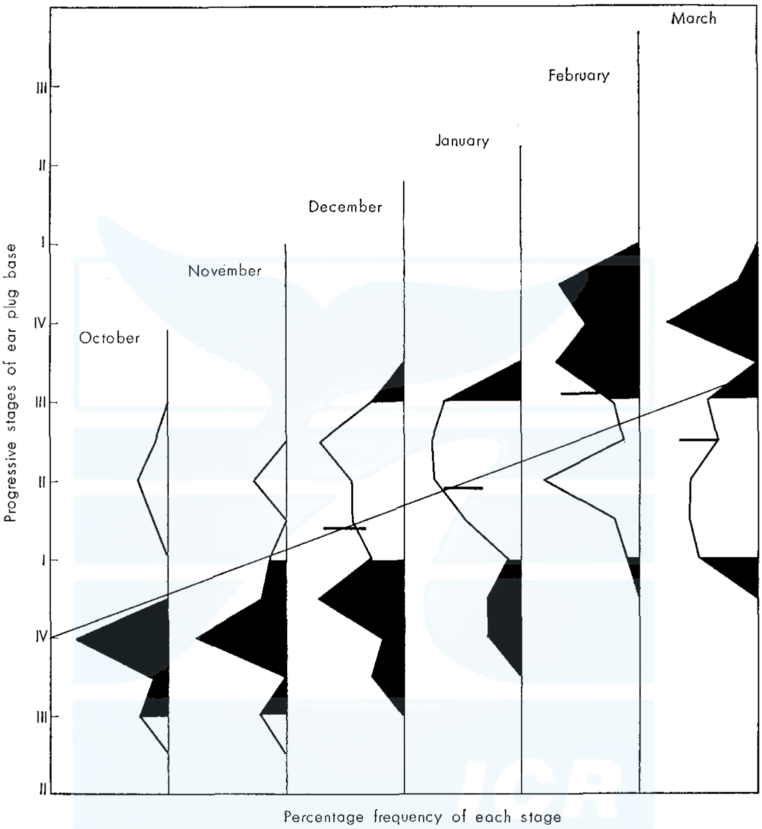

Fig. 26. Monthly degenerating stages of epidermal cells in the ear plug base. Male and female whales of sexual immaturity from the Antarctic.

The samples from March do not fall in this progressive trend from October to February. It is presumable that the catch of March belongs to the different population of the fin whale from the population captured from December to February. Examining the blood type frequency of the antarctic fin whale, Fujino (1964) has reported that whales of the Atlantic population disperse eastwards to area III (0°–70°E) and that whales of the West Indian population migrate westwards to the east-half of Area II (0°–60°W). I collected the blood samples from the fin whales captured by our fleet from the opening of the whaling to the end of February but failed to take samples in March because of lack in sampling bottle. Dr. Fujino informed me in the personal communication that whales examined by me from December to February belongs to the West Indian population. The captured fin whale in March in the west-half of Area III shows different thickness

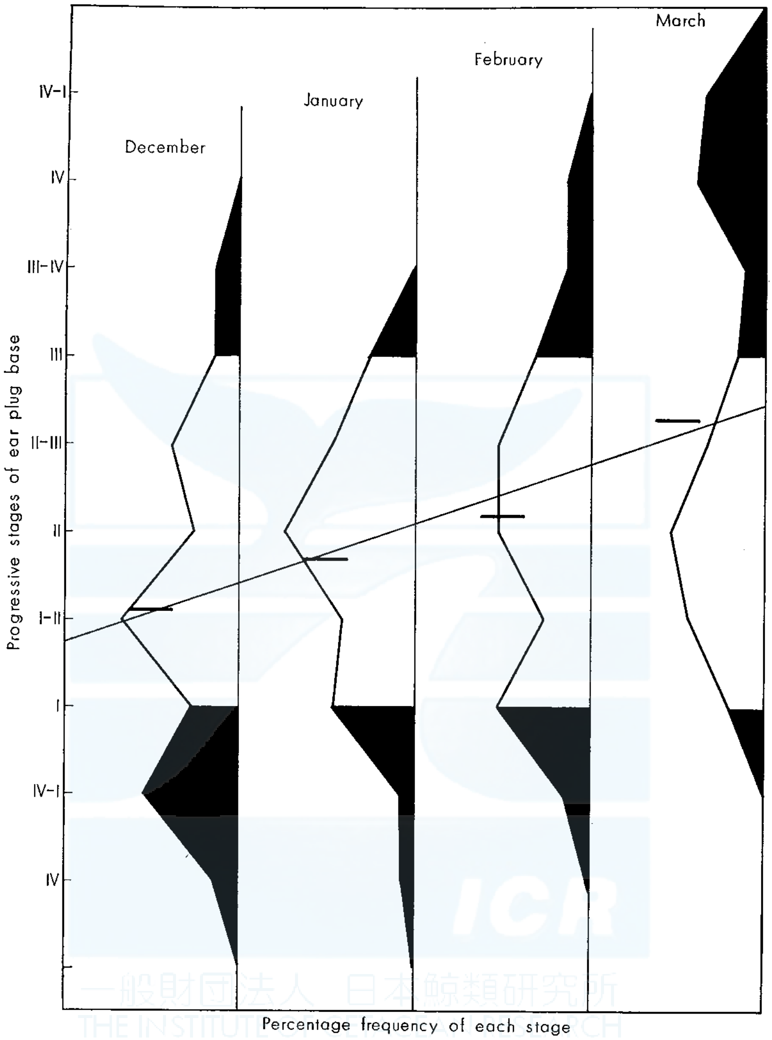

Fig. 27. Monthly degenerating stages of epidermal cells in the ear plug base. Male fin whales of sexual maturity from the Antarctic.

of blubber from that of December-February whale. The blood samples from the other Japanese fleet operating in the same time and locality shows that March whale belongs to the Atlantic population.

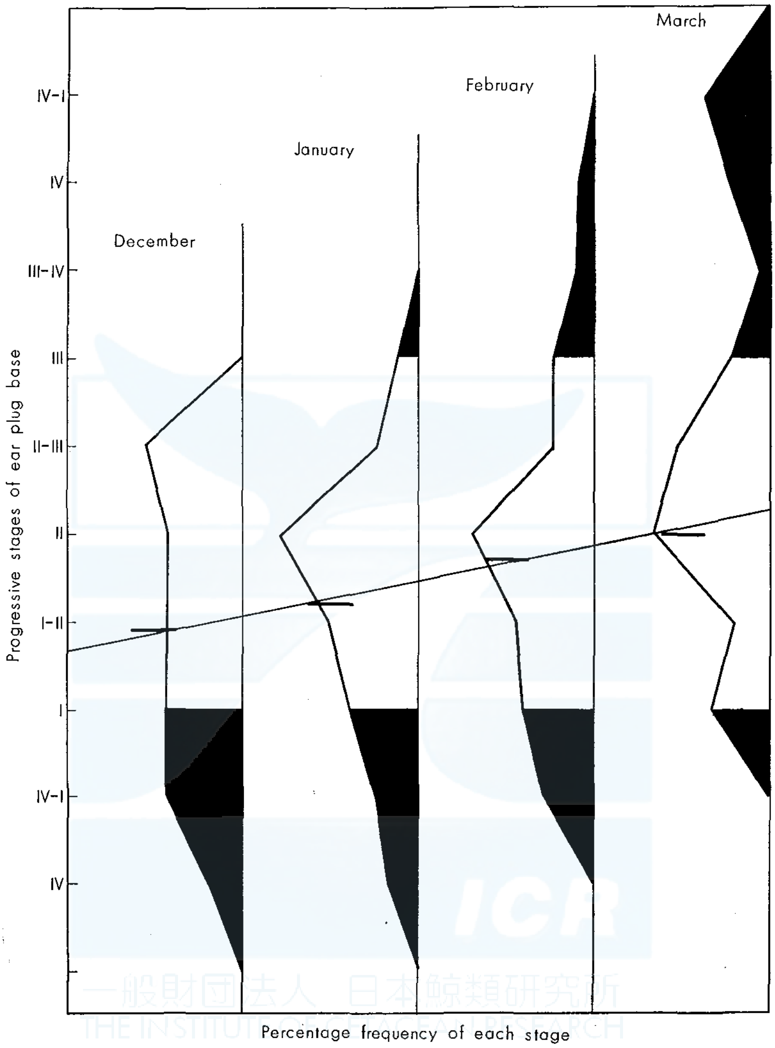

Fig. 28. Monthly degenerating stages of epidermal cells in the ear plug base. Females of sexual maturity from the Antarctic.

Mean stages for each month are indicated in Figs. 26, 27 & 28 and the mean growth of stage also is shown in the straight line. Although it is estimated that the growth ratio of layers is not constant but sigmoid with advance of time, it is approximated by the straight line.

In the mature group, there is the predominant occurrence of the bright layer from December to March and the growth of layers is slower than that in the immature group. From the growth ratio indicated in figures, the formation period of the bright layer is estimated for each group. The bright layer is formed during stage I—III with the peak of stage II. The formation period is 4.0 months for the immature group, 5.3 months for the mature male and 7.8 months for the mature female. The mean formation period is 6.0 months for the mature group including both sexes as shown in Table 10. These values are obtained by drawing the graph for each group.

The same graphic method is applied for 5 age group; under 10, 11–20, 21–30, 31–40 and over 41 in the number of laminae of the ear plugs. Counting laminae by the naked eye and by the photometric record was made before sectioning. Grouping by 10 laminae is helpful to examine the change of the formation periods with the increasing age of whale. Fin whales attain the sexual maturity at about 10 laminae in the ear plug and the physical maturity at 40–45 laminae in the ear plug (Nishiwaki, Ichihara & Ohsumi, 1958., Ohsumi, 1964).

TABLE 10. FORMATION PERIOD AND TIME OF THE BRIGHT LAYER IN THE EAR PLUG OF THE ANTARCTIC FIN WHALE.

	Advancing whale age	Formation period of bright layer (Months)	Month of peak occurrence of bright layer
Number of ear plug laminae	<10	4.0	Middle January
	11–20	6.0	Early February
	21–30	5.3	Early February
	31–40	7.5	Early March
	>41	6.4	Middle March
Sexual class	Immature male and female	4.0	Middle January
	Mature male	5.3	Late January
	Mature female	7.8	Middle March
	All mature	6.0	Middle February

The formation period of the bright layer is estimated to be 4.0, 6.0, 5.3, 7.5 and 6.4 months for respective age group and there is no increasing trend in the age group over 10 laminae. The mean occurrence of stage II indicating the maximum fatty degeneration is from January to March and it slightly advances with the increase of the whale age.

Fig. 26 indicates the shift of degenerated stages with advance of month. The lower mode of the dark layer gradually changes to the mode of the bright layer with the passage of month. On the contrary, another mode of the bright layer shifts to the mode of the dark layer. It is interesting that two different layers occurs for the immature group during 6 months. For the mature group, the bright layer occurs mainly in the antarctic summer. Taking into consideration that the bright layer is formed during 6 months and its pattern of occurrence is almost constant every year, the dark layer is formed during another 6 months for the mature group. From this fact, it is reasonable to think that the formation of lamina is annual for the mature fin whale. As there is a slight difference in the peak occurrence of the bright layer with the increasing age of the whale, the periodic formation is indicated in the diagram of Fig. 29. This diagram suggests that the bright layer is related to the feeding migration while the dark layer is related to the breeding migration of the fin whale.

For the immature group, the occurrence of two layers is irregular compared with the mature group. Whether or not the bimodal distribution is maintained during a year, is not concluded here because of lack in samples for the unexamined months. The graphic method suggests that the mean formation period of a lamina is 8 months and hence the annual increment is 1.5 lamination. This result is compatible with my findings obtained from the relation between the records of baleen plate and the photometric records of ear plugs. Both records has been already given to immature whales.

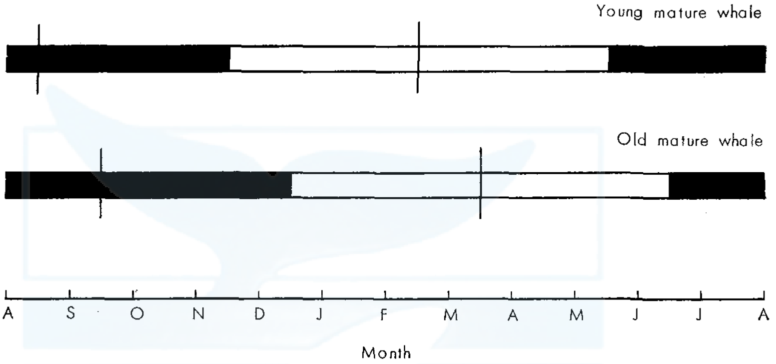

Fig. 29. Diagrammatic occurrence of bright and dark layers in the ear plug from the sexually mature fin whales in the Antarctic. Old mature whales include animals over 41 laminations.
White portion (fatty degenerated layer). Black portion (keratinized layer).

The relationship of the bright layer to the feeding stimulus will be discussed later in this paper. As a migratory rule of fin whale, older whales arrive earlier in the feeding area than younger whales (Wheeler, 1930., Laws 1961). Although there is a reverse trend in the peak occurrence of bright layer, it seems that the internal stimuli for the occurrence of bright layer is different among age groups and that the reaction of epidermal cell is more sensitive in the young whale than in the old whale.

MITOTIC ACTIVITY IN RELATION TO INCREMENT OF LAMINAE

Tissue cells generally reproduce by mitotic division and the epidermal cell belongs to the same category. It is pointed that the rapidly proliferating epidermis, as in psoriasis and other skin diseases, usually shows neumerous mitosis. Pinkus (1954, p. 586–589) stated on the reproduction by the mitotic division in the human epidermis as follows.

A fully keratinized human epidermal cell is a thin flake with a diametre of from 25 to 30 μ. A basal cell is a cuboidal or columnar body, with a diametre of

5–6 μ. Accordingly, the area of 625–900 μ^2 covered by one horny cell on the surface is occupied by 25 basal cells, each having a basal area of 25–36 μ^2. This figure does not take into account that the rate ridges and papillae increase the basal area of the epidermis several times over what it would be if the cells were arranged in one plane. As the upper surface of the epidermis is more nearly plane, the ratio of basal cells over keratin cells is increased considerably. If the duration of mitosis is 1 hour, then it follows that $1/(25\times24)$ or 1 out of every 600 basal cells, has to be found in mitosis at any given time (mitotic index or number of dividing cells per thousand cells is 1.67) in order to replace one horny flake per day under the most unfavorable theoretical circumstances. This theoretical value agrees well with actual observation in adequately preserved material. The actual observation was made by Thuringer (1928) and etc. Sutton (1938) found the renewal time of the stratum corneum, using silver nitrate and observing the disappearance of the stain. Von Volkmann (1950) found the renwal time of the human skin, pricking India ink into the epidermis and watching the gradual disappearance of the ink.

It is impossible to practise the direct experiment on the whale epidermis and to observe the duration of mitosis. However, Pinkus' theory can be applied for estimating the mitotic activity of the glove-finger epidermis, if the size of examined cell can be measured. I reported that the size of keratinized cells is larger than that of the fatty degenerated cells (Ichihara, 1959). The difference of size appears above the germinal layer in which the cell division is observed. The keratinized cell, stained densely by Eosin, is the fusiform and on the other hand the fatty degenerated cell, stained well by SUDAN III is the round form. A mass of fatty degernated cell constitutes the concentric bright layer as well as the longitudinal bright layer in the ear plug. Three kinds of layers are derived from the degeneration of cells in the basal layer of the glove-finger epidermis. As the cell division is active in the glove-finger epidermis, the degenerated cell is remarkably accumulated outwards and continues to form the core of ear plug from the latter half of foetal stage. In the fin whale, the accumulation of keratinized cells begins at the $6^1/_2$ foetal months and it is followed by the fatty degeneration which arises at 8th foetal months and continues to progress until birh (Ichihara, 1964).

In the stained germinal layer of the glove-finger epidermis, sizes of cells were measured by the ocular micrometre and shown in Table 11. For the measurements, cells which are appeared to be cut the centre approximately were chosen. The size of keratinized cell is given as a mean of the major and minor axis, because of the elliptic or fusiform cell. Fujita (1947) examined the effect of the embedding method to the measurement of the cell size and pointed that the size of renal corpuscle was slightly larger for the celloidin section than for the frozen section. Although the present foetal samples are obtained as the celloidin section and the postnatal samples are given as the frozen section, it does not seem that the measurements effects intensively to the final results, because the diametre of epidermal cell is extremetry small compared with the size of renal corpuscle examined by Fujita.

Although the size of sample is scarce for the prenatal stage, the mean diametre of cell indicates the same value in both the fatty degeneration and the keratinization. In the postnatal stage, the size of sample is enough and composed of various ages. The mean diametre of keratinized cell is 49.3 μ while that of the fatty degenerated cell is 28.5 μ. The mean cell diametre of the basal layer is slightly larger in the postnatal life than in the prenatal life. From the square of the mean diametre, the ratio of the area occupied by three kinds of cells is calculated and given in Table 11. According to Pinkus' theory, the mitosis is more active in the prenatal epidermis than in the postnatal epidermis. In the epidermis after birth, the cell division is very active for the period of the fatty degeneration and there is three times proliferation than for the period of keratinization. The difference in the activity between two kinds of layers is very important to interpret the formation of ear plug.

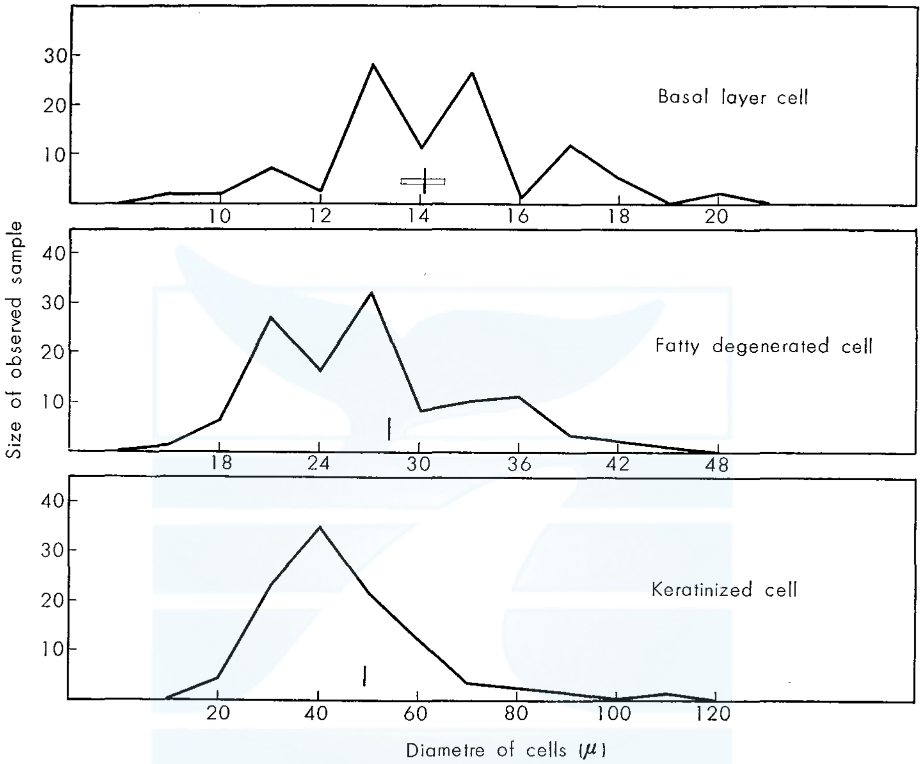

Fig. 30. Comparison of the cell size to examine the relative mitotic speed in the epidermis of the glove-finger. The cell sizes of the basal layer, under fatty degeneration and under keratitinization were measured. Mean sizes are indicated for three kinds of cell and two standard errors for the basal layer cell.

The size distribution of the cell diametre is indicated in Fig. 30 for the postnatal sample. While it is a normal distribution for the basal layer cell, it is positively skewed for the degenerated cell. For the keratinized cell, the skewness of the size distribution is more intensive than for the fatty degenerated cell. The mean diametre and two standard errors are indicated for the distribution of basal cell.

The skewness is related the age composition of sample. Fig. 31 indicates the relation between the cell size of glove-finger epidermis and the increasing age of the fin whale. As counting laminae already has been made for the examined specimens, it is possible to check the change of cell size with advance of the whale age.

TABLE 11. COMPARISON AMONG CELL SIZES OF THE GLOVE-FINGER EPIDERMIS, FROM THE FOETUS TO THE ADULT IN THE ANTARCTIC FIN WHALE

A) Prenatal life

Classification of cell	Sample size	Mean diametre of cell (μ)	Ratio of cell area
Basal layer	12	11.8	1
Fatty degeneration	24	19.5	3
Keratinization	17	19.5	3

B) Postnatal life

Classification of cell	Sample size	Mean diametre of cell (μ)	Ratio of cell area
Basal layer	100	14.1	1
Fatty degeneration	117	28.5	4
Keratinization	102	49.3	12

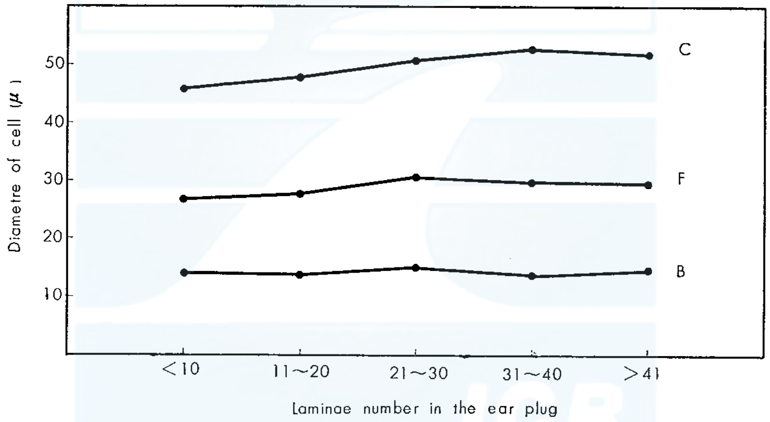

Fig. 31. Relation between the cell size of glove-finger epidermis and the advancing age of the fin whale.
C: Keratinized cell, F: Fatty degenerated cell, B: Basal layer cell of the epidermis.

Samples are grouped at each 10 laminae and the mean diametre of cell is plotted for each age group. The diametre of the basal cell (14.1 μ) is constant in spite of the advancing age, on the other hand, there is a trend that the diametre of the degenerated cell increases with the passage of the whale life. Compared with the fatty degenerated cell, the increasing tendency is remarkable in the keratinized cell. If the intensive catch is taxed at random on the population of the fin whale, most of catch is occupied by the young fin whale. About 50 percentage of the sample consists of individuals under 20 laminations. The measured size of cells is arranged for each age group and tablulated in Table 12.

If a constant mitotic activity is maintained for the degeneration of the same quality and hence the duration of the mitosis is constant in such degeneration throughout the life of whale, the relative growth of layer at a constant period is estimated. Of course, the mitotic activity of the keratinization differs from that of the fatty degeneration, therefore, it is necessary to assume two kinds of mitotic activities. In the final stage of the fatty degeneration, granules of lipoids in the cytoplasm overflow to destroy the original form of cell. Accumulated soft granules of lipoid is apt to be effected by the outward pressure which the newly proliferating cell gives. It is reasonable to examine seperately the different degeneration; the bright layer and the dark layer in the ear plug.

TABLE 12. THE CELL SIZE (μ) OF THE GLOVE-FINGER EPIDERMIS IN SEVERAL AGE GROUPS AFTER BIRTH

Classification of cell	Latter-half of foetal stage	Range of lamination number in ear plug after birth				
		1–10	11–20	21–30	31–40	41–
Basal layer (B)	11.8	14.1	14.1	14.1	14.1	14.1
Keratinized cell (C)	19.5	45.7	47.7	50.6	52.8	51.8
Fatty degenerated cell (F)	19.5	26.9	27.1	30.2	29.6	29.3

TABLE 13. THE RELATIVE ACCUMULATION SPEED OF TWO LAYERS IN THE EAR PLUG. THE VALUE IS GIVEN BY THE THEORETICAL BASIS.

	Latter-half of foetal stage	Range of lamination number in ear plug after birth				
		1–10	11–20	21–30	31–40	41–
B2/C	7.14	4.35	4.17	3.93	3.77	3.84
B2/F	7.14	7.39	7.34	6.58	6.71	6.79

When the diametre of the basal cell is B and the diametre of the keratinized cell is C, the ratio of the area occupied by the keratinized cell against the area by the basal cell is B^2/C^2. This relative mitotic activity is obtained from the value for each age group of Table 12. As B is constant throughout the life of whale, the relative mitotic activity decreases with the increasing age of whale. Under the present condition, the accumulated length of horny flake is proportional to B^2/C^2. On the other hand, the accumulated length is proportional to the size of one horny flake (C). Accordingly, the next formula is obtainable.

$$L = k\,B^2/C^2 \cdot C \cdot t$$

where L is the accumulated length of the horny flake during t time and k is a coefficient. When t is constant, L is expressed by the value of B^2/C as indicated in Table 13.

By the same method, the accumulated length of fatty layer is obtained in Table 13. These values seem to indicate the relative speed of accumulation. When the speed of the latter half of foetal stage is 100, several speeds for each age group are given and compared with each other. These relative speeds of accumulation are plotted in the semilogarithmic scale of Fig. 32. Individuals of the range from 1 to 10 laminae represents the sexually immature whale and individuals over 41 laminae represent the physically mature whale.

For the fatty degeneration, the value distributes around the standard level of the latter half of foetal stage and there is no remarkable change with advance of the whale age. Compared with older age over 31 laminations, the accumulation during a constant period is more speedy in the younger age under 20 laminations.

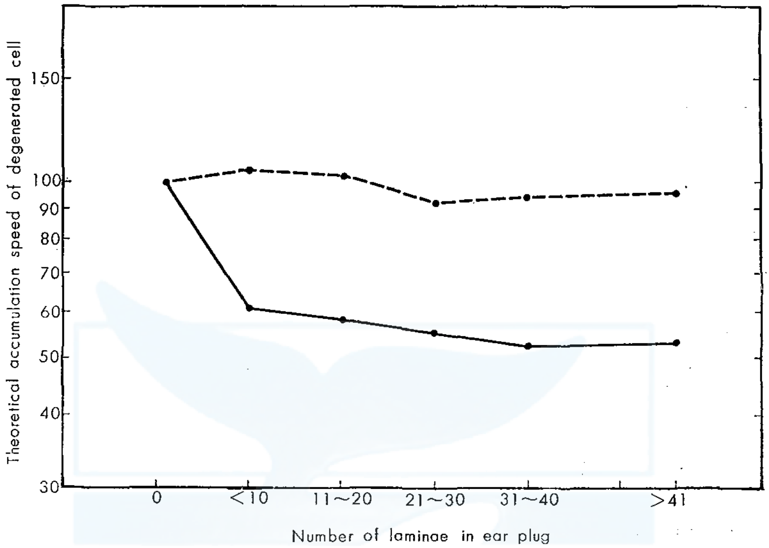

Fig. 32. The relative speed of accumulation of two layers in the fin whale ear plug.
Dotted line for the fatty degenerated (bright) layer.
Solid line for the keratinized (dark) layer.

For the keratinization, the value has a decreasing trendency with the increasing age of whale. In detail, it is represented by three steps; the immature group under 10 laminae, the young mature group from 21 to 40 laminae and the old mature group over 41 laminae indicating physically mature individuals. As the sample size for the last group is scarce, the definite findings is not obtained. It is safte to say, however, that in a constant period the keratinized layer is more rapidly accumulated for the immature group than for the mature group, and hence that the accumulation rate is different between age groups. It should be regarded that the fatty degeneration is not taken into account in this examination. There is a constant decreasing trend for the young mature group and the value again rises slightly for the old mature group. Examing the formation period of dark layer in the previous chapter, I concluded that it takes 6 months as a mean for the mature group. A constant rate of decreasing for the young mature group in Fig. 32 supports this conclusion. On the other hand, the steep slope of the immature group can not be explained by the constant accumulation rate from birth to young mature class. The slight increase of the accumulation rate after physical maturity which results from the theoretical base is discrepant from my examination in the previous chapter. According to the previous chapter, the formation period of dark layer is estimated to be 6 months and constant for the all mature group. Fig. 32, however, suggests the possible change of the accumulation rate in the old mature group. It is necessary to check this discrepancy on the basis of large samples in the future. Through the theory of the mitotic activity in the epidermal cell, I examined the accumulation rate of separate two components in the ear plug. The structure of the ear plug is not so simple as considered here but the pursuit for the mitotic activity supports the findings that the annual increment rate of laminae is not always constant throughout the life of the whale and it is closely related to the growing stage of the fin whale.

FACTORS AFFECTING THE FORMATION OF EAR PLUG LAMINAE

In the ear plug the alternation of two different layers is gradual, and the occurrence of the bright layer and the dark layer is comparatively periodical for the sexually mature whale. The gradual alternation was examined by the photometric record and applied for examining the formation period of the ear plug layer. In the previous paper (Ichihara, 1959), I have briefly concluded that the degeneration of the epidermal cells in glove-finger arises in response to many factors related to the metabolism of whale body and that the effect of hormone and enzyme on the epidermis are regarded primarily. Examining the foetal ear plug which has an alternation of the dark and bright layer, I presented my opinion that it is the most reasonable to accept the endocrinal stimulus through the blood supply from the maternal body. Reexamining these hypotheses to some degree, the factors affecting the formation of ear plug layer is discussed. The final conclusion should be examined by the tissue culture or the direct experiment to the tissue of the glove-finger. Since my material is lacking in the specimens in the major breeding season of the fin whale that exists in other months than the season of the antarctic whaling, the endocrinological examination is difficult. If there is any analogous epidermis in other animals, approaching ideas would be applied for the ear plug. I have looked for the analogous epidermis but can never find tissues like glove-finger epidermis which raises the fatty degeneration in some periods and keratinization in other periods. In this meaning, the glove-finger of the baleen whale has an unique tissue.

By classifying the degenerating stages of the epidermis in the maternal glove-finger, the relation of the ear plug layer between the mother and foetus is examined. I had already pointed that the keratinization in the epidermal cells of the glove-finger appears at the 61/2 foetal month of the fin whale and that the fatty degeneration occurs after the 8th foetal months. The ear plugs of mother whales, having the large foetuses over the 6th months from fertilization are classified from I to IV stage and compared with the ear plugs from the foetuses. The reasonable growth curve of the fin whale foetus, indicated by Laws (1959) is applied to determine the foetal month of my sample. Fig. 33 shows the occurrence of the progressive stage of the maternal ear plug, grouping into two classes. In the upper of figure the percentage frequency at each stage is indicated for the mother of the 6th and 7th pregnancy months and for that from 8th to 10th pregnancy months in the lower. As there is no difference in the distribution of stage between two classes, it is concluded that the formation of the foetal layers is independent of that of the maternal layers and probably related to the growth of foetus.

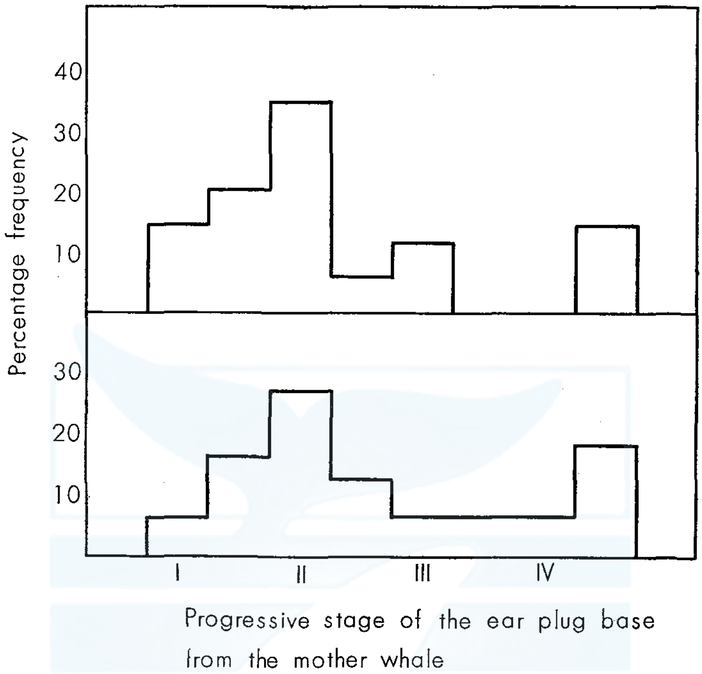

Fig. 33. Occurrence of the progressive stage of the ear plug base in the mother fin whale gestating the large foetus.
Upper: for the whale in 6th and 7th months of pregnancy.
Lower: for the whale from 8th to 10th months of pregnancy.

Ohsumi (1960) examined the relative growth of the external parts of the antarctic fin whale foetus and classified it into 4 stages; 10–30, 30–115, 115–300 and 300–650 cm of the length. According to Laws' growth curve for the fin whale foetus, 115 cm in the foetal length corresponds to the $6^1/_2$ pregnancy month and 300 cm to the end of the 9th pregnancy months. The latter half of Laws' growth curve well fits for straight lines on the semilogarithmic scale but the foetal growth ratio from the 8th pregnancy months to birth is more rapid than under the 8th month. These two findings suggest that the fatty degeneration of the foetal epidermis is related to the growth of foetus although there is no difference in the size of degenerated cells between the keratinization and the fatty degeneration (See Table 12). No difference of the cell size seems to indicate a delicate relationship between the keratinization and the fatty degeneration in the epidermal cell of the glove-finger. In the adult whale, the keratinized cell has a three times area than the fatty degenerated cell. The fatty degeneration, therefore, seems to be a transformed cornification of the epidermal cell. On the basis of the histological examination I previously showed that the longitudinal bright layer exists always between two projected papillae of the corium in the glove-finger and that no presence of such a longitudinal layer in the foetal stage besides its vague presence in the juvenile whale. The longitudinal layer is clear with the projection of papillae which occurs with advance of the whale age. The pressure of proliferating epidermal cells from the side of projected papillae inhibits the developing size of degenerated cell, inducing the fatty degeneration. Such a physical force as well as the internal physiological stimuli are essential to interpret the structure of ear plug.

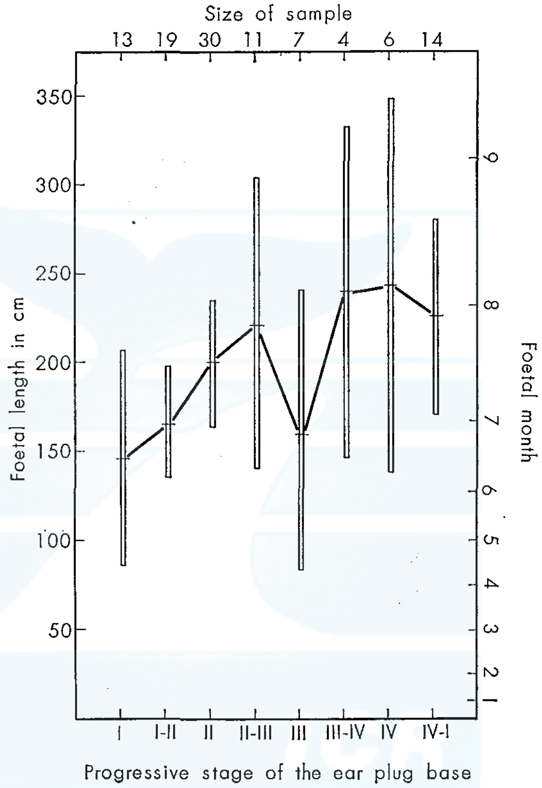

Fig. 34. Relationship of the foetal length against the progressive stage of the ear plug base of the mother whale. Mean length and two standard errors are indicated for the fin whale from the Antarctic.

In Fig. 34, the mean length of foetuses and two standard errors are indicated for each stage of maternal ear plugs. This figure is drawn on the basis of 104 pregnant females. There is a trend that the foetal length increases with the progress of ear plug stage in the mother. Stages from I to II composed of comparatively large sample is present after the 4th foetal months. It is estimated that 77% of the antarctic fin whale foetuses are conceived in the 5 monthly period between April and August and the mean date of conception is the early in June (Laws, 1961). It will be estimated that stage I indicating the alternetion from the dark layer to the bright layer in the pregnant female arises in the periods except the major breeding season. Stages I-III represent the bright layer and stages III-IV do the dark layer in the ear plug.

In the experimental work, administration of estrogens has a profound effect on the life-processes of epithelial tissues in both sexes. In squamous stratified epithelium, there is enhanced proliferation, keratinization, and desquamation. In the skin proper, the increased epithelial proliferation, cornification, and desquamation in response to estrogen were observed in the rhesus monkey (Zuckermann, 1940) on the nape of the neck, over the crown of the head, and to a lesser degree, over the upper part of the nose, in addition to the perigenital areas.

Vitamin A as well as estrogen affects the germinative cells of the epithelium and modifies keratinization indirectly. Vitamin A, essentially, inhibits the differentiation of stratified squamous epithelium (Moritz, 1943) and therefore becomes an " antikeratinizing " factor (Harris, Irmes and Griffith, 1932). The reverse " keratinizing effect " of Vitamin A deficiency was reviewed by Wolbach and Bessey (1942). To the contrary, excess of vitamin A hinders the normal development of stratified epithelium. The keratinization is an intrinsic feature of the life-cycle of epidermal cells.

Depressed mitotic activity in the epidermis may cause a decrease in the rate of cell loss. Bullough and Ebling (1952) reported that in adult male mice, maintained on calorically inadequate diets over a 4 week period, epidermal mitotic activity was depressed to 25 per cent of normal without noticeable atrophy resulting.

These experiments for other animals is helpful to interpret the keratinization and the fatty degeneration in the glove-finger epidermis of the baleen whale. The mitosis is very active in the latter degeneration. Fisher, Kon and Thompson (1952, 1962) examined the content Vitamin A in marine crustacea and reported that the free-swimming euphausiids contains high concentrations of preformed vitamin A in addition to large quantities of astaxanthin. The eyes of the euphausiids containes over 90 percentage of their total Vitamin A. *Euphausia superba* is the main food of the fin whale migrating to the antarctic region (Marr, 1962). The Japanese factory ship that I was on board in the 1961/62 season extracted Vitamin A from the whale liver. The mean value of Vitamin A content was about 8×10^4 IU/kg/BWU in the fin whale migrating to Area III. Vitamin A content of the whale liver depends on the physiological conditions of the whale body and indicates low values for the lactating whale and the immature whales, however, it is reasonable to think in general that the content of vitamin A increases with advance of feeding in the Antarctic area and decreases in the major breeding season in the low latitude area. The Union whaling Co. at Durban informed me no data on Vitamin A content in the liver of the fin whale captured in the coast of South Africa.

Mackintosh (1942) and Laws (1961) summarized many direct and indirect evidences on the seasonal migration of fin whales. These indicate the bulk of the population spends the winter months in lower latitudes and the summer in the

Antarctic. Brown (1957) has reported that 'not all rorquals go south for the southern summer and it may be that more than was thought either miss the southern migration altogether, or get out of step with the main migration movements.' According to Ash (1955, 1956), the blubber thickness and oil production increase with advance of season, when the population comes into the antarctic waters. In relation to the feeding activity, I examined the blubber thickness of the fin whale cap-

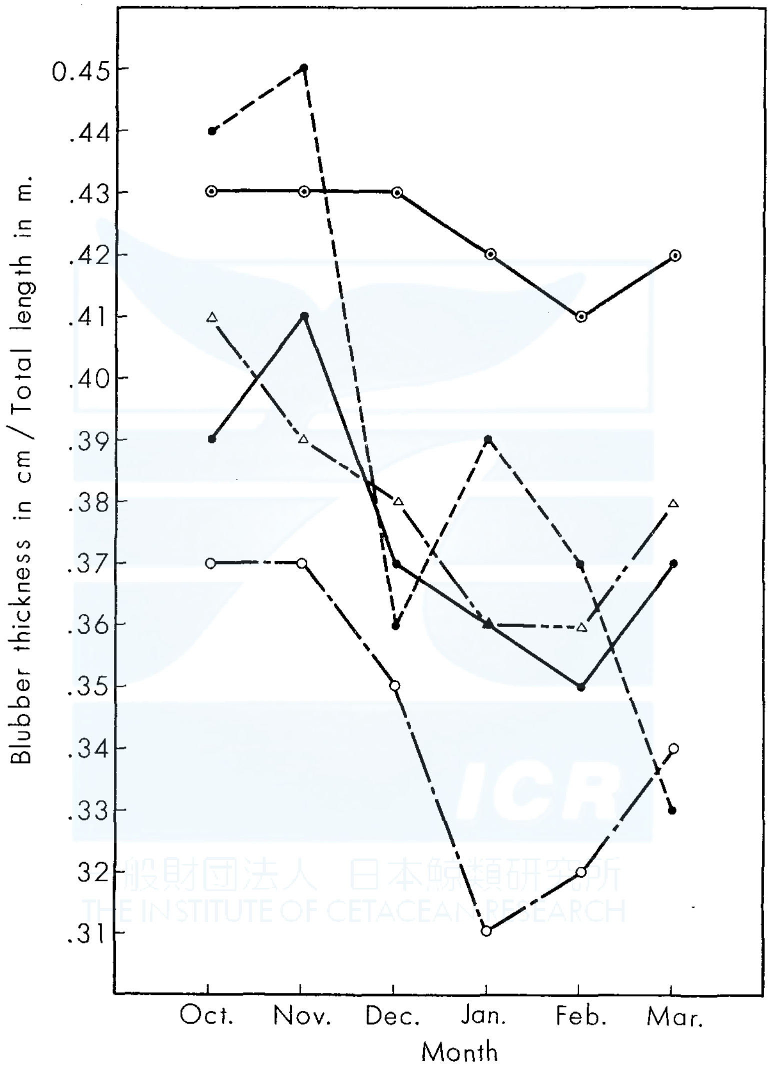

Fig. 35. Fluctuation of the bblubber thickness of the antarctic fin whale with advancement of month. From South Georgia whaling in October and November, and from the pelagic whaling from January to March.
⊙——⊙: Pregnant female. – – – –: Resting female. ——-——: Lactating female.
————: Sexually mature male. ——- - ——: Sexually immature whale.

tured in the 1961/62 season. In Fig. 35, the blubber ratio of the fin whale (average blubber thickness in cm/length of whale in metre) is plotted by month from October to March. The blubber ratios in October and November come from the South Georgia whaling in 1964. Except the resting female, there are similar tendencies for groups of the pregnant whale, the lactating whale, the sexually mature whale and the sexually immature whale. In this respect, there is no difference with Ash (1956), and Ohno and Fujino (1952). The blubber ratio, however, does not indicate increasing trend with advancing season that Ash (1955) pointed out for two consecutive season (1953/54 and 1954/55), and on the contrary there is a decreasing trend in my samples.

This discrepancy between the past and the recent examination on the blubber thickness has appeared since the 1959/60 season and probably depends on the difference of the whaling locality. In the recent antarctic expedition, the pelagic whaling has been practised far north than the past. The recent catch is intensive to the population trying to enter the feeding area and hence to that before storing the thick blubber.

When the staying period of the whale in the feeding area is reflected by the increase of the blubber thickness, the descrepancy is understandable. The rise of the blubber ratio in March probably depends on the catch for the other population than that from December to February. Attention should be paid to the occurrence of the bright layer (fatty degenerated layer) in the ear plug in spite of the decreasing thickness in blubber.

Mackintosh and Brown (1956) estimated the seasonal rise and fall of the population of large baleen whales in the ice-free antarctic waters. According to Fig. 29, the formation period of the bright layer in the mature fin whale agrees well with the rising period of the population which they estimated. It means that the occurrence of the bright layer in the ear plug is closely related the southern migration of antarctic fin whales and on the other hand the dark layer is related the northern migration.

Based on these discussions, the occurrence of the bright layer can not be interpreted without taking into account the critical point of the Vitamin A supply through food. In respect of the layer formation in the ear plug, it is also assumed that the growth hormone contributes to the bright layer and estrogen to the dark layer. This assumption will be applied for the whales migrating with seasonal regularity. Presenting the growth curve of newly mature females, Laws (1961) stated that the growth ratio was larger for the feeding season than for the paring and the parturition season in the antarctic fin whale. Finally, it is concluded that the promotion of mitotic activity in the glove-finger epidermis closely related to the growth of the fin whale. The keratinization as an intrinsic feature of the epidermal cell is influenced by the active mitosis and transformed to the fatty degeneration. For the immature whale as well as for the foetus and the adult whale, this idea will be applied. In order to interpret the alternation of two layers in the ear plug, it is essential to examine patters of the feeding activity.

ANNUAL INCREMENT RATE OF LAMINAE AND AGE DETERMINATION OF FIN WHALE

At first I review here the previous representative papers concerning this problem and the foundation in previous estimation on the annual increment rate of laminae.

Purves (1955) who found the ear plug existing in the external auditory meatus of the Mysticeti an important age material, estimated the relation between the growth of the skull width and the formation of ear plug. His statement is as follows. ' The *characteristically great lateral growth of the posterior region of the skull is apparently* almost wholly associated with the lateral extension of the zygomatic process of the squamosal, the paraoccipital process and the mastoid process of the tympano-periotic and during the lateral extension of these bones which are concerned in the formation of *the bony external meatus, the wax plug would tend to drawn away from its* contact with the glove-finger'. Laws & Purves (1956), noting such a relationship, states ' that the dark layer found in the fin whale plug marks an abrupt interruption which implies almost complete cessation in the growth of the entire skull and presumably in that of the skeleton and such an interruption, therefore, would have occurred during the migratory period when the excessive physiological demands of active swimming are coincident with complete absence of food.' Purves and Mountford (1959) and Ichihara (1959) independently deny this relationship between the growth of skull and the formation of ear plug and state that the increasing length of core should be positivly based on the internal progressing metabolism of whale body. On the annual formation of laminae, Purves and Mountford, examining the approximate numbers of laminae formed between the sexual and physical maturity, pointed out the validity of biannual formation. This estimation results from how many accumulation rate of laminae is consistent with other informations on the age determination given by the previous scientists. They state in conclusion that the rate is either one or two per year and that the latter is more consistent with all the previously accumulated knowledge of the natural history of fin whales. Comparing the ridge number of young baleen plate with the lamination number, Laws and Purves (1956) estimated the biannual formation of lamine for fin whales captured in the North Atlantic. Nishiwaki (1957) supported the biannual formation in examining the relation between the baleen ridge and the laminae in the ear plug for the young antarctic fin whale. In order of published years, Dawbin (1959) and Chittleborough (1960) obtained the direct knowledge on the accumulation rate of ear plug laminae and on the annual occurrence of baleen ridge, based on the recapture of young humpback whales which had been marked at known age. From these evidences they supported the biannual formation in the laminae of the ear plug; Dawbin indicated 5 distinct and two indistinct laminations for a estimated three years old humpback male and Chittleborough showed 12 laminations for a humpback male, estimated 6 years old. For the recaptured whale, Dawbin presented the trace of baleen sculpture indicating three years intervals. Although humpback whales were not calves accompanied by cows when they were marked, these evidence should be appreciated. The ear plug of the humpback whale indicate the same formation mechanism of that of the fin whale.

Laws (1961) gave an explanation on the assumed biannual formation of ear plug lamination and estimated that the biannual hormonal cycle, regulated by changes in day lengths associated with the long migration of the fin whale might be responsible. He states that during the southward or the northward migration, there is always a rise in the amounts of circulating oestrogens, associated with oestrus, and this is responsible for the formation of a keratinous layer in the epithelium of the glove-finger. The basis of his hypothesis results from the consistency of the biannual formation of laminae with the figure of 1.4 for the anual increment of corpora in the female ovaries. In his study on the sexual cycle for the antarctic fin whale, he obtained the figure of 1.4. Compared with the other assumptions hormonal stimuli is acceptable to interpret the formation of keratinized layer in the ear plug, however, Laws did not refer to the formation of fatty degenerated layer. His statement (p. 468) should be noticed that this hypothesis explains lamina formation in adults satisfactorily, but little is known of the migrations of immature fin whales and the early laminations are the most difficult to interpret.

Many direct knowledges on the increment rate have been obtained from the recoveries of the whale marks by the Japanese whaling. In the International Cooperation of the whale marking, prewar marks which the former Discovery Committee, the present National Institute of Oceanography in England, developed have been recovered by the Japanese expeditions since the 1954/55 whaling season. Many ear plugs have been collected from the recaptured fin whale by the method reported by Omura (1963). Examined biological materials including ear plugs and ovaries were summarized for recaptured fin whales until the 1960/61 season (Ohsumi, 1962) and for the 1961/62 season (Omura and Ohsumi, 1964). 10 ear plugs to which counting laminae was made by staffs of our Institute, came from fin whales marked in the prewar days. These direct evidence showed that about one lamina annually was laid down in the ear plug, although the accurate estimation is impossible because of unknown ages of whales at fire. Examination on the recovered whales which were marked at unknown ages is an approaching method with accuracy to estimate the increment of laminae. Ohsumi (1964) evaluated which is valid, the annual formation or the biannual formation of ear-plug laminae, applying the artificial models to the population of whale, and then took the annual formation as a better estimation. This method is significant for the practical assessment but the model should be revised by the development of biology.

These reviews clarify that there is a discrepancy in estimating the increment rate of laminae. Whether the annual increase of lamination is one or two, the basis of above estimations is present in assuming the regular formation of ear plug layer. This assumption means that the ear plug of an age character is the absolute one and hence that the occurrence of laminae indicates the calendar time. Before this as sumption is correct, it is the most important to check whether or not the physiological rhythm of the whale body arises with the calendar time.

Reviewing the various papers on the age determination of aquatic mamals, but presenting no data, Slijper, Utrecht and Naaktgeboren (1964) state as follows. ' The periodicity in baleen plates, teeth and ear plugs may be an indication that periodical changes in food supply are pricipal cause of the periodicity in these organs and that cyclic sexual events are superimposed on it.' With regard to accumulation of ear plugs and baleen plates for blue, fin and humpback whales, they think that no lamination will appear or at least an irregularity in the process of formation of these laminations will appear, when an animal stays in warm waters during the summer.

From the photometric record, it is possible to measure accurately the distance between two dark layer. I plotted the accumulated thickness at each layer for many ear plugs from the Antarctic and the North Pacific fin whale. Fig. 36 indicates the representative two patterns for the growth of core length. One growth, the left figure, follows the exponential curve and the other, the right figure, has two growth stages after weaning. Although the occurrence of layer is more irregular for the female whale than the male whale, two patterns exist for both sexes. In the ear plug represented by the left figure, the growth is regular and in the ear plug following the growth of the right figure the growth rate is different between the immature stage and the mature stage.

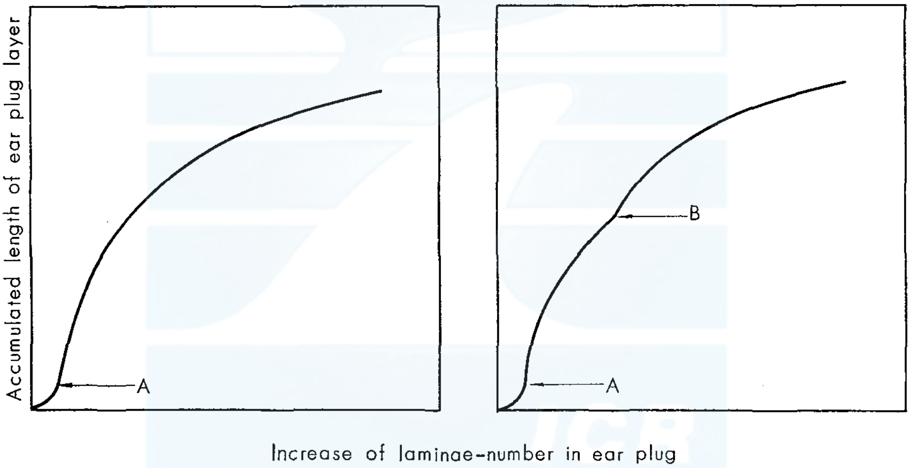

Fig. 36. Schematic growth of the fin whale ear-plug core with the increment of lamination. Inflection A point occurs at 1 lamina indicating weaning. Inflection B point occurs at about 10 laminae indicating sexual maturity.

Inflection point A appears at 1 lamina indicating weaning and point B at about 10 laminae showing the sexual maturity. When these growth curves are plotted in the Walford graphic method (1946), the clear difference is obtained. A foundation of assumption on the regular occurrence of ear plug layer lies in the exponential growth indicated by Purves (1955, Text-fig. 2). His figure for the fin whale ear plug, however, belongs to a pattern shown in the right of Fig. 36 and A point is at 1 lamina and B point is at 12 laminae.

On the occurrence of ear plug layer in the fin whale, my interpretation in conclusion is summarized as follows.

I Prenatal life

The dark layer begins at the $6^1/_2$ pregnancy months and the bright layer arises after the 8th pregnancy months. (The gestation period is the 11 3/4 month for the fin whale according to Laws (1959)).

II Postnatal life

The first lamina (an alternation of the dark and the bright layer) is formed during suckling (during 8 months after birth)

For the immature stage, the occurrence is a little complicated and three cases are considerable.

1. Annual formation of laminae
2. Complex of the annual and biannual formation of laminae
3. Biannual formation of laminae

As a mean, the figure of 1.5 for the annual increment is appropriate for the sexually immature stage in both sexes. After the sexual maturity, the regularity of annual formation is maintained, but after the physical maturity there is a possibility which such a regularity is disturbed and the increment rate become increase again annually. I can not here comment on the figure for the increment rate in the very old whale after the physical maturity. Such a possibility resulted from the examination on the mitotic activity in the glove-finger epidermis. In the ear plug indicating large numbers of laminae, for example in a sample (100 laminae) shown by Nishiwaki, Ichihara and Ohsumi (1958), the distance of neighbouring laminae is remarkably reduced and does not indicate the regular decrease, however, it seems that an assumption on the annual formation rate for very old fin whales has no intensive effect on the practice of the stock assessment for the fin whale. There are gradual shifts in the incremrnt rate of laminae at the sexual maturity and the physical maturity.

My proposal suggests that the laminae of ear plugs indicates the relative indicator of age for the fin whales, probably for other baleen whales. In this respect, my conclusion disagrees with the previous opinions on the ear plug, but the conflict among the previous estimations is disolved to some degree through my interpretation. Ecological studies for young fin whales is not so advanced as humpback whales reported by Dawbin (1956), because there is few chance to observe the fin whale as an oceanic species compared with the many chances for the humpback whale as a coastal species. With regard to the occurrence of fin whales off Durban in South Africa, Bannister and Gambell (1965) presented valuable informations. Fin whales off South Africa is closely related to the population of the Antarctic Area III (0°–70°E) from which material of my study comes, according to the movement of marked whale (Rayner, 1940). Examing the sexual state of captured fin whale, they pointed that the sexually immature group of fin whales has the peak influx in June during the 1954–57 seasons and in August during the 1960–63 seasons, while the mature group in July through the 1954–63 seasons. For the presence of a number of immature whale in both sexes, they state it is impossible to say whether these are simply young whales that have got out of step with the main migrations for some reason, or whether a large proportion than has been previously suspected do not migrate south until young whales are older, and they described further that a higher proportion of young fin whales than of adults are apparently feeding off the Natal coast but this evidence is mostly from whales observed the end of the season.

In the antarctic area, the percentage of immature whales in the catch generally increases towards the end of the season (Mackintosh, 1942) and the Japanese pelagic catch also supports this tendency. However, the examination on the South Georgia fin whales during the 1925–31 seasons shows evidence that the influx of immature whale is bimodal for both sexes; one smaller mode (24.1–25.4%) is present in October and the other (46.0–50.0%) in March according to Mackintosh.

From the mark recovery, Brown (1954) suggests that fin whales are shown to return from their migrations year after year to somewhere near the marked place and that the dispersal may take place among the younger whales rather than among older whales.

These evidences shows that in general the migratory habit and hence the feeding habit is irregular in the immature group than the mature group. These also support my opinion on the rather irregular occurrence of bright layer in the immature whale. It is interesting to find that the peak of baleen plate records agrees with the peak of the photometric record for the ear plug. Some of young fin whales presumably feed in spring and autumn even in the antarctic area. The indirect evidence that the bloom of diatom occurs twice in spring and autumn of the temperate zone and once in summer of the high latitude zone presumably suggests that some of young fin whale feed irregularly both in the temperate zone and in the Antarctic.

TABLE 14. EAR PLUG LAMINAE AT THE SEXUAL MATURITY OF THE FIN WHALE.

Author	Year	Male	Female	Locality
Laws and Purves	1956	8–12	—	North Atlantic
Nishiwaki	1957	—	10	Antarctic
Nishiwaki, Ichihara and Ohsumi	1958	11	11	Antarctic & North Pacific
Purves and Mountford	1959	9	10–12	Antarctic
Laws	1961	—	10	Antarctic
Ohsumi	1964	9.4	10.7	Antarctic

The age of fin whale will be determined more accurately from the proposed annual increment rate of ear plug laminae. Previous opinions concerning the accumulated laminations until the sexual maturity of fin whale are summarized in Table 14.

In the point of the large size of sample, I support Ohsumi's figure for the Antarctic fin whale. According to my examination, the same figure is given to the population of the fin whale inhabiting Area III (0°–70°E) in the Antarctic. Individuals having testis over 2.5 kg are diagnosed as the mature male and individuals indicating the first ovulation as the mature female. Accordingly, the mean age of maturity is 6 years for the male and 7 years for the female. This interpretation for the antarctic fin whale is applied for the North Pacific fin whale because of the same formation mechanism in ear plugs between two localities. The figure presented by Nishiwaki, Ichihara and Ohsumi (1958) is slightly higer for the North Pacific male.

According to the growth curve, the maximum length is reached at 40–45 ear-plug laminae for both sexes in the Antarctic and the North Pacific fin whale. When the maximum leghth is considered to correspond to the length of physical maturity, the physical maturity is attained within 40 years from birth for both sexes. As far as some doubts remain for the increment rate of laminae after the physical maturity, the rigid longevity of the fin whale is not determined here. Judged from the countable maximum laminae in the ear plug; 101 laminae in the male and 100 laminae in the female in the Japanese material, however, it is concluded that the fin whale has a longer life span than that estimated by previous scientists. Table 15 shows the body length at the sexual maturity of the fin whales. When the maturity percentage in each length is plotted, these figures are obtained at 50 percent level of maturity. From the examination on reproductive organs by Japanese biologists from the 1955/56 to the 1962/63 seasons in the antarctic pelagic whaling, I summarize them in each Area. The length at the sexual maturity of the North Pacific fin whale results from the examination from the 1956 to the 1964 season in the Japanese pelagic whaling.

TABLE 15. THE BODY LENGTH IN FEET AT THE SEXUAL MATURITY OF FIN WHALES, DETERMINED BY THE EXAMINATIOH ON REPRODUCTIVE ORGANS OF CAPTURED WHALE BY THE JAPANESE PELAGIC WHALING. PARENTHESES SHOW THE SIZE OF SAMPLE.

North Pacific

Male	57.5	(6018)
Female	60.2	(5513)

Antarctic

	Area I 60°W–120°W	Area III 0°–70°E	Area IV 70°E–130°E	Area V 130°E–170°W	Area VI 120°W–170°W
Male	61.0 (1408)	62.6 (627)	61.7 (609)	62.8 (887)	61.5 (5887)
Female	64.7 (1289)	65.6 (1454)	65.6 (1665)	65.6 (1124)	64.5 (5116)

Mackintosh (1942) reported that the antarctic fin whale reaches the sexual maturity at 63.0 feet in the male (473 sample sizes) and 65.3 feet in the female (770 sample sizes) on the basis of biological examination from the 1927/28 to 1940/41 season in the antarctic whaling. Although his criterion for the mature male is different from mine, his results are very near to my findings except for Area I (60°W-120°W) and Area VI (120°W-170°W). In the Pacific sector, the fin whale of both sexes attains to the sexual maturity in smaller length than in other sectors. 61.7 feet of the male in Area IV (70°E-130°E) seems to be too small because of the scarcity in the sample size. Based on the large sample size, the North Pacific fin whale attains to the maturity at 57.5 feet in the male and at 60.2 feet in the female.

During my field work in the Grytviken Station at South Georgia, No. 1294, a prewar mark of the Discovery Committee was recovered after 29 years and 9 months from fire. Two perfect ear plugs were collected from the female fin whale of 74 feet in length and showed 40 laminations. Both ovaries were lost because the belly of this whale was cut.

Record at fire;
53°48′S, 40°56′W, 16 January, 1935.
Record at recovery
56 43′S, 39 24′W, 17 October, 1964.

SUMMARY

Age determination is very important for the fisheries biology of whales and many studies on this project have been carried out during the past 40 years. Compared with other age charactors, the accumulated laminae in the ear plug which has been recently found is the most believable as the ageing method for baleen whales. This paper results from my continuous study in a series on the biology of fin whale ear-plug from the foetus to the very old whale and includes comments on the previous papers related to the age determination by means of the ear plug layer. In the course of this study, the structure of the baleen plate which is another valuable age indicator for the young fin whale had to be examined again by the devised photographic apparatus. The photometric apparatus recording the alternation of ear plug layer was devised as a method researching for the biological meaning of each layer. The race of fin whale population was considered particularly in estimating the aunual increment rate of laminae. The results of this study are summarized as follows.

1. The improved photometric recording apparatus for the ear plug layer was accomplished. Main improved points exist in the development of compensation method for recording, and in the semi-automatic mechanism. By this apparatus, the alternation of the dark layer (keratinized cell layer) and the bright layer (fatty degenerated cell layer) in the ear plug was accurately recorded in the undulating brightness on a standard level.
2. Photographic method for the long strip of baleen plate was devised and the structure of the longitudinally sectioned baleen plate was examined by this method. The unique mechanism exists in the photographic method to shorten the long baleen plate and simultaneously enlarge the thickness of thin plate.
3. The baleen plate has several inflections in its longitudinally growing direction. These inflections result from the different growth rate of plate between the active and the quiescent formation of the medullary layer, and the numbers of inflections are closely related to the age determined by the baleen sculpture. The increasing medullary layers in thickness correspond to these inflection points in their positions. The change of thickness in the medullary layers has an intensive effect on the periodical change of thickness in the baleen plate and supports the previous finding that the baleen ridge is a valuable ageing charactor for the young fin whale. The varying thickness of the cortical layer is not so significant for the age determination as that of the medullary layer.

4. It is impossible to determine the age of fin whale over 4 years by means of the baleen ridge count because the neonatal mark of plate begins to wear off at 3 years from birth.

5. Except the suckling stage, the sculpture record of baleen plate corresponds to the photometric records for the ear plug. In typical records the increasing thickness of plate corresponds to the occurrence of bright layer in the ear plug.

6. It is estimated that the period of suckling is about 8 months for the antarctic fin whale and the calf weans at about 43 feet in the length in the end of January.

7. Ear plugs are derived from the glove-finger epidermis. The keratinization of the foetal glove-finger epidermis arises from the $6^{1}/_{2}$ pregnancy months and the fatty degeneration occurs after the 8th pregnancy months in the fin whale. The occurrence of bright layer in the foetal ear plug is closely related the increasing growth rate of foetus proper and independent of the occurrence of bright layer in the maternal ear plug. All degenerated cells of the glove-finger epidermis remain in the external auditory meatus throughout the life of whale from the $6^{1}/_{2}$ foetal months. This is an indication that the ear plug is the most valuable ageing material for the fin whale of both sexes.

8. The next dark layer to the foetal layers indicated the neonatal mark in the ear plug. It is estimated that the first lamina (an alternation of the dark and the bright layer) is formed during the suckling stage of the fin whale.

9. Previous hypotheses for the formation of ear plug layer were commented. The laminae of ear plug does not infer an absolute age indicator for the fin whale but a relative age indicator.

10. Factors affecting the formation of ear plug layer after birth were examined in relation to the life history of fin whale. In the glove-finger epidermal cell contributing to the formation of ear plug, the fatty degeneration shows three times mitotic activity than the keratinization. It is assummed that Vitamin A, rapid food supply and growth hormone induce the formation of bright layer and that on the other hand Vitamin A deficiency, starvation and estrogen do the formation of the dark layer. The relation between these factors and the epidermal mitosis was discussed.

11. The formation time and period of the ear plug layer after birth were examined by an application of SUDAN III staining method to the base of ear plug. During the examined 6 monthly period in the Antarctic, both dark and bright layers occur in the sexually immature whale but the occurrence of bright layer is predominant in the mature whale. The bright layer in the sexually mature whale is formed during the period of feeding migration and the dark layer during that of breeding migration.

12. The ear plug of young whale shows the irregular occurrence of layers. The annual increment rate of layer is 1.5 lamination for the sexually immature fin whale of both sexes. It was checked by three kinds of approaching method. From the sexual maturity to the physical maturity, one lamina is annually laid down. After the physical maturity, the increment rate probably increases again but the rigid conclusion is not given in this respect.

13. The age at the maturity of the fin whale was estimated on the basis of the aunual increment rate of ear plug layer. The male fin whale attains to the sexual maturity at 6 years after birth and the female at 7 years. This finding is applied for both the Antarctic and the North Pacific fin whale. Both sexes reach to the physical maturity until 40 years after birth.

14. On the basis of large samples, the length of the sexual maturity was estimated for the fin whale. For the North Pacific population, it is 57.5 feet for the male and 60.2 feet for the female. In the east Pacific sector in the Antarctic, it is shorter by about one foot than the other area and 61.3 feet for the male and 64.6 feet for the female.

15. The accurate knowledge for the ecology of young and very old fin whales is necessary for the future development of whale biology.

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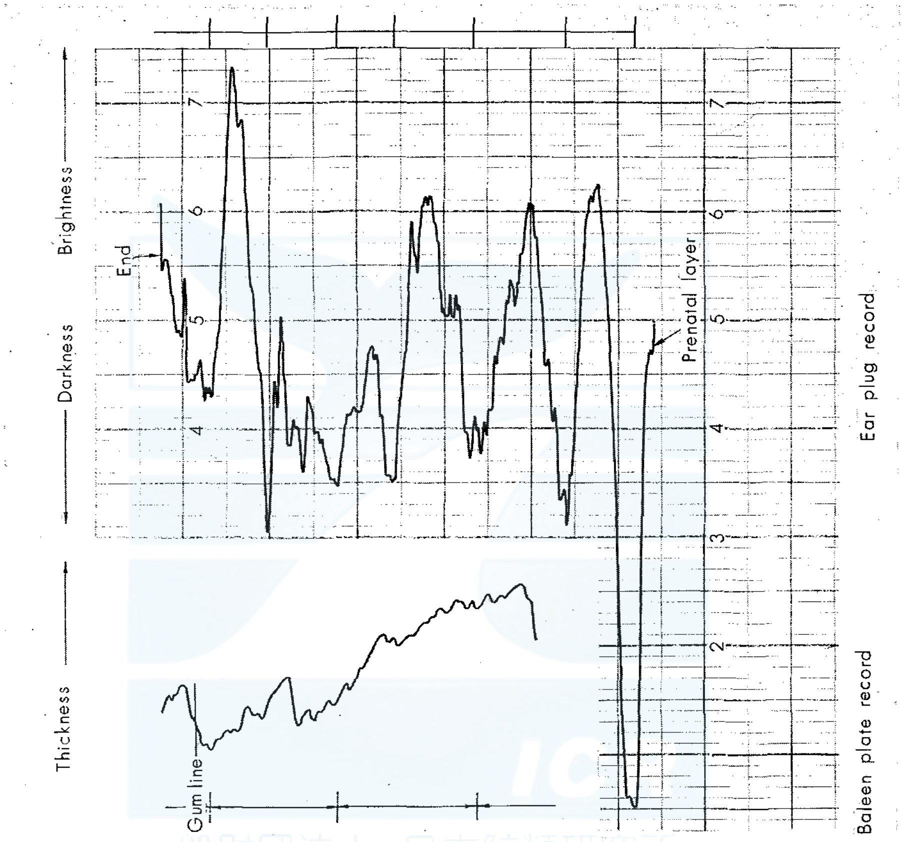
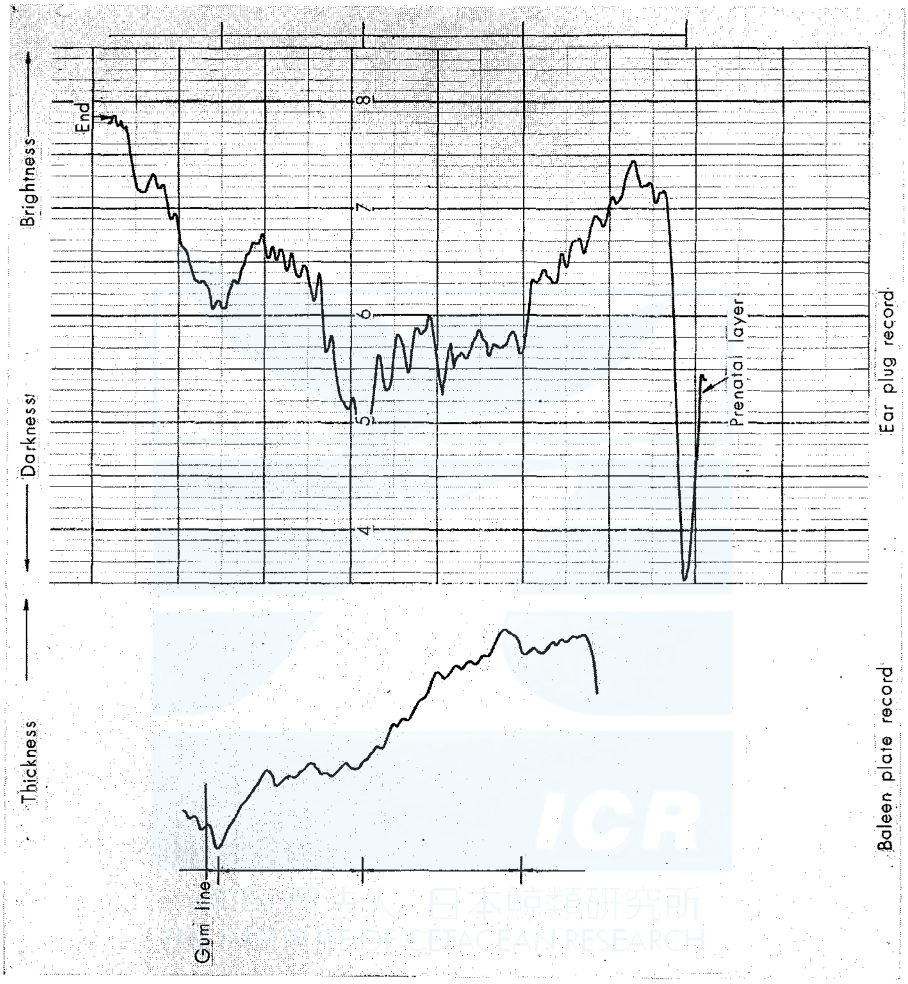
EXPLANATION OF PLATES
I—VIII

Comparisons between the sculpture records of baleen plates and the photometric records of ear plug layers in 8 young fin whales from the Antarctic.

The age mark for baleen plate is given in the lower and the border of each lamina in the ear plug in the upper. All ear plugs have prenatal layers but tips of baleen plates have been already worn off. These figures show that the photometric record is very sensitive. When the photometric records are reversed, the dark layers are emphasized.



Records for No. 10 fin whale. Unit of horizontal scale is 1.40 mm



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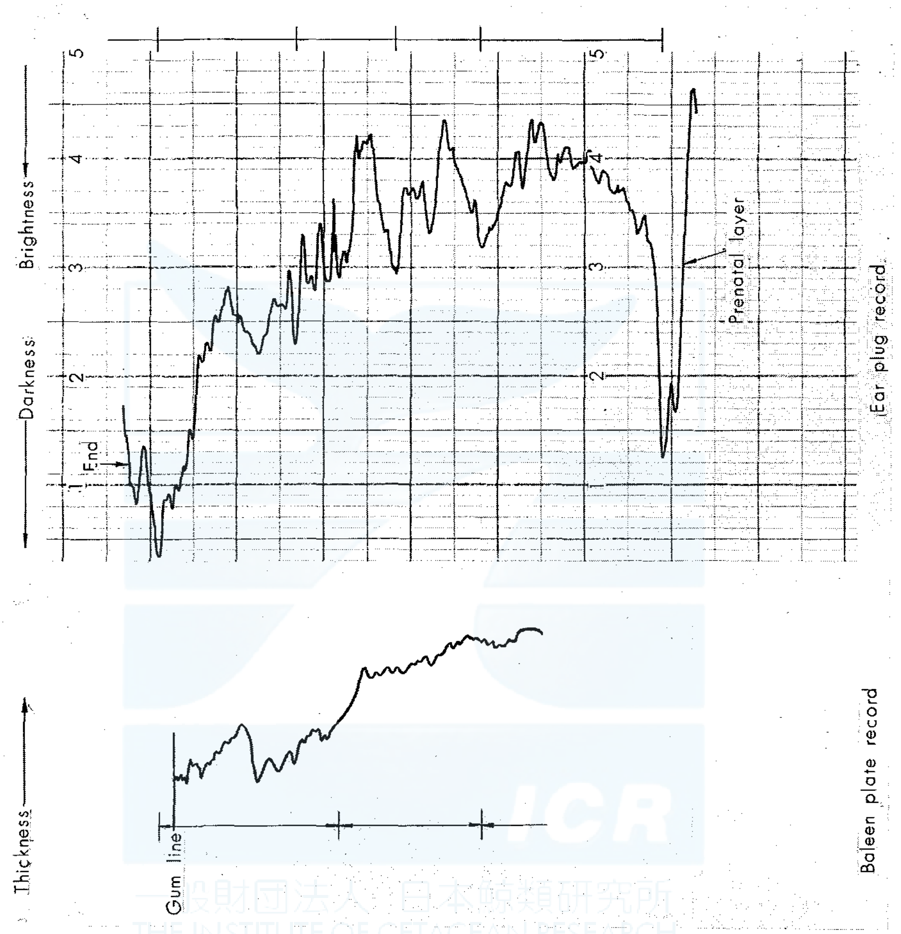

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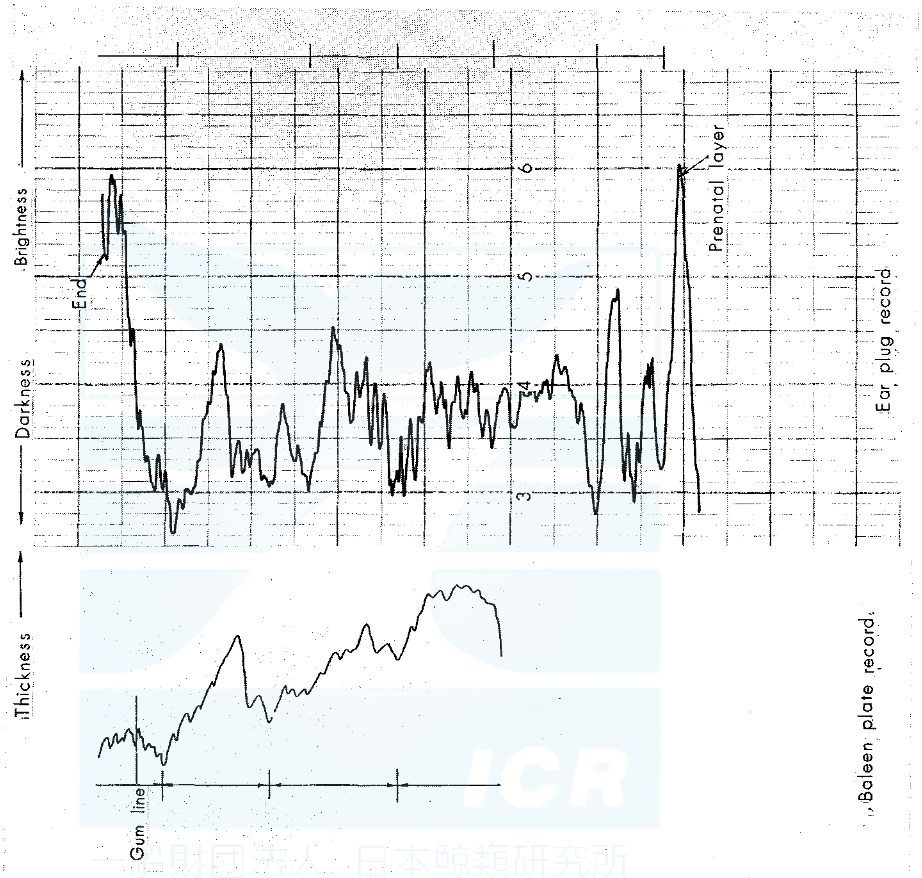

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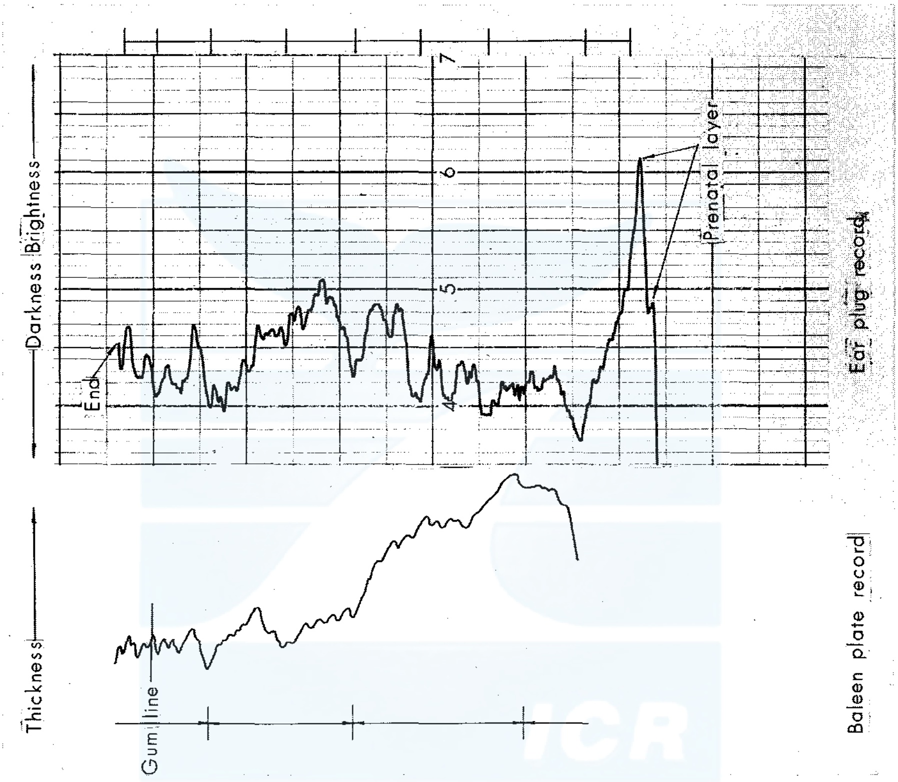

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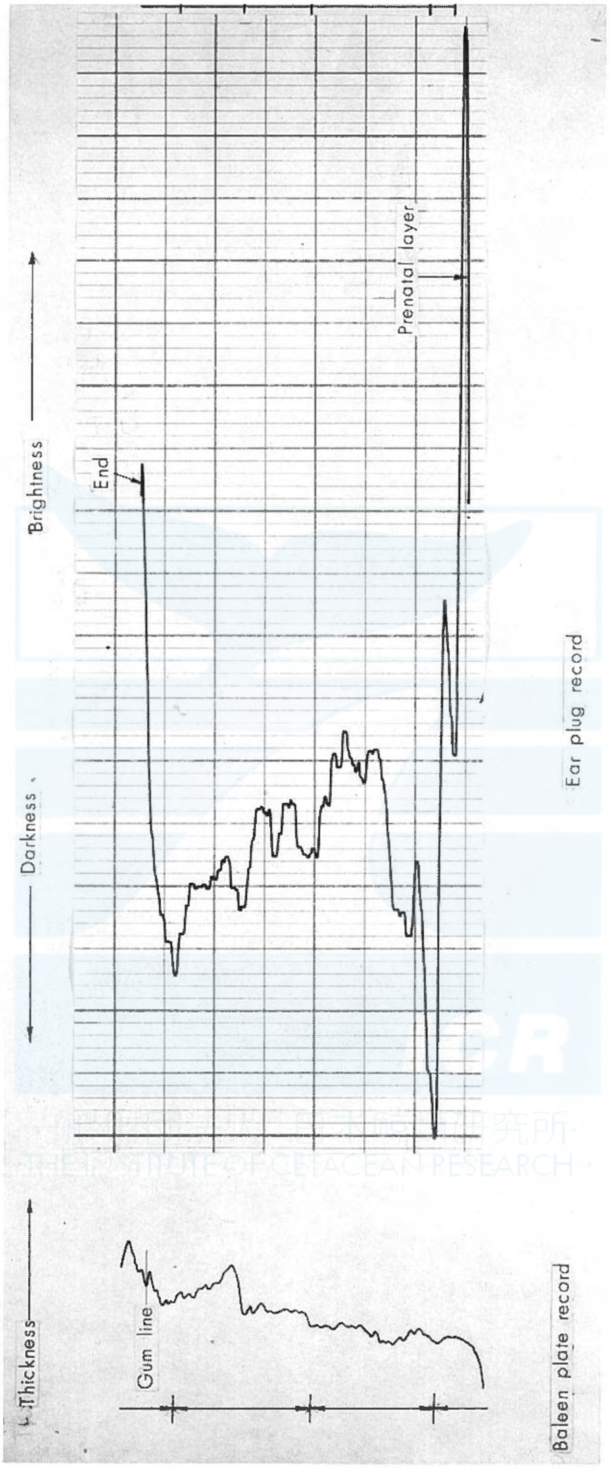
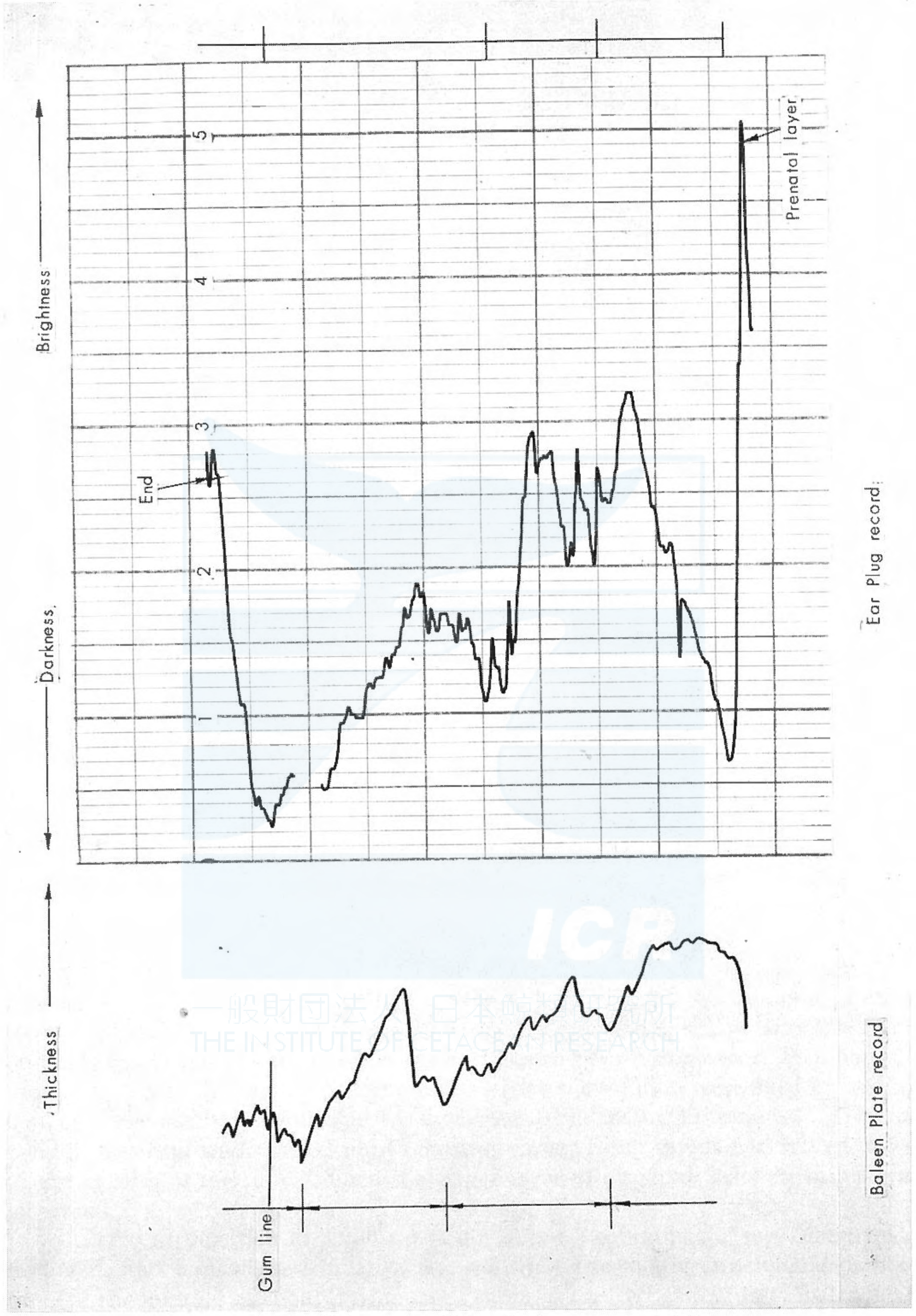
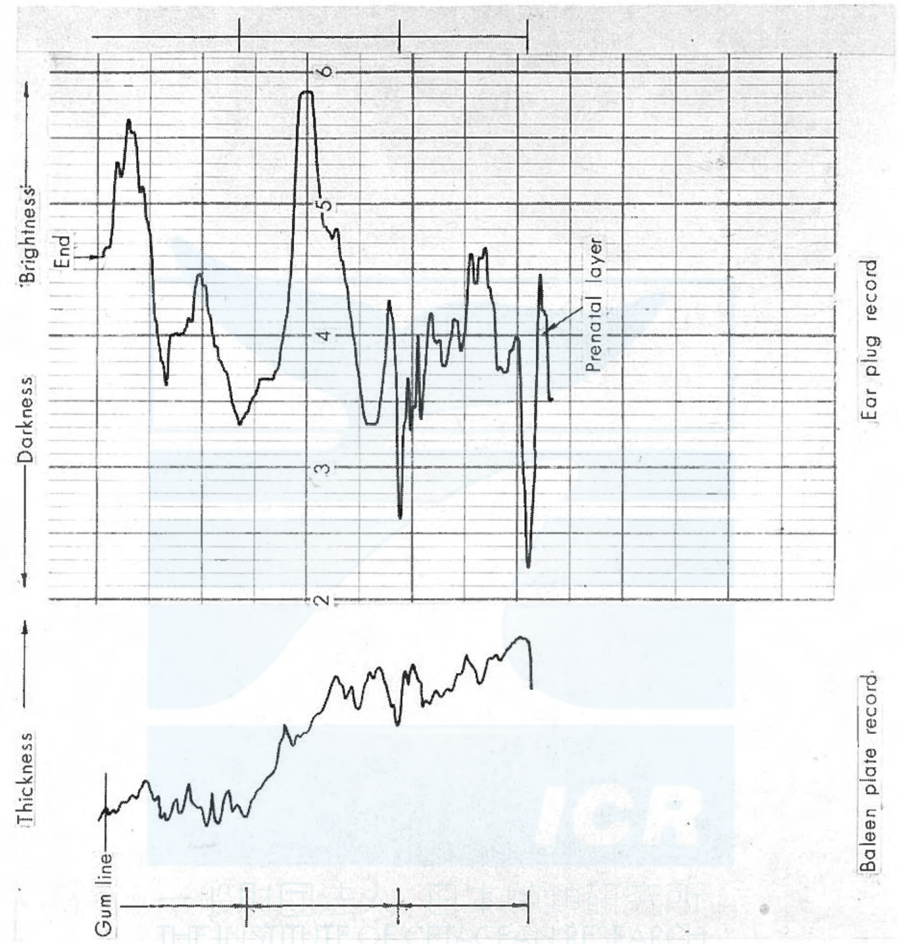


Records for No. 17 fin whale. Unit of horizontal scale is 2.81 mm.



Records for No. 18 fin whale. Unit of horizontal scale, is 1.40 mm.



Records for No. 19 fin whale. Unit of horizontal scale is 1.40 mm.

KARYOTYPE OF A SEI WHALE

TOSHIO KASUYA

The chromosomes of the Mammalia have been studied for a long period, and many species of mammals except those belonging to the Lemures, Proboscidea, Hyracoidea and Sirenia were analyzed their karyotypes (Matthey, 1949).

In the order Cetacea, Makino (1948) first reported a study on the chromosomes of Dall's porpoise, *Phocoenoides dalli* (True). He concluded that the diploid number of the chromosome is 44 and it has sex chromosomes of XY type. And also he pointed out the resemblance between the karyotype of the Dall's porpoise and that of the Ungulata rather than that of the Carnivola.

Nowosielski-Slepowron and Peacock (1955) reported a study on the chromosomes of the blue, fin and sperm whales. In this report chromosome numbers were not decided and were only suggested the approximate diploid number 48 in the above three species.

I report here a study on the chromosomes of the sei whale based on a testes sample obtained from the North Pacific.

I am much indebted to Dr. M. Sasaki of the Hokkaido University, who gave me valuable suggestions on the cytological technique. Greater thanks are due to Prof. T. Hibiya of the University of Tokyo who kindly discussed the draft.

MATERIAL AND METHOD

The material used in this report was collected from a sei whale captured in the northern part of the North Pacific in the summer season of 1966 by a Japanese whaling factory ship. In the external characters and internal organs of this whale, no abnormality was found.

The animal had been dead about 4 and a half hour when the testicular material was collected. After removal from the animal, the piece of testicular tissue was minced with sharp scissors on a small petri dish without adding any saline. 2 ml of 0.6% hypotonic sodium citrate solution was added to about 0.5 ml of the tissue shred and mixed. Then it was allowed to stand at the room temperature for about 40 minutes. Then, the cells suspending in the hypotonic solution were fixed by adding 6 ml of acetic alcohol (acetic acid 1 : methanol 3) for about 30 minutes. The suspension was kept undisturbed until relatively larger tissue shreds had settled down to the bottom of the tube. Then the upper layer of dispersed cell suspension was separated.

After centrifugation at 3,000 r.p.m. for about 3 minutes, the supernatant was decanted, and 6 ml of fresh fixative was added. The fixative was changed three times at the interval of about 20 minute or more. The cell pellet of the final centrifugation was resuspended in 2 ml fresh fixative.

Some preparations for microscope were made on the factory ship after the method of Sasaki (1964). But most of the preparations were made by the same method at The Whales Research Institute, after the cell suspension was stored in a freezer for about 4 months.

For staining the slides, diluted Giemsa solution (1 : 20) was applied for 10 to 20 minutes.

NUMBER OF CHROMOSOMES

Chromosomes in spermatogonia

The material provided fairly numerous spermatogonial nuclei undergoing division. And many of these were relatively free from overlapping of chromosomes, which allowed the counting of number. Most of these nuclei contained one or two of the nucleoli stained pale, which suggested that these cells are not in the stage of metaphase but probably in the late prophase.

Spermatogonial nuclei with diploid chromosomes were easily recognized from those of the spermatocyte by their large chromosome number and the simple shape of each chromosomes.

TABLE 1. NUMBER OF CHROMOSOMES OBSERVED IN THE SPERMATOGONIAL NUCLEI

Number of chromosomes	40	41	42	43	44	45	46	47	48	49	Total
Number of occurrence	2	2	1	1	38	3	4	1	1	1	54
Percentage of occurrence	3.7	3.7	1.9	1.9	70.3	5.4	7.4	1.9	1.9	1.9	100.0

By the treatment of the hypotonic sodium citrate solution, the chromosomes in some spermatoganial nuclei revealed the chromatids and the position of the attachment of fibre. They were used for the morphological investigation mentioned later.

The number of diploid chromosomes was counted after their relative arrangement in a nucleus was sketched. In some nuclei which seemed difficult to count the chromosomes, above procedure was repeated independently two or three times. And the coincided number was taken.

The chromosome number was counted on 54 spermatogonial nuclei by this method. Its results is shown in Table 1. It shows that about 70 percent of the nuclei examined gave counts of 44, though the counts falls relatively wide range, 41 to 49 in diploid number. And it can be concluded that 44 is the diploid number of the chromosomes of the sei whale.

Chromosomes in spermatocytes

The spermatocyte nuclei undergoing division were not common comparing with those of spermatogonia. Four primary spermatocytes were observed with spreaded chromosomes. And only one secondary spermatocyte nucleus was observed with the chromosomes spreading fairly well.

Though, only from these spermotocyte nuclei the final conclusion on the number of chromosomes of the sei whale could not obtained, all of them suggested the diploid number of chromosomes to be 44.

MORPHOLOGY OF THE CHROMOSOMES

Morphological measurements were made on the enlarged photograph of 10 spermatogonial nuclei which showed fine structure of the chromosomes, in parallel with microscopical observation.

After the total length and the length of the shorter arm of each chromosomes were measured, the total length was standardized by the following formula.

$$\text{R.L.} = \frac{\text{Total length of a chromosome}}{\text{Length of } (21\text{A's}+\text{X})} \times 1{,}000$$

R.L.: Relative length of a chromosome
A : Autosome
X : X chromosome

TABLE 2. RELATIVE LENGTH, PERCENTAGE OF SHORTER ARM AND RATIO OF ARMS1)

Serial No.	Relative length		Percentage of shorter arm	Ratio of arms2)
	range	mean		
1	76–102	86	18	4.5
2	67–83	73	30	2.3
3	62–78	67	23	3.3
4	58–65	60	26	2.8
5	53–58	55	26	2.8
6	49–53	51	23	3.4
7	47–49	49	32	2.1
8	44–48	46	32	2.1
9	43–47	46	44	1.3
10	42–46	44	34	1.8
11	41–46	43	37	1.7
12	39–44	42	46	1.2
X	39–45	42	43	1.4
13	37–42	40	35	1.9
14	34–42	39	32	2.1
15	34–41	38	40	1.5
16	29–39	35	40	1.5
17	29–38	35	32	2.1
18	27–35	32	33	2.0
19	25–34	30	41	1.4
20	24–27	27	44	1.3
21	17–22	20	29	2.4
Y	7–12	9	—	—

1) Mean value obtained from ten spermatogonial nuclei.
2) Calculated from the former column.

The ratio of the two arms, which are devided by a kynetochore, are calculated by dividing the longer arm by the shorter. And the relative position of kynetochore is also shown by the percentage of the length of shorter arm to the total length of a chromosome.

Each spermatogonial chromosomes were placed into the homologous pairs, being based on the relative length, the relative position of kinetochore and the characteristic shape observed under microscope. A representative serial alignment is given in Fig. 1, which is a rearrangement of the chromosomes shown in PLATE 1.

Fig. 1. Serially aligned arrangement of the paired chromosomes of the sei whale.

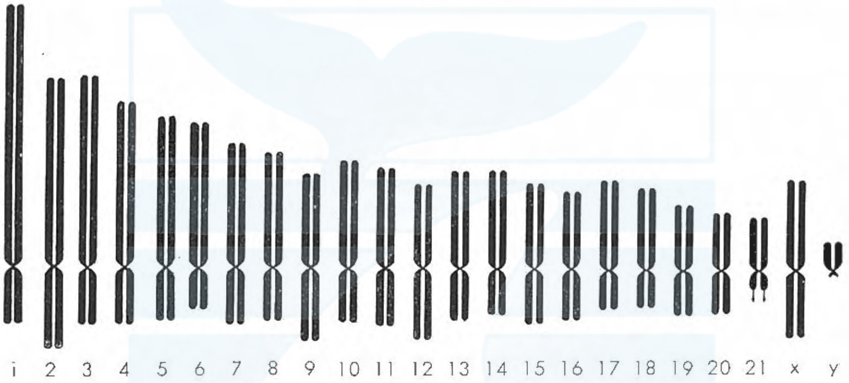


Fig. 2. Schematic figure of the chromosomes of the sei whale drawn from the measurements shown in Table 2.

The mean value of the measurements of chromosomes in 10 spermatogonial nuclei are shown in Table 2, in which the ratios of the two arms are calculated from the second column. Fig. 2 shows a schematic shape of chromosomes drawn from the value in Table 2. Out of 44 diploid complements, 42 elements can be recognized as constituting 21 homologous pairs, but 2 members are remained without mate of same size or shape. These are the sex-chromosomes. The longer one is considered to be X chromosome and the shorter Y chromosome. The length of X chromosome is nearly same with that of 12th autosome but the percentage of the shorter arm is smaller. It shows somewhat peculiir form having a vague constriction on the longer arm and can be distinguished relatively easily.

Y chromosome is the smallest in the 44 diploid chromosomes and its relative length is 9. Though it is difficult to observe the morphology, I suggest it to be a tero- or acrocentric chromosome.

The karyotype of the sei whale is the polymorphic same as that of many mammals, and the lengthes of chromosomes distribute continuously from the longest to the shortest. It is usually very difficult to classify the chromosomes without taking into consideration the relative length and the position of the kinetochore of the all chromosomes in a nuclei. When they are considered, the chromosomes can be classified into some groups.

As shown in Table 2 and Fig. 2. the chromosomes from 1st to 6th are acrocentric and have relatively larger length. The ratio of arms is 2.3 or more.

The 7th and 8th have medial length and their ratios of arms are 2.1. The ratio of arms of the 9th is 1.3 and kinetochore seems to situate nearly middle of the chromosome. The 10th and 11th chromosomes have the nearly same length and ratio of arms. The 12th and X chromosomes have the same length and both are metacentric chromosomes but the latter have the shorter arms than the former.

From the 13th to the 18th chromosomes are composed with acrocentric and relatively shorter chromosomes, and it is difficult to distinguish each other. Their ratios of arms fall between 1.5 and 2.1.

Fig. 3. Satellite on the 21st autosome.

The 19th and 20th are nearly metacentric chromosome, the ratios of the arms are 1.4 and 1.3 respectively. The 21st is an acrocentric chromosome of which ratio of the arms is 2.4. A satellite is observed on the shorter arms of this chromosome, which are shown on Fig. 3. The Y chromosome, which is the shortest chromosome, was already mentioned above.

When the karyotype of the sei whale is compared with that of the Dall's porpoise (Makino, 1948) some resemblances are found, namely the total number, X chromosome with the length corresponding to 10th or 11th (in the case of sei whale 12th), Y chromosomes with shortest length and autosomes composed of metacentric and acrocentric elements. But when compared precicely, some differences are found. In the case of the Dall's porpoise (Makino, 1948) the 5th and 6th elements are metacentric chromosomes and other relatively larger chromosomes are the acrocentric, and he suggest the members of the 9th to the 21st pairs to be acrocentric.

Among relatively larger autosomes of the sei whale, the 9th and 12th are metacentric or V shaped chromosomes. And I think that these differences of karyotypes between the two species are not unreasonable, when it is considered that they belong to the different suborder or Odontoceti and Mysticeti.

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EXPLANATION OF PLATES

PLATE I

Fig. 1–3. Spermatogonial nuclei of the sei whale at the late prophase of the division.

PLATE II

Fig. 1. Spermatogonial nucleus of the sei whale at the late prophase of the division.

Fig. 2. Spermatocyte nucleus at the second division.

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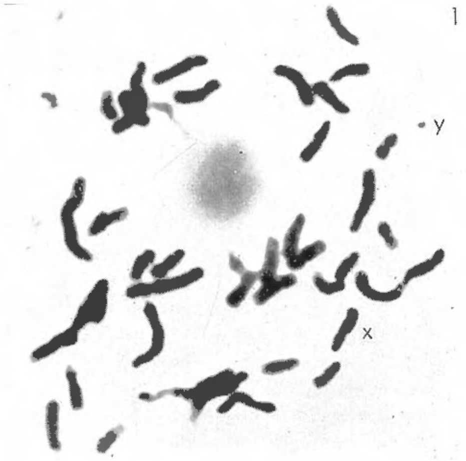

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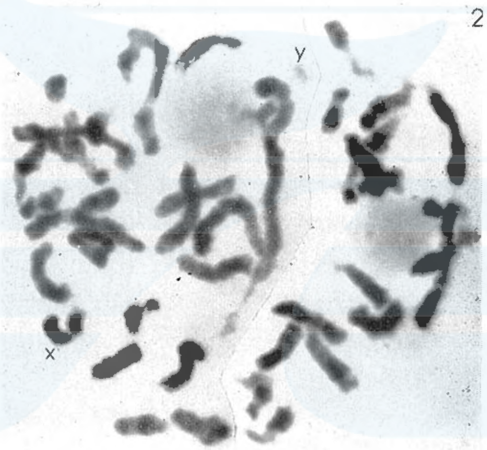

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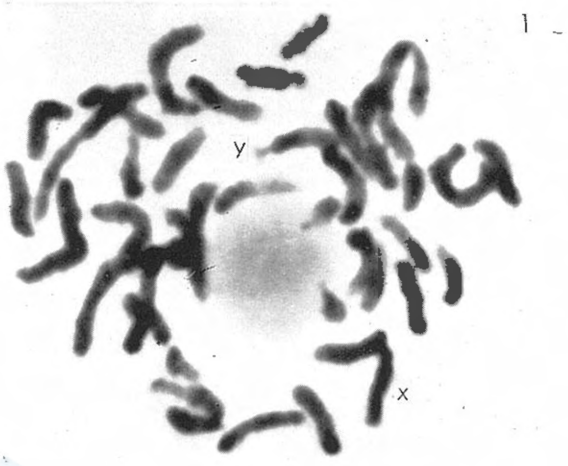
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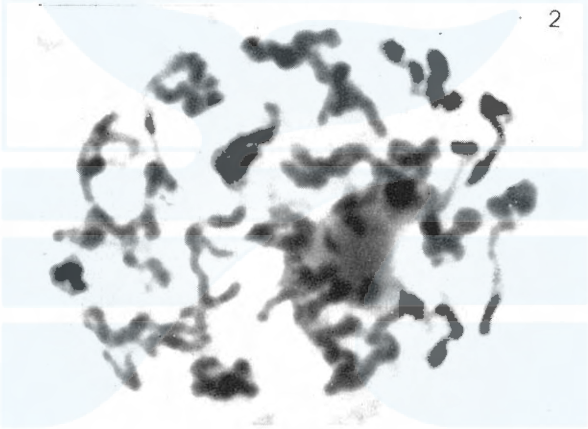
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A SECONDARY SEXUAL CHARACTER OF THE SPERM WHALE

TOSHIO KASUYA AND SEIJI OHSUMI

In the Cetacea body length is commonly known as a secondary sexual character. In the sperm whale the male grows larger than the female. The distance between the center of genital aperture and anus shows also a sexual difference. Other secondary sexual characters of the Cetacea are known on the shape of the snout of the fin whale (Nemoto, 1962) and on the tooth of some Odontoceti.

A peculiar feature of the skin, a callus, on the tip of dorsal fin of the sperm whale was noticed in the summer season of 1964. We are convinced now that this is one of the secondary sexual characters of the sperm whale, and report it here.

Many thanks are due to Dr. Keiji Nasu of the Whales Research Institute, who kindly collected the data and samples of the skin of dorsal fin. We are much indebted to Dr. Shyojiro Inoue of the Tokyo Medical and Dental University, who discussed our materials and gave us valuable suggestions on endoclinology.

MATERIALS AND METHOD

Materials were obtained mainly from the whales captured in September and October 1964 and 1965 by the Japanese coastal whaling. In addition to them, 19 whales captured in September 1965 under a special permission of the Japanese government for the scientific purposes and a female calf captured accidentally by a set net were also used here.

The condition of the callus on the dorsal fin was recorded in the following three categories, namely " present ", " absent " and " indistinct ". The " indistinct " includes the intermediate stage of the former two categories, where the condition of skin on the top of dorsal fin is not quite smooth but shows a faint callus.

Together with this observation, mammary gland, number of corpora luteum and corpora albicantia, weight of testes and fetus were observed, and the sexual condition of the animals was decided.

GENERAL CHARACTER OF THE CALLUS

The callus is found on the dorsal fin of most of adult females and some of young males. It situates usually on the area around the top of dorsal fin, but in some animals it situates on the anterior or posterior edge. The outline of the callus is nearly oval or round, but it has a wide variation in size and shape. The shape and the situation of the callus are shown in Text-Fig. 1 and PLATE 1, Figs. 1–3.

Differing from the smooth epidermis on the most parts of the body, the surface of the callus shows a roughness, which feature resembles to the surface of the small callosities of the right whale but the former is not so rough and hard as the latter. The colour of the callus is paler than the other part of skin.

The vertical section of the callus is shown in PLATE 1, Fig. 4. The depth of epidermis of the callus is very irregular and is nearly 17 mm at the thickest part and 5 mm at the thinnest part. The darmal papillae are more developed than those on the other part of skin but do not seem to differ much from the latter. The base of epidermis shows a wave form generally coinciding to that of the surface of callus, but the structure of the dermis and blubber does not show any difference from that of the dorsal fin without callus. And so, we can not think that the callus is a product of diseased skin.

RELATION TO AGE AND SEXUAL CHARACTERS

Table 1 shows the change of the frequency of the occurrence of callus in different age classes. The age was determined by the number of laminations in maxillary tooth which are considered to be accumulated annually (Ohsumi *et al.*, 1963).

In the males callus seems to occur in some young animals, but entirely disappears in all males older than 9 years old. The sexual maturity of the sperm whales is attained at the age of 9 or 10 laminations in both sexes (Nishiwaki *et al.*, 1958). The age of the disappearance of callus in males nearly coincides with the age at sexual maturity. In the females, the occurrence of the callus does not show clear relation with the age of whales. However, callus does not seem to appear in the calf.

The relation between the frequency of callus and sexual conditions is shown in Table 2. In the males, maturity is classified by the weight of larger testis, namely the testes which weighs 0.4 kg or less is classified into immature, 0.5 kg–0.9 kg into mature-1 which is supposed to include the puberty, and 1.0 kg or more into mature-2 respectively. In the females, puberty includes those which have experienced ovulation but have no experience of pregnancy. The primiparous or multiparous was distinguished by the total number of ovulations and the state of mam-

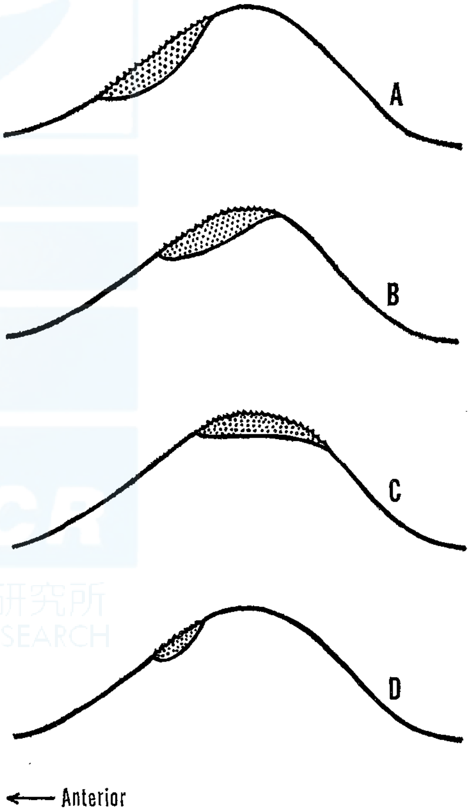

Fig. 1. Schematic figure of some variations in the position and size of callus (dotted area) on the dorsal fin of the sperm whale (lateral view.)

mary gland or whether it has experienced lactation or not. Some indistinguishable females are not included in Table 2.

TABLE 1. FREQUENCY OCCURRENCE OF THE CALLUS IN AGE CLASSES

	Age	0	4	7	8	9	10	11	12	13	14	15–24	25–34	35–	Total
Male	absent	—	—	—	1	2	1	1	1	4	1	9	1	2	23
	indistinct	1	1	—	—	—	—	—	—	—	—	—	—	—	2
	present	—	—	—	—	2	2	—	—	—	—	—	—	—	4
Female	absent	1	—	2	1	4	2	2	—	—	—	3	—	1	16
	indistinct	—	—	—	—	—	2	—	—	2	—	—	—	3	7
	present	—	—	—	3	—	—	3	—	2	2	17	4	4	35

TABLE 2. OCCURRENCE OF CALLUS ON THE DORSAL FIN OF SPERM WHALE

Sex	Maturity	Callus on the dorsal fin			Total
		absent	indistinct	present	
Male	Immature	5	2	3	10
	Mature-1	9	—	1	10
	Mature-2	12	—	—	12
	Total	26	2	4	32
Female	Immature	4	1	1	6
	Puberty	7	—	2	9
	Primiparous	3	—	3	6
	Multiparous	6	7	42	55
	Total	20	8	48	76

Mature-1 ; Larger tests weighs 0.5 kg–0.9 kg.
Mature-2 ; Larger tests weighs 1.0 kg or more.

Out of 22 mature males, the callus was observed only in one case which is a newly matured male or in the stage of " mature-1 ". On the other hand, some of the immature males have callus. Although the scarcity of immature samples does not allow to conclude the frequency of the occurrence, the immature males with callus seems not to be so rare. The callus observed in the immature period will disappear after or near the attainment of sexual maturity, and probably the male sex-hormone inhibits the manifestation of the callus.

TABLE 3. FREQUENCY OF CALLUS IN SEXUAL CONDITIONS OF MATURE FEMALE

Callus	Resting	Pregnant	Lactating	Lact. and preg.	Total
absent	3	3	2	1	9
indistinct	1	2	2	—	5
present	3	11	21	4	39
Total	7	16	25	5	53

Callus occurs on the female whales at every sexual conditions. Table 3 also shows the frequency occurrence of the callus in various sexual conditions of mature females. Fig. 2. is obtained from Tables 2 and 3, and it does not include 5 females which are pregnant and lactating simultaneously. This figure shows that, in the females, the manifestation of callus begins in the immature. Its frequency increases in pregnant and lactating whales, and decreases again in resting whales. There is an immature female with callus, which is suggested to attain soon the puberty. And in the mature females, the formation of callus seems to have some relations with the sexual cycle, although there is no evidence that the manifestation or disappearance of callus is controled directly by some endoclinological factors. When it is assumed, next supposition is possible. Chuzhakina (1961) concluded, after histological observation, that corpus luteum tissue of the pregnant sperm whale begins to degenerate when the fetal length attains to 199 cm. So the secretion of the progesteron can be supposed to decrease in the latter half of the pregnancy as in the case of some mammals. On the other hand, secretion of estrogen, though which is not studied in the sperm whales, is known in many mammals to increase gradually untill just before the parturition, and it is also secretted in the immature and mature mammals of both sexes in various degree. As mentioned above, callus is found on the immature animals in both sexes and on the mature females, so we prefer to think that estrogen has charge of the manifestation of callus and that androgen inhibits it.

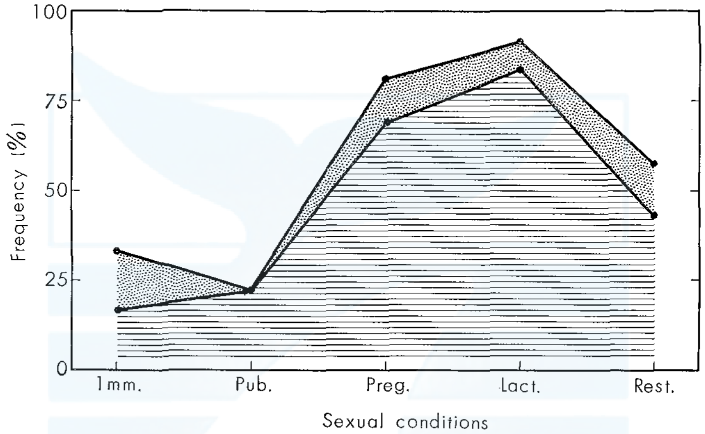

Fig. 2. Frequency occurrence of the callus in various sexual conditions in females. Whales lactating and pregnant simultaneously are excluded. White: absent, Dot: indistinct, Horizontal line: present.

We have rare chances to observe the dersal fin of 7 fetuses (3 males and 4 females, body lengthes 51–108 cm) but callus was not found on them. And there was no callus on the dorsal fin of a new born female calf of which body length was 426 cm. We must get more materials on the fetal and calf stage of the sperm whale, and it is one of the subject to investigate the age when the callus appears on the dorsal fin.

Callus on the dorsal fin in the sperm whale is different from callosities on the mouth parts of the right whale, because in the latter whale they appear already in fetal stage, and they are found in every one.

SUMMARY

A secondary sexual character of the sperm whale is reported based on the materials obtained from the Japanese coastal waters.

1. A callus is formed on the skin near the top of the dorsal fin of some sperm whales.

2. The shape of callus is nearly round or oval, and it is distinguished externally from the usual skin by paler colour and unevenness. Internally, it is characterized by a well developed thick epidermis.

3. The callus is not observed on the fully mature males, but observed on some immature one.

In the females, it occures more often on pregnant and lactating whales than on the immature, pubertal and resting whales.

4. It is presumed that male sexual hormone inhibits the manifestation of the callus, and some female sexual hormone, probably estrogen, stimulates it.

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EXPLANANATION OF PLATE

Fig. 1. Lateral view of dorsal fin without callus, adult male.
Fig. 2. Lateral view of dorsal fin with callus, adult female.
Fig. 3. Dorsal view of dorsal fin with callus, adult female.
Fig. 4. Section of skin of the dorsal fin through callus, adult female.


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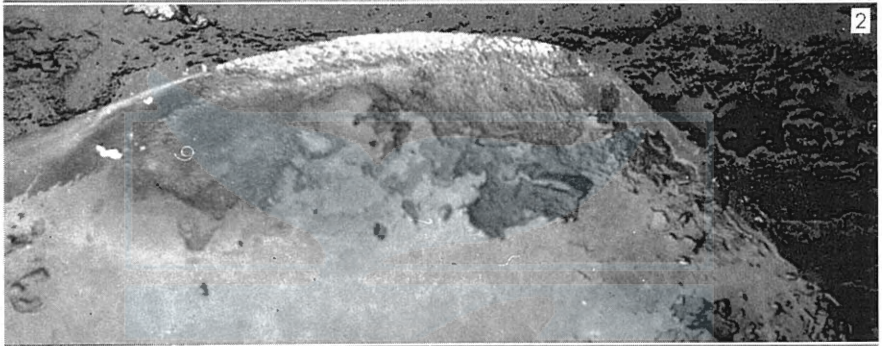
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一般財団法人　日本鯨類研究所
THE INSTITUTE OF CETACEAN RESEARCH

A NEW GENUS, *PEPONOCEPHALA*, FOR THE ODONTOCETE CETACEAN SPECIES *ELECTRA ELECTRA*

MASAHARU NISHIWAKI* AND KENNETH S. NORRIS**

INTRODUCTION

On 20 August 1963 a porpoise was stranded on Hiratsuka Beach, Honshu, Japan. It was examined by M. Nakajima and M. Nishiwaki and was determined by them to be *Lagenorhynchus electra* as described by Gray (1846). On June 27, 1964 K.S. Norris obtained a stranded newborn specimen at Kahuku, Oahu, Hawaii (British Museum 1964–6–2–1). Communications were exchanged and it became evident that both animals might belong to the same species. In the Scientific Reports of the Whales Research Institue, No. 19, Nakajima and Nishiwaki (1965) concluded about their Hiratsuka specimen that it was clearly distinct from *Lagenorhynchus*, the genus to which the form had earlier been referred, and allocated it to *Electra* (Gray, 1868). However, Dr. P.J.H. van Bree of the Zoologisch Museum in Amsterdam, Mr. W. E. Schevill of the Woods Hole Oceanographic Institution and Dr. F. C. Fraser of the British Museum (Natural History) informed the authors that the generic name *Electra* was preoccupied by a genus of bryozoans, and hence not available for this species.

On 23 March 1965, a herd of about 500 porpoises of this species came into Suruga Bay, Honshu, Japan, and about half of them were caught. Most of the captives were sold for human consumption, and only 15 individuals were obtained and brought to the Whales Research Institute. Meanwhile. on June 15, 1965, Norris obtained another specimen from Lahaina, Maui, Hawaii. Examination of these specimens confirmed the idea that the species could not be assigned to the genus *Lagenorhynchus*, but was generically distinct from all other cetaceans. The authors, therefore, propose here a new generic name, *Peponocephala*, for the form, which is a delphinid odontocete cetacean apparently most closely allied to the genera *Pseudorca*, *Feresa* and *Lagenorhynchus*.

COMPARISONS

About 10 species comprise the genus *Lagenorhynchus*. Of the northern hemisphere forms *L. obliquidens*, of the North Pacific, and *L. acutus* and *L. albirostris* of the North Atlantic are well known. Much less is known of the southern hemisphere species and more study is needed before the variation within the genus can be considered well understood. However, even in our present state of knowledge, *Peponocephala*

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* Ocean Research Institute, University of Tokyo.

** Department of Zoology, University of California, Los Angeles, and The Oceanic Institute, Oahu, Hawaii. Contribution No. 71, from The Ocean Research Institute, University of Tokyo.

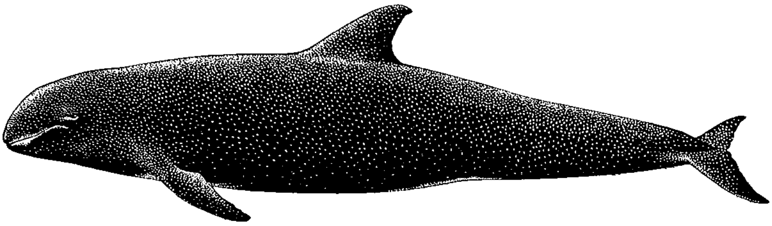

Fig. 1. Hawaiian porpoise, or many toothed blackfish, *Peponocephala electra*.

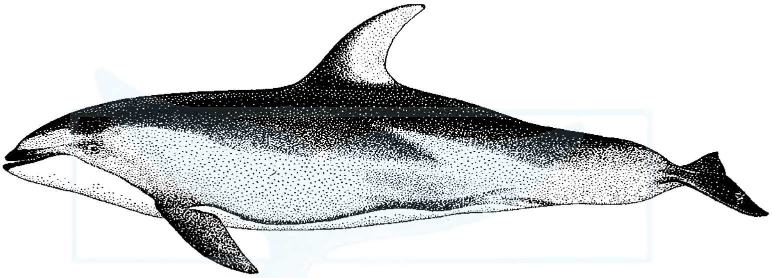

Fig. 2. Pacific white sided dolphin, *Lagenorhynchus obliquidens*.

Fig. 3. Atlantic white sided dolphin, *Lagenorhynchus acutus*.

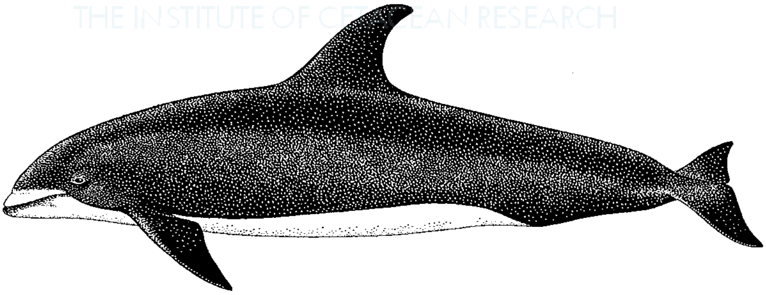

Fig. 4. White beaked dolphin, *Lagenorhynchus albirostris*.

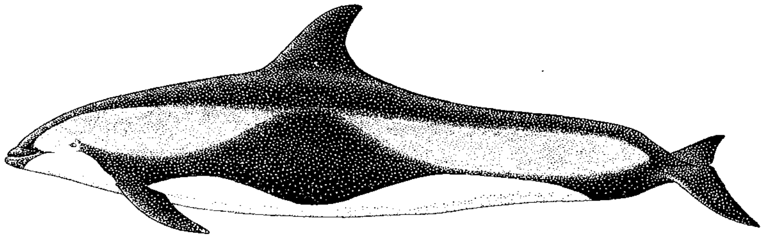

Fig. 5. Crusiger's white sided dolphin, *Lagenorhynchus crusiger*.

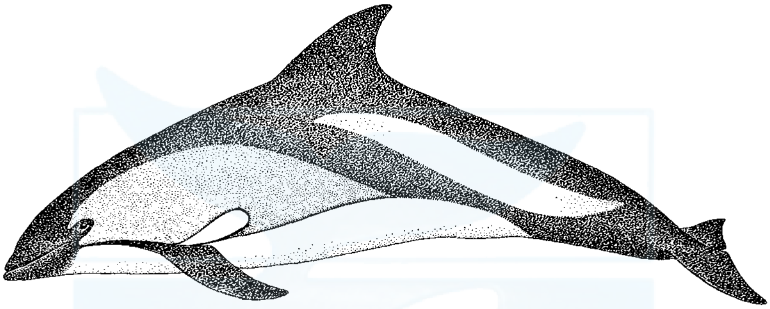

Fig. 6. Peale's porpoise, *Lagenorhynchus australis*.

Fig. 7. Dusky dolphin, *Lagenorhynchus obscurus*.

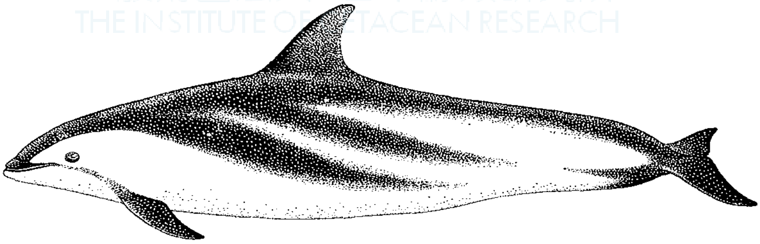

Fig. 8. Fitzroy's dolphin, *Lagenorhynchus fitzroyi*.

is clearly distinct from *Lagenorhynchus*, on the basis of the following characters.

The species of *Lagenorhynchus* have a beak clearly demarcated from the forehead or melon by a groove while *Peponocephala* has no beak, the forehead being rounded, curving smoothly from the anterior tip of the rostrum to the blowhole, and overhanging the lower jaw to some degree.

The antorbital notches of *Peponocephala* are larger and deeper than those of *Lagenorhynchus*, or even those of *Feresa*, which are unusually well developed. The dorsal aspect of the maxillary bones of *Peponocephala* shows a consistent narrowing about 1/3 the distance anterior of the base of the snout, while this feature is absent in *Lagenorhynchus*. In *Peponocephala* the anterior 3 cervical vertebrae are fused, while in *Lagenorhynchus* only the atlas and axis are fused. Phalangeal numbers are different in the two genera; *Lagenorhynchus* has 1 or 2 phalanges in the thumb while *Peponocephala* commonly has 3. *Lagenorhynchus* usually has 8 phalanges in the index (in exceptional cases reaching 10 is some species), but *Peponocephala* usually has 9. Generally speaking, *Peponocephala* seems to have one more phalanx in each digit than does *Lagenorhynchus*.

In addition to these distinctive features the body proportions of *Peponocephala* are much more reminiscent of *Pseudorca* and *Feresa* than *Lagenorhynchus*, the body being rather elongate and slim with a long tail stock. Further, *Lagenorhynchus* tends toward a complex dorsal and lateral pattern of distinct black, gray, and white areas, while that of *Peponocephala* is more unicolored with a pectoral blaze mark ventrally.

Peponocephala is separated from other beakless genera such as *Pseudorca*, *Feresa*, *Globicephala*, *Grampus* and *Orcinus* because tooth numbers in each row around 24, while these genera all have less than 15 in each row.

SUMMARY AND CONCLUSION

On the basis of a number of newly acquired specimens from Japan and Hawaii the odontocete cetacean known as *Electra electra*, and once relegated to the genus *Lagenorhynchus*, is found to be a distinct genus requiring a new name. The name *Electra* was found to be preoccupied by a genus of bryozoans.

The following features differentiate the form from *Lagenorhynchus*:

(1) The forehead of the form has no demarkated beak by a groove, and is rounded smoothly curved directly from the mouth to the blowhole,

(2) The antorbital notches are very much larger than those of other species,

(3) The first three cervical vertebrae are fused, while in *Lagenorhynchus* only the atlas and the axis are fused, and,

(4) In body form and color pattern the form resembles *Pseudorca* and *Feresa*, rather than *Lagenorhynchus*.

The authors propose the new genus *Peponocephala* for the form, and designate the form previous known as *Lagenorhynchus electra* as the type species. *Peponocephala* is of femine gender and means melon head (pepo: melon and cephalo: head).

The proposed generic name *Peponocephala* was suggested to us by Dr. Fraser.

ACKNOWLEDGEMENT

The authors extend their sincere appreciation to Dr. P.J.H. van Bree of the Zoologisch Museum in Amsterdam, Mr. W. E. Schevill of the Woods Hole Oceanographic Institution and Dr. F. C. Fraser of the British Museum (Natural History) for pointing out the preoccupation of the genus *Electra.* We also thank Dr. Fraser for suggesting the name *Peponocephala.*

Acknowledgement is made of the partial financial support of this investigation through grants from the Japan Society for the Promotion of Science as part of the U.S.-Japan Cooporative Science Program.

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EXPLANATION OF PLATES

PLATE I

Upper: A heard of *Peponocephala electra* captured on 23 March 1965 at Tabi, Suruga Bay, Japan. (Photo by Dr. M. Nakajima)

Lower left: Frontal view of *Peponocephala electra* No. 6 (242 cm female).

Lower right: Frontal view of *Peponocephala electra* No. 2 (231 cm male).

PLATE II

Upper: Upper lateral view of the head of *Peponocephala electra* No. 2.

Middle: Lateral view of the head of *Peponocephala electra* No. 4 (248 cm male).

Lower: Frontal view of the head of *Peponocephala electra* No. 5 (246 cm male).

PLATE III

Lateral, dorsal and ventral views (top to bottom) of *Peponocephala electra* No. 1 (222 cm female).

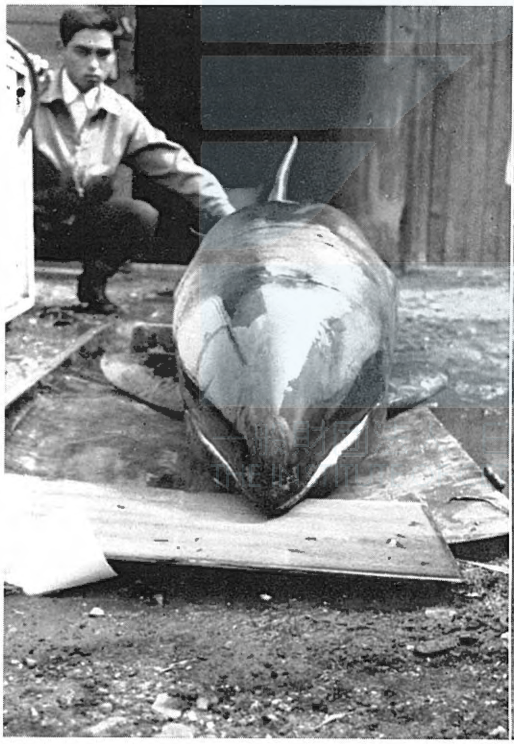
PLATE IV

Lateral and ventral views of *Peponocephala electra* No. 2 (231 cm male).

Lateral and ventral views of *Peponocephala electra* No. 2 (231 cm male), and lateral and ventral views of *Peponocephala electra* No. 3 (169 cm female). (top to bottom)

PLATE V

Dorsal and ventral views of skull (Fig. 1 and Fig. 2) and inner and outer lateral views of mandible (Fig. 3) of a young male *Peponocephala electra* stranded at Kahuku, Oahu, Hawaii on 27 June 1964. [Photographs are courtesy of Dr. F. C. Fraser of the British Museum (Natural History)]

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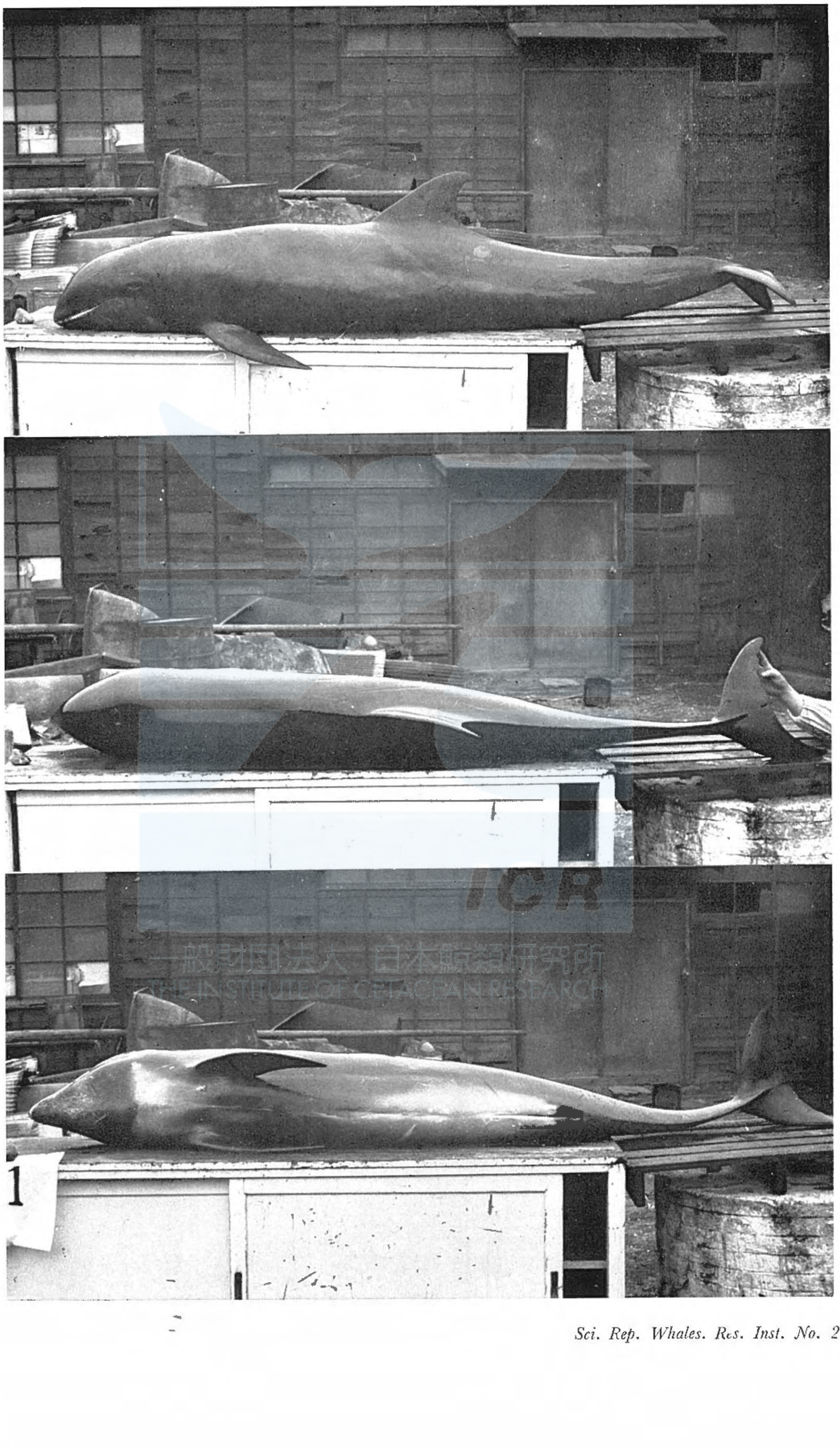
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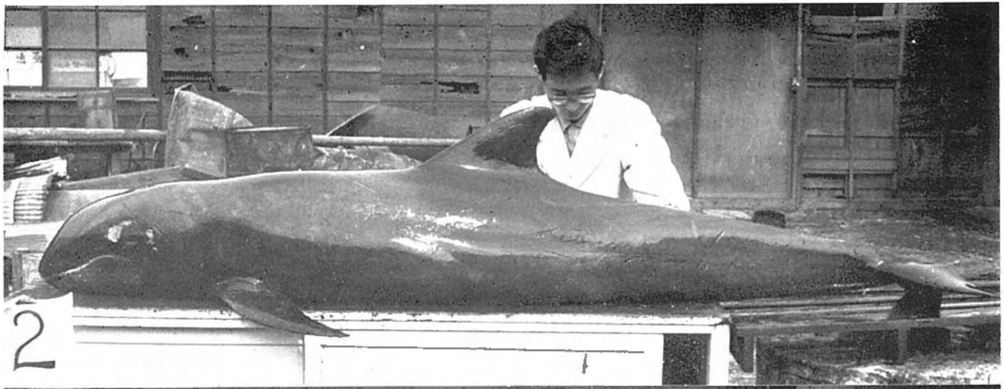
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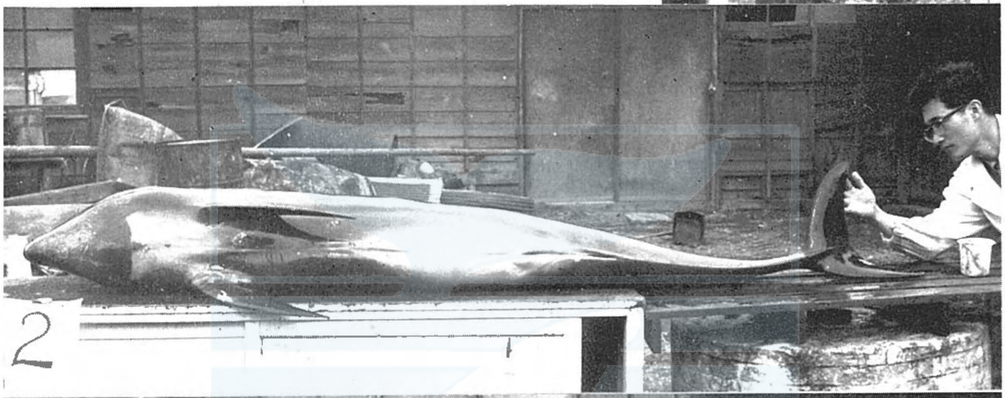
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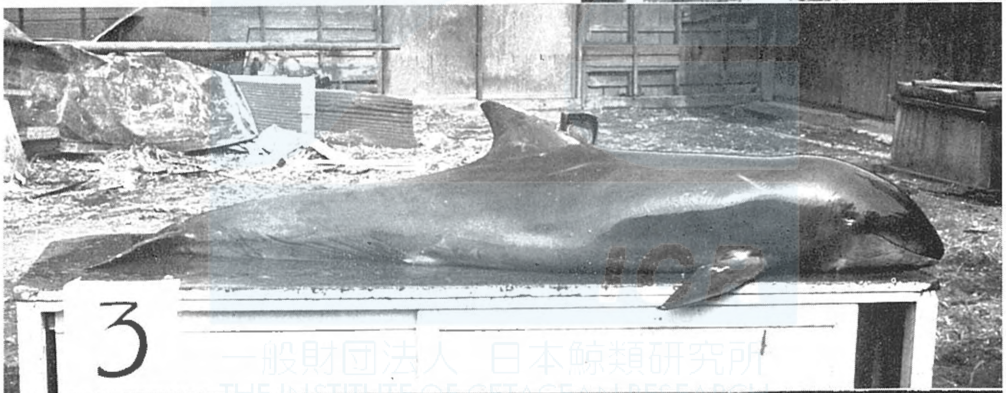
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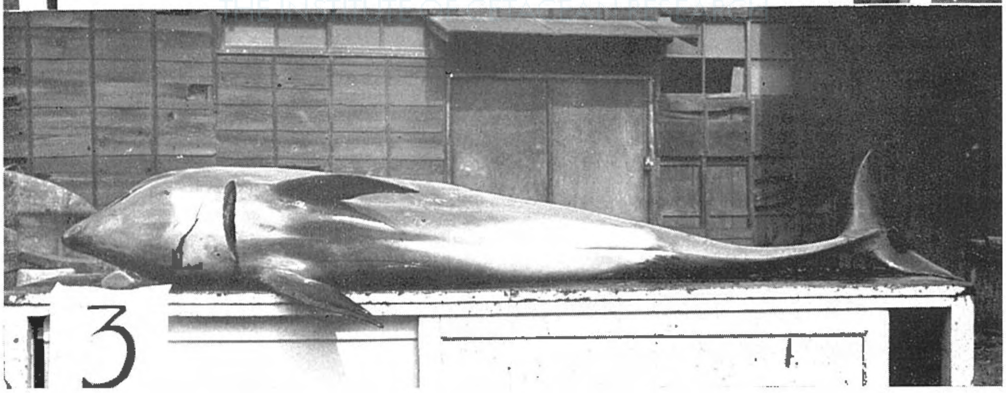
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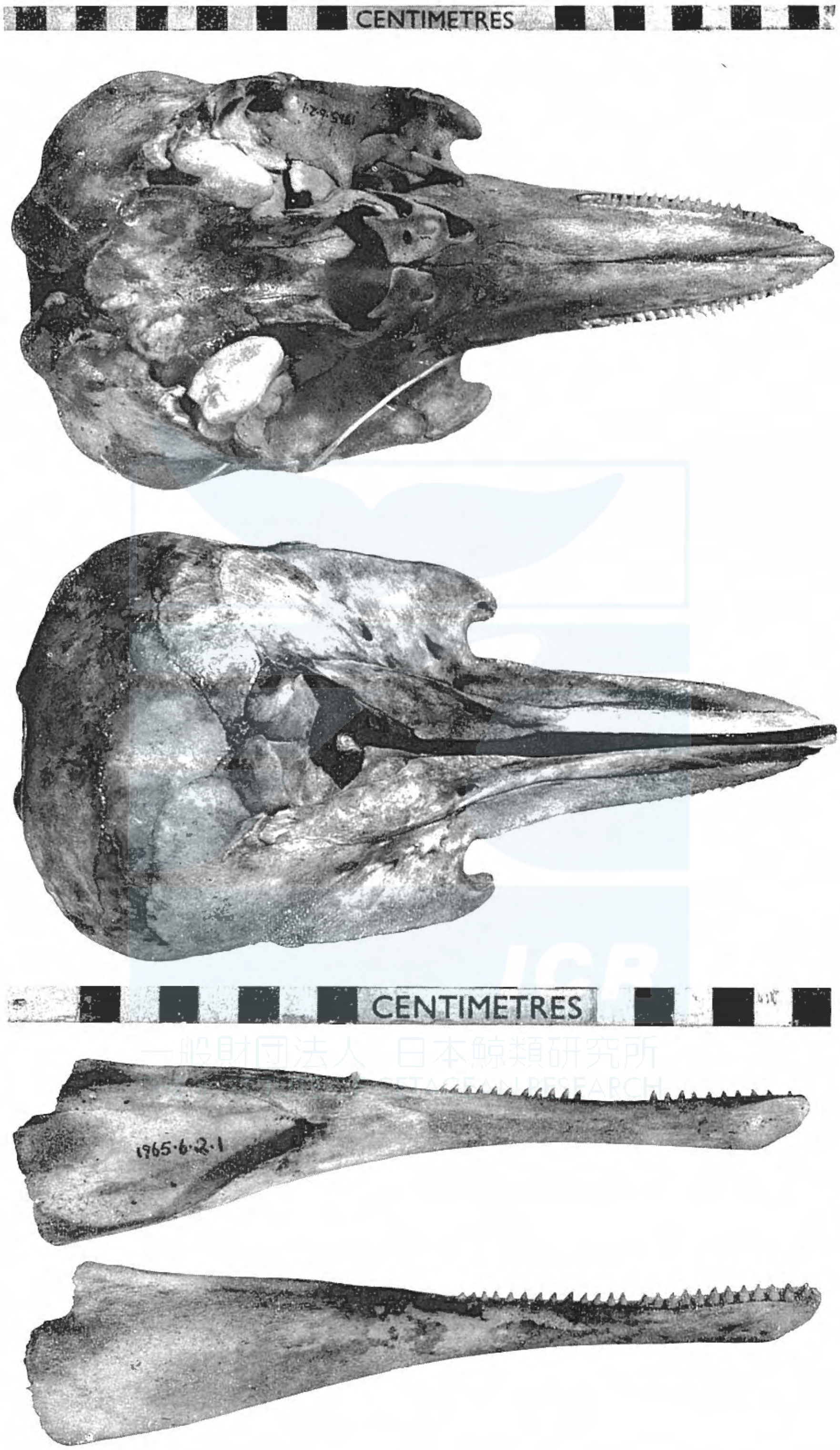
CENTIMETRES
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一般財団法人　日本鯨類研究所
THE INSTITUTE OF CETACEAN RESEARCH

PRELIMINARY EXPERIMENTS FOR DOLPHIN MARKING

MASAHARU NISHIWAKI*
MASAYUKI NAKAJIMA** AND TERUO TOBAYAMA***

INTRODUCTION

For the purpose of getting biological data on the stock of large whales, whale marking has been done for past 30 years. However, nothing has been done on the small toothed whales. There has been no demand for scientific investigations on these whales because they have little industrial value.

In Europe, these whales, mainly the common porpoise (*Phocaena phocoena*), had been caught and utilized in the past. The oil had been used for lamplight, and the oil and the meat had been used for human consumption. Now only in the Black Sea area, they are still caught and utilized. In the other European countries, none of the small toothed whales are harvested.

In Japan, exceptionally large numbers of small toothed whales are taken annually. Over 20,000, primarily the blue white dolphin and the Dall's and True's porpoise, are harvested each year for human consumption.

The actual migration routes of these small whales are poorly known. It is known that the during October through December groups of the blue white dolphin (*Stenella caeruleo-alba*) migrate from the northeast coast of Japan to the east coast of the Izu Peninsula where thousands are caught by means of the driving method. During May through July, thousand of this species are also taken on the west coast of the Izu Peninsula.

Heedless of the scientists' warnings that the stocks of this species may soon be depleted, the fishermen year after year continue to capture all ages of these dolphins including the very young. If the stock of these to be maintained, problems concerning their biology must be investigated. It is of primary importance to determine where these animals go and by what routes, once they leave the Izu shores. Occasionally this species is caught or stranded on the west coast of the United States. It is unknown if these are close relatives of those from the Japanese side.

Briefly, a marking program is essential to determine migration routes and to estimate the size of the stock from which the harvest is being made.

Dall's porpoise (*Phocaenoides dalli*) occurs on both the coasts of Japan and Western United States. True's porpoise (*Phocaenoides truei*) seems to occur only in limited waters of the Japanese side. The migration routes of both these forms are completely unknown and therefore should be studied.

In order to investigate the above problems, it is necessary to accumulate biological data based on the results of marking. Before doing the actual marking, the

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* Ocean Research Institute, University of Tokyo

** Enoshima Marineland

*** Ito Aquarium

Contribution No. 72, from The Ocean Research Institute, University of Tokyo.

staff made some preliminary experiments and the results are reported in the following.

METHOD OF EXPERIMENT

The necessity of a marking program was explained in the Introduction. However since this was a relatively new undertaking as it applies to small whales a method had to be developed. Since it would be extremely difficult to evaluate these experiments in the open sea ; they were preformed in a marine aquarium. These investigations described below were preformed on dolphins at the Enoshima Marineland which is located on the Katase Beach in Kanagawa Prefecture and at the Ito Aquarium in Shizuoka Prefecture. Both of them were built for the exhibition of captive dolphins.

Vinyl line method

This method consists of fastening a vinyl line to or in the base of the tail flukes or dorsal fin. This is usually done by making a small incision and tying the line through it.

In the Enoshima Marineland a total of 78 dolphins, consisting of the common dolphins (*Delphinus delphis*), the Pacific white sided dolphins (*Lagenorhynchus obliquidens*),

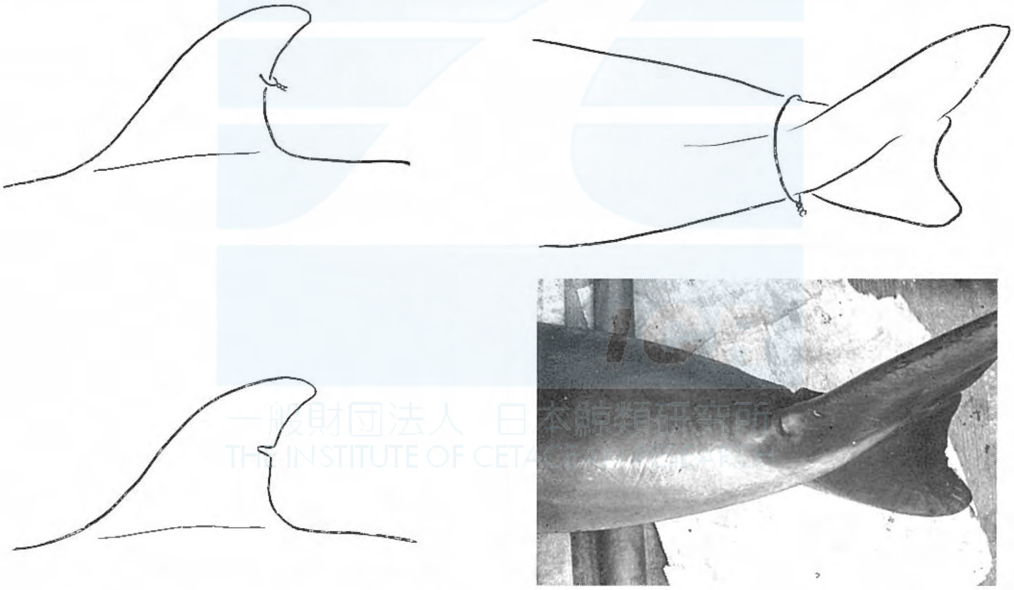

Fig. 1. Marking by vinyl line Method.
Left: Tied through the dorsal fin.
Right: Fastening to the tail.
Upper: Soon after marked.
Lower: After the mark dropped.
(A female bottle-nosed dolphin, 268 cm long marked on 11 Jan. 1958, died on 5 Jan. 1960).

the Risso's dolphins (*Grampus griseus*) and the Pacific bottle-nosed dolphins (*Tursiops gilli*) have been marked for identification prior to exhibition at the Marineland. The marks were made of copper wire 0.5 mm in diameter and covered with a vinyl tube 1 mm in diameter. Tubes of several different colors were used. An individual would be marked with one or two tubes. Also the tubes were tied by various methods by which means the animals were discriminated.

The species and numbers of these dolphins are as follows :-

1. In the 65 dolphins consisting of above four species, the lines were tied around the base of their tail flukes. (Fig. 1 right)
2. With 13 bottle-nosed dolphins a tiny incision was made with an awl in the edge of the dorsal fin and the lines were tied through it. (Fig. 1 left)

When the lines were tied around the tail, nearly all of them were dropped within a month or two. Exceptional cases were the 2 Pacific white sided dolphins which retained lines for 7 months and the one Pacific bottle-nosed dolphin which retained one for almost one year.

In the other cases, lines were tied through an incision in the dorsal fin. These lines lasted longer ; dolphins retained them for 3 or 4 months. The longest period was when a bottle-nosed dolphin retained the mark for one year and eight months.

Consideration of the causes of mark failures suggests that the copper line with its vinyl covering was too thin to be long maintained by such delicate skinned animals without doing considerable injury. The skin suffered more serious injury than did the dorsal fin. Abrasions of the skin were usually evident within a month after marking. When a mark is placed in the dorsal fin a little bleeding occurs when the incision is made. A scar results at this site. The strong up and down swimming movements of the tail flukes usually cause any lines placed on the tail to saw or cut into that member resulting in injury to that animal.

Tuna tagging method

This method is to use the same type tag as is used for tuna marking. This is a desirable type in that a number, the place to be returned etc. can be placed on the nylon tube as shown in Fig. 2. On one end of the tube is a nylon hook which is used to attach the tube to the animal. These tubes were 23.5 cm long and 3 mm in diameter. The hooks were inserted into the muscle of the animal by the use of a sharp needlelike stainless steel tube as commonly used in tuna tagging. The object of this experiment was to determine the most suitable portions of the body in which to place this type mark.

This type mark was placed on the dolphins used in this experiment immediately prior to their release in the Ito Aquarium. The dolphins were divided by species. Six rough toothed dolphins (*Steno bredanensis*) and four bottle nosed dolphins were placed in separate tanks which were each 15 m by 5 m long and 1.5 m deep.

The results of the marking are shown in Table 1.

Above experiment was done over a rather short period ; therefore the results are not conclusive but the following facts were presumed. That is, if the marks were placed into the front portions of the body, they were soon losted. Marks placed into the rear portions of the body, were comparatively more permanent. It seems that the skin itself presents some problems. In an individual which survived a while after the mark had dropped away, showed no damage in the muscular tissue. In another one which retained marks until death showed a purulent condition and damage in a small area around the maintained mark as shown in Fig. 6.

Fig. 2. Tuna tag, used in this experment. (Courtesy of Mr. David W. Waller).

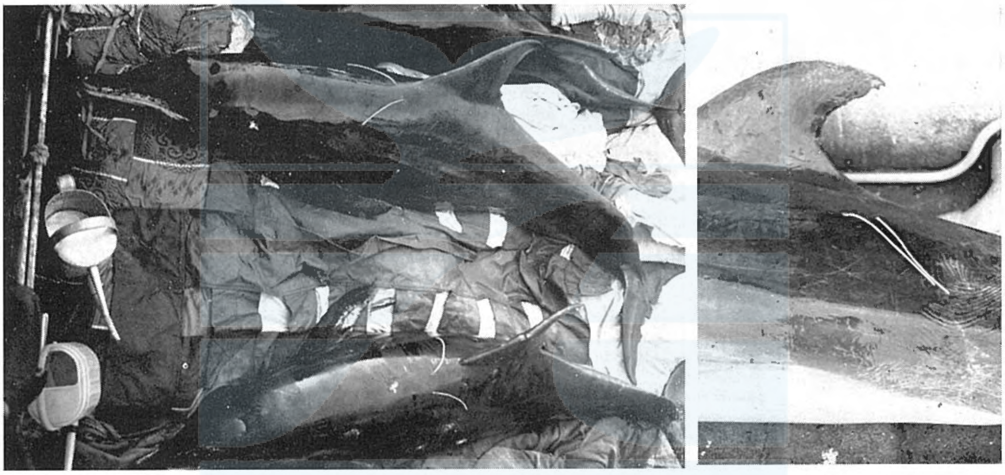

Fig. 3. Marking with tuna tag.
Left: Rough toothed dolphin (*Steno bredanensis*) during the transportation.
Right: marked below the dorsal fin, left side of a bottlenosed dolphin (*Tursiops gilli*) (Ito No. 3).

TABLE 1. RESULTS OF THE MARKING IN THE ITO AQUARIUM

Serial No.	Species of dolphin	Body length	Sex	Date marked	Date mark lost	Date dead	Remarks
1	Rough toothed dolphin (*Steno bredanensis*)	241	M	26 Sep. 1965	27 Sep. 1965	2 Oct. 1965	One mark remain until death
2	”	234	M	”	6 Oct. 1965	5 Nov. 1965	Two marks dropped same date
3	Pacific bottle-nosed dolphin (*Tursiops gilli*)	315	F	14 Oct. 1965	—	2 Nov. 1965	Two marks remain until death
4	”	286	F	”	16 Oct. 1965	3 Dec. 1965	Two marks dropped same date

Body length measured in cm.
M—male, F—Female.

Fig. 4. Marked rough toothed dolphin (*Steno bredanensis*) swimming in the Ito Aquarium. A tag on the back of the dolphin at this side already lost.

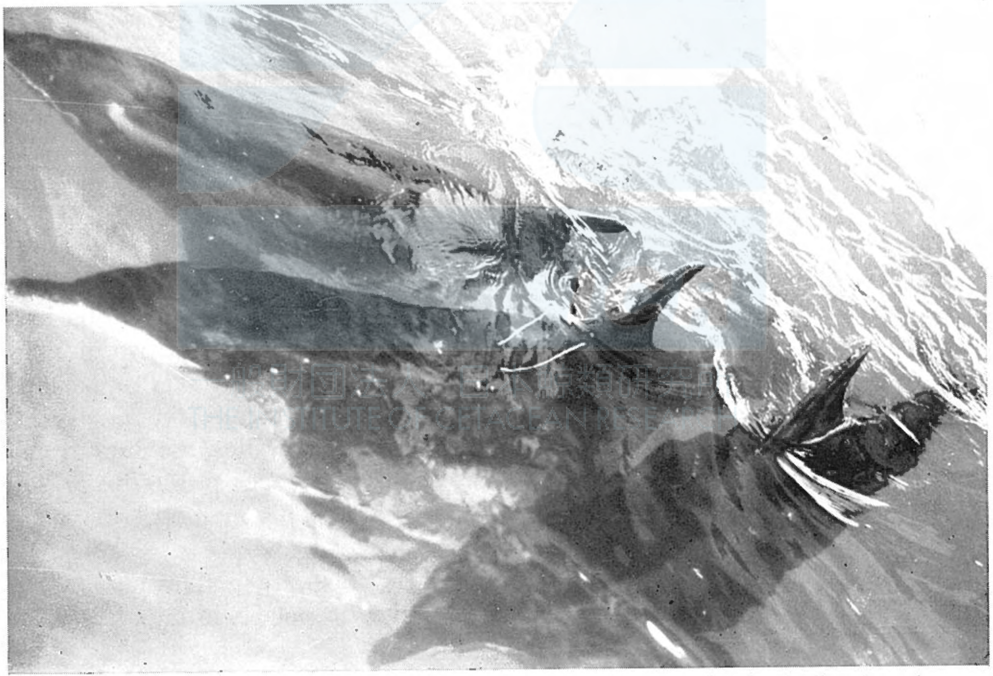

Fig. 5. Marked rough toothed dolphin (*Steno bredanensis*) swimming in the Ito Aquarium. The tags on the dolphins were lost. The dolphin in the middle still marked.

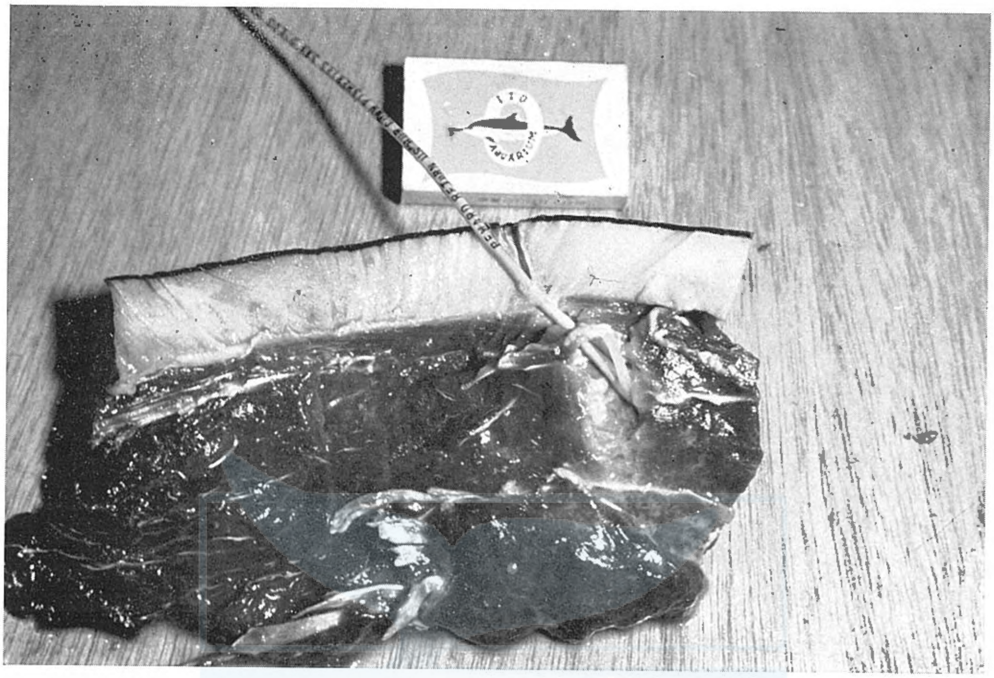

Fig. 6. Purulence condition and damage around the mark in the muscle.

It was considered that a process must be working in the tissue that rejects all foreign material which enters the skin.

In this experiment no effective method of marking small toothed whales was developed.

SUMMARY

1. The marking of the small toothed whales is necessary for the same reasons as the marking of the large whales.

2. Marking Experiments on the small toothed whales were carried on in the huge tanks of the seaquariums which are used for exhibition of captive dolphins.

3. The first experiment was to tie vinyl lines to the tail flukes or dorsal fin or cut a little portion of the skin in the flukes or fins to tie them through. Because of the water pressure against the swimming porpoises or dolphins, the lines dropped in a few month or they cut the skin and caused serious damage to the fins or flukes and sometimes endangered the lives of the animals. This method was tried in Enoshima Marineland, was decided to be " not effective ".

4. The second experiment was to use the tags which are used for tuna taggings on the dolphins in the Ito Aquarium, but they also dropped within a month and were decided to be " not effective ".

5. Both methods of tagging that were tried proved not effective. Therefore, other methods must be investigated. Some other methods that hold some promise

are as follows ; Metal bands such as used in the tagging of fur seals are a possibility. Finding a suitable location for the placement of such a tag will require investigation. Branding both by heat or extreme cold may also provide a means by which the smaller cetaceans and other marine mammals might be marked.

ACKNOWLEDGEMENT

Acknowledgment is made of the partial financial support of this investigation through a grant from the Japan Society for the Promotion of Science as part of the Japan-U.S. Cooperative Science Program.

The authors are indebted to Mr. David W. Waller of the U.S. Fish and Wildlife Service, Fishery-Oceanography Center, Tuna Resources Laboratory, La Jolla, California, for his kind cooperation to use the tuna tags, and thanks are also due to the management stuffs of the Enoshima Marineland and the Ito Aquarium for their effective cooperation.


ICR
一般財団法人　日本鯨類研究所
THE INSTITUTE OF CETACEAN RESEARCH

THYSANOESSA EUPHAUSIIDS, COMPARATIVE MORPHOLOGY, ALLOMORPHOSIS AND ECOLOGY

TAKAHISA NEMOTO

The genus *Thysanoessa* was established by Brandt for *Thysanoessa longipes*. These diagnoses were again well examined by Hansen in 1911, who gave the refined generic description (Hansen, 1911).

There have been nine or ten species of *Thysanoessa* euphausiids considered up to these days, and the morphology and ecology on those species have been contained fragmentaly in many previous papers on euphausiids (Einarsson, 1945: Boden, Johnson & Brinton, 1955: Brinton, 1962b: Ponomareva, 1962: Nemoto, 1959: 1962: etc).

This study is mainly concerned with the comparative morphology, relative growth (Allomorphosis or interspecific relative growth allometry) and discussions on the characteristic in distributions and systematic relationships of each species among the genus and other euphausiids.

In the morphological study, general external points considered as important for taxonomies and other studies are examined, and some other internal characteristics such as structures of the stomach, are also investigated. The allomorphosis among different species has been examined to consider the ecological and phylogenetic characters of each species too.

MATERIALS AND METHODS

MATERIALS

The materials of *Thysanoessa* have been collected through the following expeditions in the Antarctic and the North Pacific as shown in Table 1. They are mainly composed of two different lines of works, namely plankton net samplings and collec-

TABLE 1. EXPEDITION AND COLLECTIONS OF PLANKTONS FROM WHICH *THYSANOESSA* EUPHAUSIID SAMPLES ARE DERIVED

Cruise	Area sampled	Year	No. of sample	Remarks
North Pacific whaling expeditions	Bering and adjacent seas	1952–1964	Ca990**	Stomach contents of whales.
North Pacific whale marking	”	1955, 1958, 1959, 1960,	Ca500**	45 cm vertical haul.
KT-64-17*	South of Izu.	1964	9**	1.6 m oblique haul.
KT-65-12*	Off Wakayama	1965	5**	80 cm vertical haul.
Antarctic whaling expeditions	Antarctic	1954–1965	Ca1500**	Stomach contents of whales.
Atlantic st. M	North Atlantic		2	By courtesy of Dr. Jones.
Others	North Pacific		30**	JEDS-Cruise etc.

* Cooperative research cruise by Tansei-maru, Ocean Research Institute, University of Tokyo.

** Not all samples contained *Thysanoessa* euphausiids.

tions of euphausiids from the stomach contents of baleen whales.

MEASUREMENT OF BODY PARTS

The measuring positions are illustrated in Fig. 1, in which each indication is measured with built-in micrometer in binocular microscope. As for the length of carapace the cephalothorax length is considered as the common measureing position. But it is rather convenient to measure the edge along the lower margin of the carapace, to compare the ratios of length between anterior top and carapace denticle with the length of the carapace, and without dissection of the body. It may be called ' carapace margin length ' in this report.

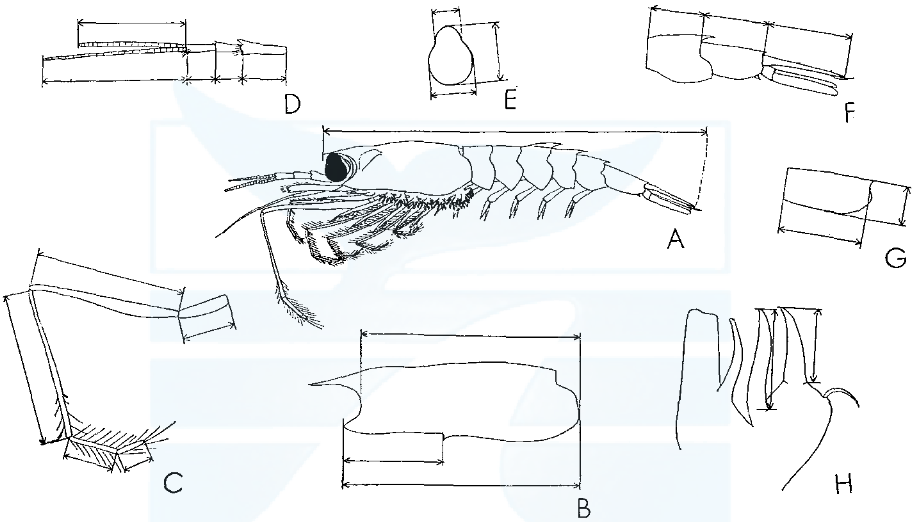

Fig. 1. Measuring positions of *Thysanoessa* euphausiid. A-Body length: B-Carapace length, carapace margin length and denticle length. C-Leg: D-First antenna: E-Eye: F-Sixth and fifth abdominal segments and telson: G-Sixth abdominal segment: H-Male copulatory organ.

The mature specimens are measured for the relative growth study. Those are males having fully developed external copulatory organs and distinct spermatophores in the reproductive organs or ducts and females with spermatophores in their thelycums or having fully developed thelycums (Einarsson, 1945).

From 5 to 15 specimens of males and females have been measured in each body length group for the allomorphosis study. About 100 specimens are selected from the mature or copulated samples, for the measurement of body length and growth, and the geographical cline examination in *T. inermis*.

KEY TO THE ADULT *THYSANOESSA* EUPHAUSIIDS

The following simple key may be applied as expressing the taxonomical characters for *Thysanoessa* euphausiids.

1a Eye has clear transverse constriction above the middle. Second pair of legs elongated.

2a Lateral margin of carapace has denticle.

3a Lateral denticle in the margin of carapace situated approximately at the middle of the carapace.

4a Strong dorsal keel and spines present at third and fourth abdominal segments.

T. longipes

3b Denticles situated considerably posterior part of the lateral margin.

5a Keels absent in the dorsal segments.

6a Sixth abdominal segment is much shorter than the sum of preceding two segments.

7a Setae on carpus and propodus of the first to third thoracic legs are as long as those of dactylus.

T. gregaria

7b Setae on carpus and propodus of the first to third legs are short and fine compared with those of dactylus.

T. parva

6b Sixth abdominal segment is longer than or as long as the sum of the two preceding abdominal segments.

8a The end of terminal process of male copulatory organ is serrated. Antennulae with the upper flagellum somewhat or considerably longer than the sum of distal peduncular joints.

T. vicina

8b The end of terminal process of male copulatory organs is not serrated. Antennulae with the upper flagellum somewhat or considerably shorter than the sum of distal two joints.

T. macrura

5b Keels present on third to fifth segments.

T. inspinata

2b Lateral margin of the carapace lacks the denticle.

T. longicaudata

1b Eye has only slight transverse constriction or without clear constriction. Second pair of legs are not so elongated or not elongated.

9a Lateral margin of carapace with lateral denticle.

T. raschii

9b Lateral margin of carapace without lateral denticle.

10a Dorsal keels present from first to fifth abdominal segments.

T. spinifera

10b Dorsal keel absent, only spines on fifth and sixth or sixth abdominal segments.

T. inermis

MORPHOLOGY AND ALLOMORPHOSIS

FIRST ANTENNAE

The first antenna, the peduncle and flagellum are often considered as sexual and taxonomical characteristics. In *Thysanoessa* euphausiids, they are rather simple

TABLE 2. RATIO AND NUMBER OF ARTICULATION OF ANTENNULAR FLAGELLUM IN *THYSANOESSA* EUPHAUSIIDS

		Example of Ratio for peduncle (%)	No. of articulation
Longer group	*T. spinifera*	Ca 90	39–50
	T. raschii	Ca 120	50–54
	T. inermis	Ca 93	27–28
Intermediate group	*T. longicaudata*	Ca 89	22–30
Shorter group	*T. vicina*	Ca 40	9–14
	T. macrura	Ca 52	9–13
	T. inspinata	Ca 56	16–18
	T. longipes	Ca 56	16–19
	T. gregaria	Ca 48	10–10

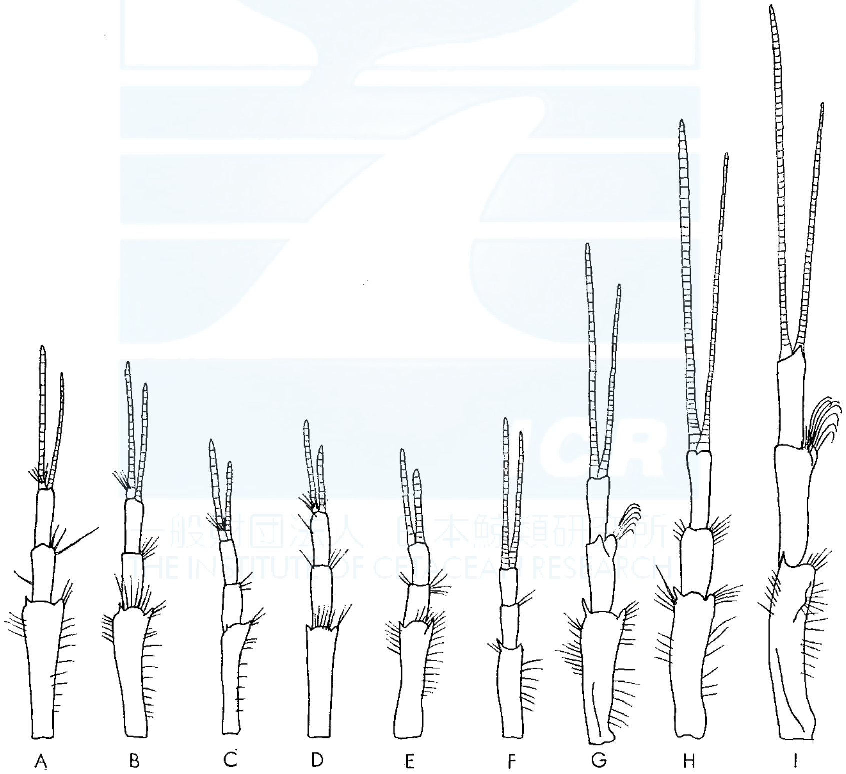

Fig. 2. Male first antenna of *Thysanoessa* euphausiids. A-*T. longipes*,B-*T. inspinata*, C-*T. vicina*, D-*T. macrura*, E-*T. gregaria*, F-*T. longicaudata*, G-*T. inermis*, H-*T. raschii*, I-*T.spinifera*, x10.

and Hansen (1911) used the length of antennule with the upper flagellum as the taxonomic character for the closely related *Thysaneossa macrura* and *T. vicina*. Three types of flagellum, longer, intermediate and shorter types are observed as shown in Fig. 2. The number of the articulations in upper and lower flagella are also divided into two or three groups.

The flagellum of longer group is rather tough in preserving, but those of shorter group are fragil especially in the intermediate species *T. longicaudata*. In the longer groups, the articulations are ranging from 20 to some 60 and lengths of longer flagellum are almost the same or longer than the peduncles. On the other hand, the shorter group has less than 20 articulations and the flagella are shorter than the peduncles. The distal fringes of flagellum are almost the same among specimens of *Thysanoessa* euphausiids. They have usually four small setae in the distal ends of the upper and lower flagella. One of the four setae has broad and tough base which sometimes two storied structure.

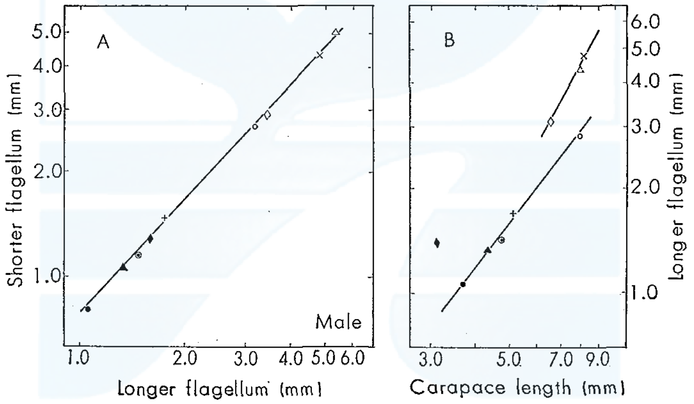

Fig. 3. Allomorphosis in *Thysanoessa* euphausiids. Relation between longer and shorter flagella, and carapace length and longer flagellum in males. Open circles-*T. longipes*, Closed circles-*T. gregaria*, Crosses-*T. inspinata*, Oblique crosses-*T. spinifera*, Open triangles-*T. raschii*, Closed triangles-*T. vicina*, Open lozenge-*T. inermis*, Closed lozenge-*T. longicaudata*, Circles with dot- *T. macrura*. Symbols are the same in following figures.

The sexual dimorphism in the peduncles of *Thysanoessa* euphausiids is typical in *T. inermis* and *T. spinifera*. Einarsson (1945) considered the possible relationships of *T. inermis* to the Pacific species *T. spinifera* which has the antennule armature of which bears close resemblance to that of *T. inermis*. The male *T. inermis* has a rounded lobe on its inner side, in the first antennular segment, bearing slightly curved spines (Einarsson, 1945).

The relation between the longer flagellum and the carapace length as allomorphosis gives three allometric tribes as shown in Fig. 3. The longer group, namely *T. inermis*, *T. spinifera* and *T. raschii* form one tribe, and *T. longicaudata* which has intermediate number of articulation between shorter and longer groups, forms another point alone. The shorter group of other species runs the same regression both in males and females. *T. longicaudata* ecologically bears the wider distribution from temperate and boreal Atlantic Ocean to the Arctic, from the atlantic by 80°N (Einarsson, 1945), than other *Thysanoessa* euphausiids belonging to the shorter group. On the other hand, it also covers the neritic and other shallow waters like the longer group.

CARAPACE

The carapace of the *Thysanoessa* group is various, but the rostrum is always well developed in every species, which is one of the generic character of the *Thysanoessa* (Hansen, 1911). All species have keels in the center of rostrum part of the carapace, longer or short, and seven species out of ten have denticles in the lateral margin of the carapace. The general outlines of each species are illustrated in Fig. 4 which do not differ from those of other euphausiids.

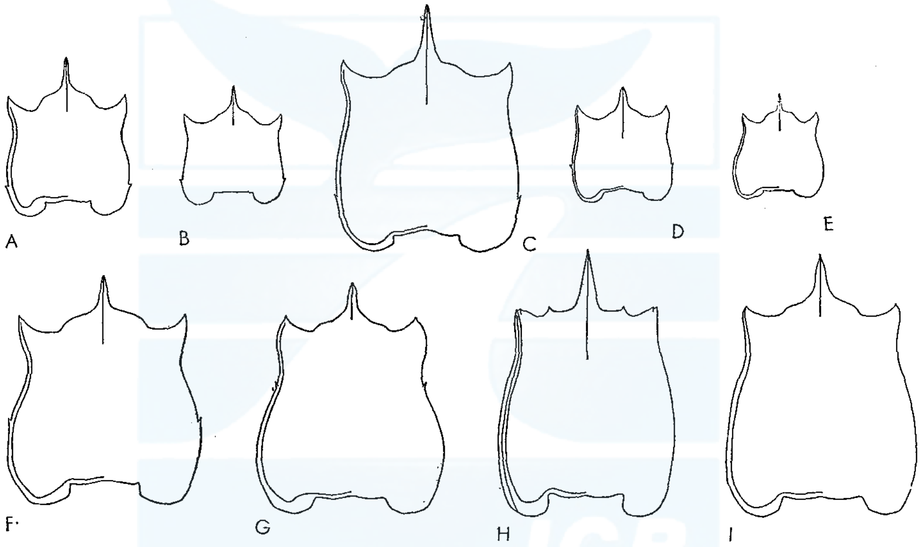

Fig. 4. Carapace of *Thysanoessa* euphausiids. A-*T. inspinata*. B-*T. vicina*. C-*T. macrura* D-*T. gregaria*. E-*T. longicaudata*. F-*T. longipes*. G-*T. raschii*. H-*T. spinifera*. I-*T inermis*.

Rostrum and keel

All *Thysanoessa* species have well developed spear pointed rostrums, but *T. gregaria*, *T. raschii* and *T. inermis* have rather broad oblong tops. Other *Thysanoessa* have acute distal ends when they are pressed on the deck glass for observations.

Thysanoessa spinifera have the most acute triangular, and longest rostrum, which is narrower than other *Thysanoessa* euphausiids. Three species, *T. longipes*, *T. vicina* and *T. macrura* have broader tryangular rostrums. The tip of the rostrum of *T. longipes* is somewhat slender and differes from other two species. The general shape of the rostrum of *T. macrura* is closely related to that of *T. vicina*. And it is also interesting that the rostrum of *T. raschii* is similer to *T. gregaria*, which is different conssiderably in other external points. *T. gregaria* has oblong and broader rostrum, and the shape of the keel in rostrum is different from *T. raschii*. The vertical sections of the keel in the rostrum and the carapace show also two types. The keels in the rostrum of *T. inermis* and *T. raschii* are rather gentle crest ridges, but *T. longipes*, *T. gregaria*, *T. vicina* and *T. macrura* have the sharp ridges as shown in Fig. 5. The geographical variation in rostrum of carapace in *Euphausia diomediae* is reported by Hansen (1911). Some taxonomical importance in the strech of rostrum in *Thysanopoda*, *T. aequalis* and *T. subaequalis*, is also obtained (Boden & Brinton, 1957). No geographical difference is observed in *Thysanoessa* euphausiids in rostrums in this studies.

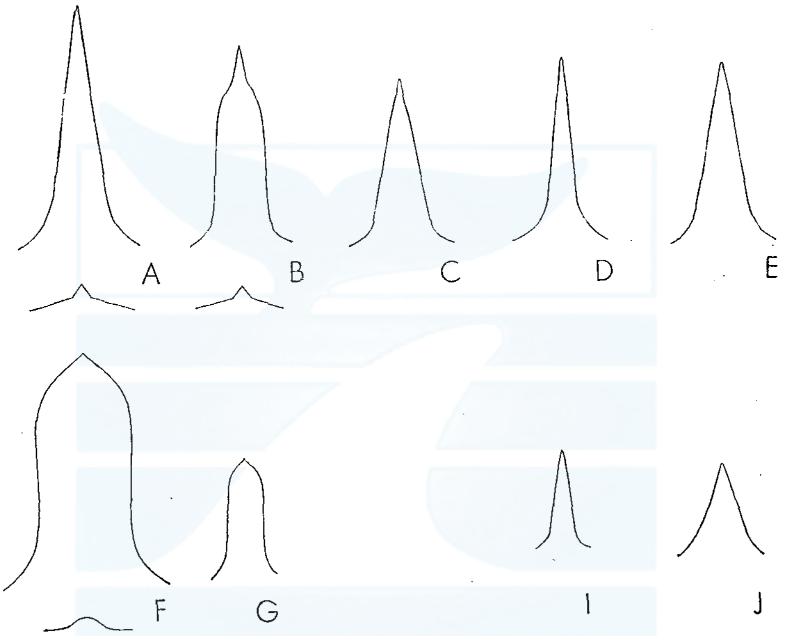

Fig. 5. Rostrums of male *Thysanoessa* euphausiids. A-*T. spinifera*: B-*T. inermis*: C-*T. longipes*: D-*T. inspinata*: E-*T. vicina*: F-*T. raschii*: G-*T. gregaria*: I-*T. longicaudata*: J-*T. macrura*.

The edge in the cove between rostrum and the anterior top of the margin of the carapace swells out in the larger *Thysanoessa*, *T. macrura*, *T. inspinata*, *T. raschii* and *T. inermis*. But it is not so clear in *T. gregaria* and *T. vicina*. *T. spinifera* has a prominent supraorbital spine in the top of the swell. The sexual dimorphism is not observed in all species but *T. raschii*, the male of which has broader rostrum than females. In the younger stages of *Thysanoessa*, the rostrums are also well developed. But their tip ends are not so pointed and they have rather blunt ends.

The anterior top of lateral margin of the carapace

Thysanoessa euphausiids have pointed ends except *T. spinifera* which has two points in the anterior top of the carapace along the supraorbital cove. As illustrated in Fig. 6, *T. gregaria*, *T. longipes* and *T. raschii* have all pointed ends, the group also includes other species but *T. spinifera*. *T. spinifera* has one keel like spine slightly upper positions of the end of the margin of the carapace. The end of the margin of the carapace also makes point, from which two streaks run along the edge of the lateral margin of the carapace.

Lateral denticle

Seven species out of ten in *Thysanoessa* have lateral denticles in the lower margin of the carapace, and other three species completely lack the denticles.

Lateral denticle present *Thysanoessa raschii*
T. longipes, *T. gregaria*, *T. macrura*, *T. vicina*, *T. inspinata*, *T. parva*.
Lateral denticle absent *T. inermis*, *T. spinifera*, *T. longicaudata*.

All species are bearing only one denticle in one side margin of the carapace.

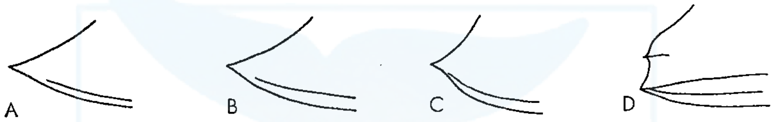

Fig. 6. The anterior top of the lateral margin of the carapace in *Thysanoessa* euphausiids. A-*T. gregaria*, B-*T. longipes* C-*T. raschii*, D-*T. spinifera*.

Fig. 7. Carapace denticles in *Thysanoessa* euphausiids. A-*Thysanoessa longipes*. B-*Thysanoessa raschii* deformed denticle. C-*Thysanoessa raschii*.

There are two types of lateral denticles of carapace. One is *Thysanoessa raschii* bearing a acute spine in the anterior part of which is also rather completely free from the margin of the carapace. On the other hand, *T. longipes* has the acute but narrower base spines which directly rise up from the margin of the carapace in the posterior position. *T. gregaria*, *T. macrura*, *T. vicina* and *T. inspinata* all show latter characteristic and *T. parva* also possibly belong to this group.

In one specimens of *T. raschii* a deformed denticle which has two character of them is observed as illustrated in Fig. 7.

T. gregaria, *T. vicina* and *T. inspinata* have sometimes very incomplete lateral denticles. Especially, *T. gregaria* sometimes completely lacks them. Samples of *T. gregaria* collected in KT-64-17 and *T. macrura* collected in the Antarctic also lack the lateral denticle in the lower margin of the carapace.

In other species of euphausiids, the local difference of the presence of this denticle is reported on *Nematoscelis tenella*. The male *Nematoscelis* has this denticle in the Atlantic, but it is absent in Pacific specimens. (Boden, Johnson & Brinton, 1955). Recently Mclaughlin (1965) described two forms, denticled and original forms of *Nematoscelis difficilis*. Mclaughlin described that the prominent lateral denticle, varying somewhat in size, occurres on the posterior third of the inferior margin of the carapace about *Nematoscelis difficilis* denticle form, (Mclaughlin, 1965), but it has another ' no-denticle ' form.

Position of lateral denticle

The position of lateral denticle is a very important taxonomic characteristic especially on *Thysanoessa longipes* and *T. inspinata* (Nemoto, 1963). Hansen also used the position of the lateral denticle for the taxonomic considerations on *Thysanoessa* groups. He (1911) stated that lateral margins of the carapace with a denticle at the middle on *Thysanoessa longipes* and denticles situated before the middle of the lateral margin of the carapace on *T. raschii*. As for *Thysanoessa gregaria* group, that the denticles is conspicuously posterior the middle of the lateral margin, is also noted as the taxonomic character by him.

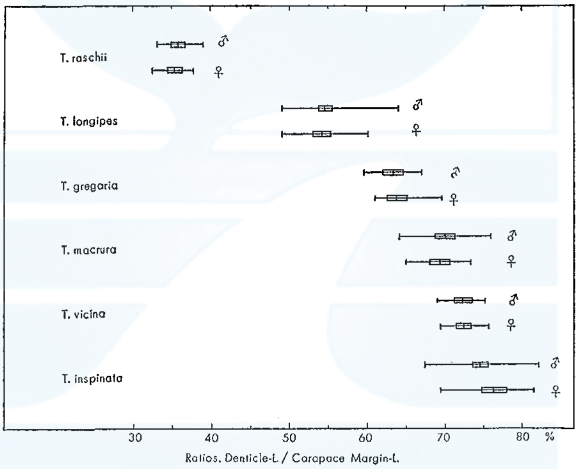

Fig. 8. Ratios, denticle length divided by carapace margin length of the carapace of *Thysanoessa* euphausiids in the world ocean. Range, mean and each standard deviations are illustrated.

The positions of lateral denticles expressed as ratios, denticle length / carapace margin length are shown in Fig. 8. There are fairly good expressions of the species range, which also confirmes the taxonomic importance of them. And there is few difference between males and females in all species.

The denticles of *T. longipes* is situated at the middle of the lateral margin, but *T. inspinata*, the closely related species of the *T. longipes*, has its denticle in far posterior position as illustrated in Fig. 8. The position of the denticles in *T. macrura* and *T. vicina* are rather similer in their positions, in which *T. vicina* shows slightly posterior position of denticles. In other closely related euphausiids species, *Euphausia pacifica* and *E. nana* established by Brinton (Brinton, 1962a) also show such tendency. The larger *E. pacifica* has the comparatively anterior lateral denticles as shown in Fig. 9, and *E. nana* from the East China sea has posterior lateral denticles. There is very clear difference between typical *E. pacifica* in the northern waters and *E. nana* in the Eastern China sea, however, some vague samples have been collected from the intermediate regions in the southern waters of the sea of Japan. These samples collected from Tsushima waters are now under examination.

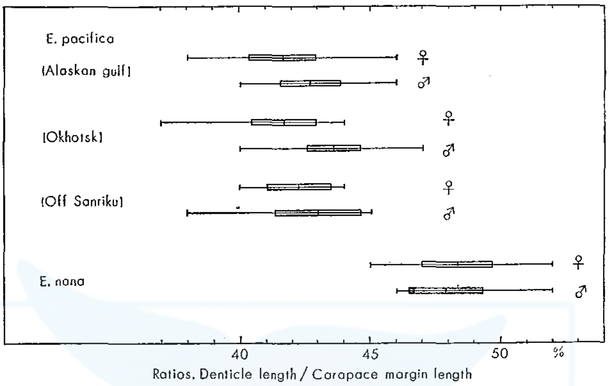

Fig. 9. Ratios, denticle length/carapace margin length of *Euphausia pacifica* and *E. nana*. Ranges, means and standard deviations are illustrated.

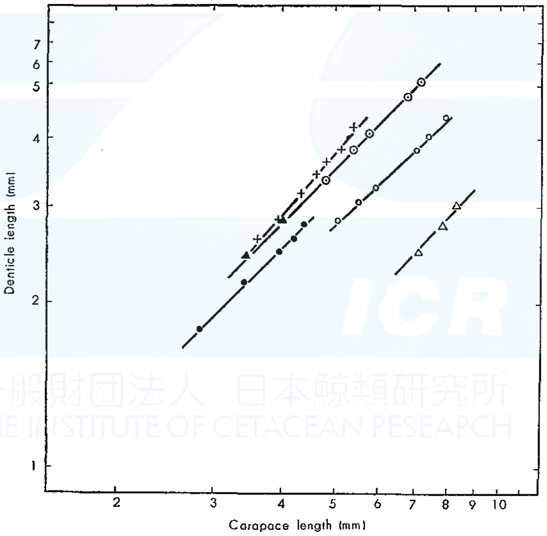

Fig. 10. Allomorphosis in carapace of *Thysanoessa* euphausiids. Relation between denticle length and carapace margin length.

Allomorphosis in the position of denticles

The allomorphosis in the relation between denticle length and carapace length for *Thysanoessa* group is given in Fig. 10. There is no difference between males and females in all species. In a previous report (Nemoto, 1963), I noticed the clear different allometry lines in *T. longipes* and *T. inspinata* which is one of the critical point for dividing those two species. The relative growth coefficient for *T. longipes* is 0.973 and *T. inspinata* 1.19. *Thysanoessa macrura* and *T. vicina* draw the same allometry line, the growth coefficient of which is 1.000.

Thysanoessa gregaria shows growth coefficient 0.925 which differs from those of other *Thysanoessa*. *Thysanoessa raschii* draw the line apart from other species as shown in Fig. 10. Those growth coefficients are as follows.

Thysanoessa raschii	1.034
longipes (adult)	0.973
macrura & vicina	1.000
gregaria	0.925

EYE

Shape and arrangement

The eye of *Thysanoessa* euphausiids are usually higher than broad with transverse constrictions or sometimes almost circular (Hansen, 1911 : Bodon, Johnson & Brinton, 1955). The ratio, lateral length/vertical length and the general shape of eyes are illustrated in Fig. 11. *Thysanoessa raschii* has almost completely circular and broad eye, and the ratio of lateral and vertical length is about 95%. But from the side view, the upper part is rather compressed as compared with *Euphausia* which is almost circular. *T. spinifera* agrees with *T. raschii* in this point showing the ratio 95%, and the upper half of the eye is also compressed. *T. inermis* has a little higher eyes showing the ratio about 87%, but no heavy constriction is observed in the fully developed specimens. The compression in the upper part in *T. inermis* is heavier than *T. raschii* and *T. spinifera*.

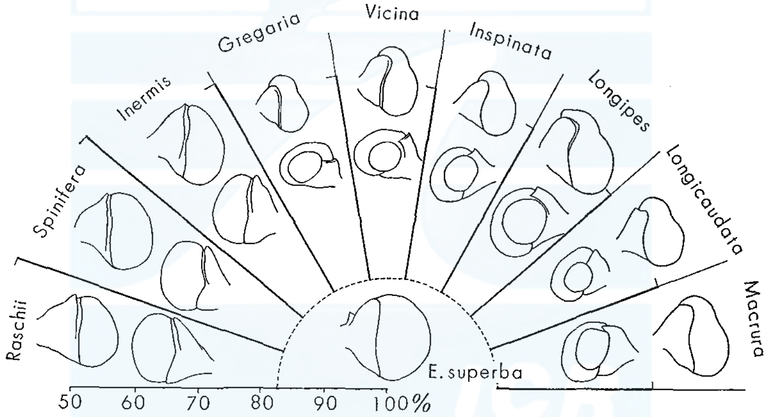

Fig. 11. Profiles and ratios of the width of the eye divided by the vertical length of bilobate eye in *Thysanoessa* euphausiids in the world ocean.

As it has been discussed by Hansen (1911), and Einarsson (1942), the younger specimens of *T. inermis* shows more higher than broad eyes. Many examples of the younger juvenile stage after the furcilia possess more typical *Thysanoessa* eyes also in *T. inermis*, but *T. longipes* of the same vertical size shows the narrower upper part of the eye and constriction. The ratio, lateral/vertical length is about 81% in *T. inermis* and 78% in *T. longipes*, latter value of which is not so different as those in adults.

TABLE 3. ARRANGEMENT OF EYES IN EUPHAUSIIDS

Species and genus	Eye	Constriction	Size Upper Lower	Crystalin cones visible	Depth of living range
Bentheuphausia	(+)	—	—	—	500–4000
Thysanopoda	+	—	—	—	0–4000
Nyctiphanes	+	—	—	—	0– 300
Meganyctiphanes	+	—	—	—	0– 300
Pseudeuphausia	+	—	—	—	0– 150
Euphausia	+	—	—	—	0– 300
Thysanoessa raschii	+	—	—	—	0– 200
„ *inermis*	+	—	—	—	0– 300
„ *spinifera*	+	—	—	—	0– 300
„ *longipes*	+	+	Upper < Lower	—	0– 500
„ *inspinata*	+	+	„ < „	—	0– 500
„ *gregaria*	+	+	„ < „	—	0–1000
„ *parva*	+	+	„ < „	—	500–2000
„ *macrura*	+	+	„ < „	—	0– 300
„ *vicina*	+	+	„ < „	—	0– 300
„ *longicaudata*	+	+	„ < „	—	0–1000
Tessarabrachion	+	+	„ < „	—	0–1000
Nematoscelis	+	+	„ ≷ „	—	0–1000
Nematobrachion	+	+	„ > „	—	100–1000
Stylocheiron	+	+	„ < „	+	0–1000

The general arrangement of the eyes in euphausiids are shown in Table 3. *Thysanoessa* euphausiids are divided into two groups. One is having the constricted eyes group and the other is round eyes group. *T. raschii* having rounded eyes is living in the shallow waters, and *T. spinifera* also is mainly living in the shallow waters although it is sometimes found in the deeper waters along the edge of coastal regions (Banner, 1954).

Other euphausiids bearing constricted eyes live in broader range in vertical distribution in the sea. *Thysanoessa, Tessarabrachion, Nematoscelis, Nematobrachion,* and *Stylocheiron* have the constricted eyes. Those species have rather bigger eyes and the range of the vertical distributions attain deeper waters in the sea except some Antarctic and Arctic species of *Thysanoessa*. The upper and lower part of the constricted eyes are sometimes about same size and sometimes different. In *Thysanoessa*, the lower part is generally bigger than the upper part. In *Stylocheiron* and *Tessarabrachion*, the lower parts are also larger than the upper parts. The lower parts of some species are larger than the upper but smaller in other *Nematoscelis*. The upper parts are generally larger in *Nematobrachion* euphausiids.

The size of the eye

The male has larger eyes than females in general comparing with the body size. The series of the relative size indicates that the smaller the body length is, the larger the eye is among the gregaria group, which has constricted eyes in adults. And this is not the same in *T. spinifera*, *T. inermis* and *T. raschii*.

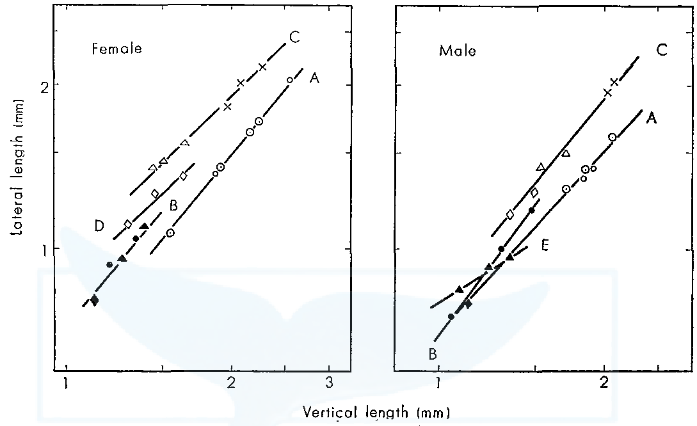

Fig. 12. Allomorphosis in eye of *Thysanoessa* euphausiids in the world ocean. Relations between lateral and vertical length. A-*longipes, macrura:* B-*gregaria, vicina, longicaudata:* C-*raschii, spinifera:* D-*inermis*

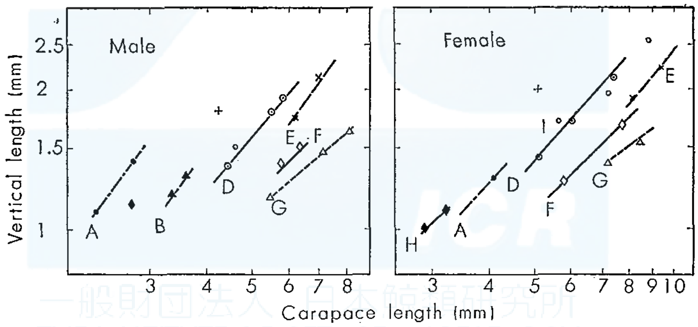

Fig. 13. Allomorphosis in eye of *Thysanoessa* euphausiids. Relation between vertical length of eye and carapace margin length.

Allomorphosis in eyes

The relation between vertical and lateral lengths of eyes in adult specimens are plotted in chart as shown in Fig. 12. There are three or four allometry groups both in males and females group.

T. macrura and *T. longipes* form the same line, the coefficient of relative allomorphosis of which is about 1.2. But *T. gregaria* and *T. vicina* shift the line, although the constriction in the upper part of eyes is positive, and the growth coefficient of the allometry is ranging 1.33–1.57. *T. spinifera*, *T. inermis* and *T. raschii* also form one allometry group, but *T. raschii* shifts to a little high initial growth index in females as illustrated in Fig. 12.

The relative growth between the vertical length of the eye and carapace length is very various as illustrated in Fig. 13. There are many allometry lines in males. Only *T. macrura* and *T. longipes* take the same line, but *T. gregaria*, *T. vicina*, *T. raschii*, *T. inermis* and *T. spinifera* occupy different allometry lines respectively. That *T. gregaria*, *T. vicina*, and *T. macrura* differ considerably in the relative growth indices between carapace length and the vertical length of eyes is possibly due to two reasons. The relative growth for the carapace in *T. longipes* is the same as *T. macrura*. The body length of *T. longipes* is about the same as *T. macrura*, and they are both living in cold pelagic waters. They are considered to be surface living euphausiids shallower than 500 meter and the ecological position in the sea may be related with each other both in northern and southern hemisphere.

TABLE 4. RELATIVE GROWTH COEFFICIENT IN ALLOMORPHOSIS BETWEEN VERTICAL AND LATERAL LENGTH IN EYES OF *THYSANOESSA* EUPHAUSIIDS

Species	Coefficient	
	Male	Female
T. macrura, T. vicina	1.16	1.19
T. gregaria	1.33	1.57
T. spinifera, T. inermis	1.17	1.17
T. raschii	(1.17)	(1.17)

On the other hand, *T. gregaria* group, *T. gregaria*, *T. macrura* *T. vicina* are different considerably in males. in *Thysanoessa* euphausiids, the sexual difference in the body length of males and females is very clear in *T. gregaria* and other species which have bilobate eyes. The type of eyes of females in those species are that of younger stages of the same species eyes of males especially in *T. gregaria* and *T. vicina*.

The upper part of bilobate eye of males swells like horse bean but guiter-shaped in females. This character is not so clear in *T. macrura*, *T. longipes* and *T. longicaudata*. In the younger stages of some *Thysanoessa* euphausiids, eyes are rather related to each other even in the *T. inermis*. The eye of *T. inermis* in about 5 mm specimen is nearly the same with that of *T. longipes* in the same body length as illustrated in Fig. 14 and former discussions. This shape is that of females in adults in *T. gregaria* group as illustrated also in Fig. 14. The female type is becoming to the younger type is already pointed out as for many other species as the evolution in speciations. This sexual difference may be firstly connected to the step of the development of variations in the body parts (Eimer, 1890).

Brinton (1962b) considered the evolution and local forms of *Stylocheiron affine* and *S. longicorne* in the Pacific areas according to the combinations of the variations in the ratios, length of sixth abdominal segment divided by depth and width of lower section of eye divided by width of upper section. This combination is also checked for *Thysanoessa* euphausiids in which possible relationship among species is also suggested. The inter specific differences in the ratios in those points nearly coincide with other characters.

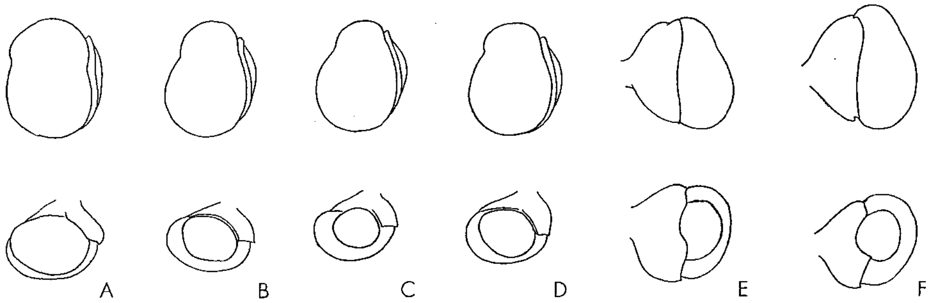

Fig. 14. Eyes of *Thysanoessa* euphausiids. A-Male *T. gregaria*, B-Female *T. gregaria*, C-Female *T. vicina*, D-Male *T. vicina*, E-Young *T. inermis* in juvenile stage 5 mm, F-Young *T. longipes* in juvenile stage 5 mm.

Among *Thysanoessa* euphausiids, *T. inermis*, *T. raschii* and *T. inermis* make group apart from other species, although species contained show sexual dimorphism. Except *T. gregaria*, other four species form group of high ratio in the upper and lower parts of eye and fifth and sixth abdominal segments. The former group scarcely show the differences in two points, but *T. gregaria* and *T. vicina* show the sexual dimorphism in the ratio of abdominal segments. *T. longicaudata* and *T. longipes* show little difference in the ratio of eyes. On the other hand, *T. gregaria* shows heavy sexual dimorphism in the ratio of eyes.

ABDOMINAL SEGMENTS

Keel and abdominal spines

The arrangement of keels and abdominal spines are given in Table 5. Among nine species of *Thysanoessa* euphausiids treated here, three species have

TABLE 5. ARRANGEMENT OF KEELS AND ABDOMINAL SPINES ON THE ABDOMINAL SEGMENTS IN *THYSANOESSA* EUPHAUSIIDS

	Abdominal segments					
Species	1	2	3	4	5	6
T. raschii	—	—	—	—	—	—
T. inermis	—	—	—	(ksp)	(k)sp	SP
T. spinifera	K	K	K	KSP	KSP	SP
T. longipes	—	—	KSP	KSP	KSP	SP
T. inspinata	—	—	K	K	K	SP
T. longicaudata	—	—	—	(k)	(k)	—
T. gregaria	—	—	—	—	—	(sp)
T. parva	—	—	—	—	—	—
T. vicina	—	—	—	—	—	—
T. macrura	—	—	—	—	—	—

K: Well developed dorsal keel. SP: Well developed dorsal spine. Smalls show the presence of keel or spines, but they are not well developed. Extraordinary ones are in bracket.

dorsal keels and four species have abdominal spines. Dorsal keels are well developed in *T. spinifera*, *T. longipes* and *T. inspinata*. *Thysanoessa raschii*, *T. gregaria*, *T. parva*, *T. vicina* and *T. macrura* have no developed keel and no spine. *T. inermis* has only abdominal spines on fifth and sixth segments or sixth segment only, but some extraordinary specimens have also keels and spines on fourth segment. Two closely related species, *T. longipes* and *T. inspinata* have keels on third, fourth, fifth segments, and spines on sixth segments. But well developed abdominal spines are present on third, fourth and fifth segments of *T. longipes* alone. *Thysanoessa longicaudata* has no clear keel and spine but it is considered to belong to *T. longipes* group. In some younger furcilia stage 5, slight keels are described on third and fourth abdominal segments by Einarsson (1945) and some present specimens from the station M also bear keels on fourth and fifth segments.

Thysanoessa gregaria and three other *gregaria* type euphausiids are without any keels and abdominal spines.

Thysanoessa spinifera has keels on the first, second, third, fourth and fifth segments and abdominal spines of fourth, fifth and sixth segments. The presence of clear keels on first and second segments is only found in *T. spinifera*.

Two and one spine forms of Thysanoessa inermis

In a previous report, (Nemoto, 1959), I described the possible difference beween one and two spine forms of *Thysanoessa inermis* in the Atlantic and the Pacific.

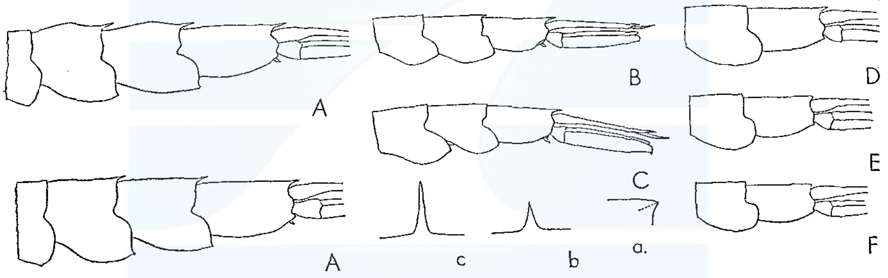

Fig. 15. Three spine, two spine and one spine forms of *Thysanoessa inermis*. A-Three spine form *T. inermis*: B-Two spine form: C-One spine form: D-10.5 mm larva: E-9.4 mm larva: F-8.2 mm larva. a-fifth dorsal segment in one spine form: b-fifth dorsal segment in two spine form: c-sixth dorsal segment in two spine form.

According to Hansen (1911), the majority of specimens taken in the Pacific has a dorsal spine which semetimes proportionaly long, sometimes rather short, and sometimes nearly or completely rudimentary, in the fifth abdominal segment and in rare case wanting. On the other hand, Einarsson (1945) stated none of the numerous specimens examined by him had shown even the slightest sign of a spine on the fifth segment in the Atlantic. Hansen (1911) also saw some specimens, taken off Cape Cod, with a conspicuous spine, while in another it was rudimentary I found none of the two spine form in the sample of Okhotsk Sea in my previous investigation, (Nemoto, 1959). I have examined many specimens of *Thysanoessa inermis* in the Okhotsk Sea after then, and the average values 16.7% in females and 11.1% in males are obtained by present examination as the percentage occurrence of two spine form. Further the occurrences of two and one spine forms of *Thysanoessa inermis* are examined on the materials collected from the Bering Sea to the waters of the Gulf of Alaska in the North Pacific. The occurrences of one and two spine form of *Thysanoessa inermis* are shown in Fig. 16. The two spine form is about 50 to 60 percent of the total in the waters off Kamtchatka, and about 60 to 70 percent in the eastern waters of the Bering Sea. The two spine form occupies about 75 or more percent in the waters of the Gulf of Alaska. This geographical cline is more appreciable when we consider the lower occurrences of two spine form in the Okhotsk Sea.

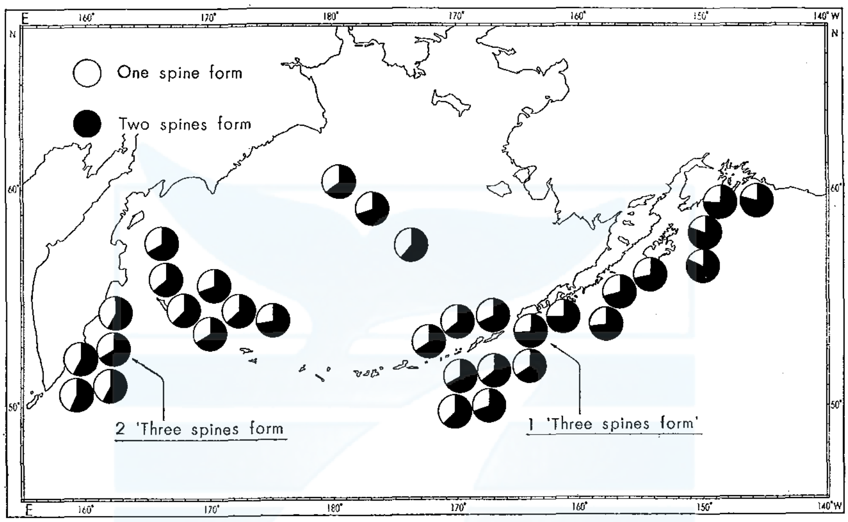

Fig. 16. The occurrences of one and two spine forms of *Thysanoessa inermis* in the northern part of the North Pacific. Black-Percentage occurrence of two spine form. White-One spine form.

This type of geographical cline, specific cline (Huxley, 1940) is also found in a plaice *Platichys stellatus* (Pallas) in the North Pacific. *Platichys stellatus* has the eyes in the right side of the body. But it has eyes in the left side from the specimens in the western Pacific and Japan. The percentage occurrence of left side eyes is about 70% from the specimens collected from Alaskan Peninsula and about 50% in the California. The occurrence of the two spine form of *T. inermis* is somewhat or considerably lower than those reported in the former report, (Nemoto, 1957), and this is attributable to the number of specimens examined and the selection of samples.

The younger *T. inermis* lacks completely abdominal spines of fifth and sixth segments. As a example, small size specimens collected at 53–40N, 165–20W, are examined. The average length is 8.2 mm in which both abdominal spines are undeveloped. Slight protrusion is observed on sixth abdominal segment at the average body length of 9.4 mm. The well developed abdominal spine is observed in samples of 10.5 mm long. So, it is desirable to treat the adults or well developed specimens to compare the occurrences of two and one spine forms of *T. inermis* as it is done here.

Three spine form of T. inermis

The three spine form of *Thysanoessa inermis* is reported in 1962 (Nemoto, 1962). Two new female specimens are found among samples collected at 52–53N and 162–12E, which also bear the abdominal denticles on the fourth segments. One specimen has strong spines on fourth, fifth and sixth abdominal segments with well developed keel on fourth and fifth abdominal segments. The another one is without keels but has spines on fourth, fifth and sixth segments too. The body length are 21 and 18 mm respectively and copulated.

Einarsson (1945) stated that " I will here confine myself to pointing out the possible relationship of this species to the Pacific species *Thysanoessa spinifera* Holmes, which has dorsal spines on the three last abdominal segments and the antennal armature of which bears close resemblance to that of *T. inermis* ". It is very interesting to note that one keel on the fourth abdominal segment is higher in the middle position and resembles rather to that of *T. spinifera* than to *T. longipes.*

Allomorphosis in length of abdominal segments

The sixth abdominal segment has been generally used as a taxonomical character to some extent for the species of euphausiids. It has been used as the combined or direct comparison with fifth or fifth and fourth abdominal segments. Here the length of sixth abdominal segments is plotted against the carapace margin length in logarithmic chart in Fig. 17. *T. macrura* and *T. vicina* form one allometric tribe and *T. longipes*, *T. inspinata* and *T. raschii* form another tribe. *T. longicaudata* belongs to *T. macrura* tribe in males but it shifts in females slightly.

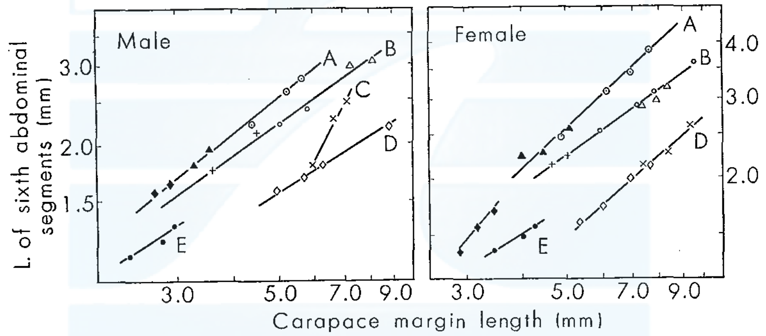

Fig. 17. Allomorphosis in abdominal segment of *Thysanoessa* euphausiids. Relation between carapace margin length and length of sixth abdominal segment.

T. spinifera and *T. inermis* occupy the same allometric tribe in females but they take different lines in males respectively.

T. gregaria is one species which forms allometric tribe by itself. The growth constant values are about the same for every groups except male *T. spinifera.*

It is very interesting to see that the *T. raschii* which differs consideraly from *T. longipes* group in other external characters form the same allometric tribe with *T. longipes* in sixth abdominal segment for carapace.

As the next step, the length of sixth abdominal segments are plotted against the length of fifth abdominal segments as shown in Fig. 18. Like above case, *T. macrura* and *T. vicina* form the same allometric tribe, but *T. longipes*, *T. inspinata* and *T. longicaudata* make another tribe. Other *T. gregaria*, *T. inermis*, *T. raschii* and *T. spinifera* draw respective allometric tribe by themselves. There is no difference between males and females of each species.

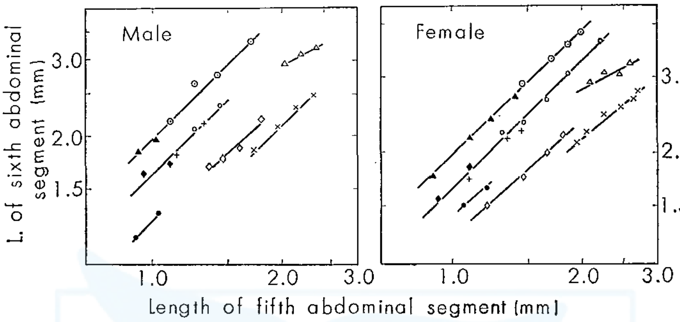

Fig. 18. Allomorphosis in abdominal segments of *Thysanoessa* euphausiids. Relation between length of fifth abdominal segment and length of sixth abdominal segment.

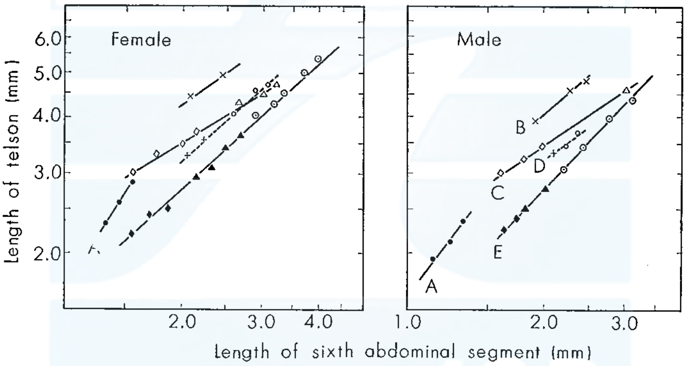

Fig. 19. Allomorphosis in telson of *Thysanoessa* euphausiids. Relation between length of telson and length of sixth abdominal segment.

The telson attached to the sixth abdominal segment is considered as one swimming apparatus. The length of telson against sixth abdominal segment in logarithmic chart is given in Fig. 19.

T. macrura, *T. vicina* and *T. longicaudata* form the same allometric tribe and growth constant. *T. longipes* and *T. inspinata* make the same tribe and *T. inermis* and *T. raschii* make another one. *T. gregaria* and *T. spinifera* make respective allometric tribe by themselves.

PREANAL SPINES

The preanal spines of euphausiids sometimes have been considered as a taxonomic character. The illustrations of them in *Thysanoessa* have been drawn for *Thy-*

sanoessa longipes and *T. gregaria*. (Boden, Johnson & Brinton, 1955) and *T. macrura* (Nemoto & Nasu, 1958). The latter is also drawn for the sexual dimorphism from the young stages. The preanal spines of available species of *Thysanoessa* group are illustrated in Fig. 20. These spines are divided into following three groups.

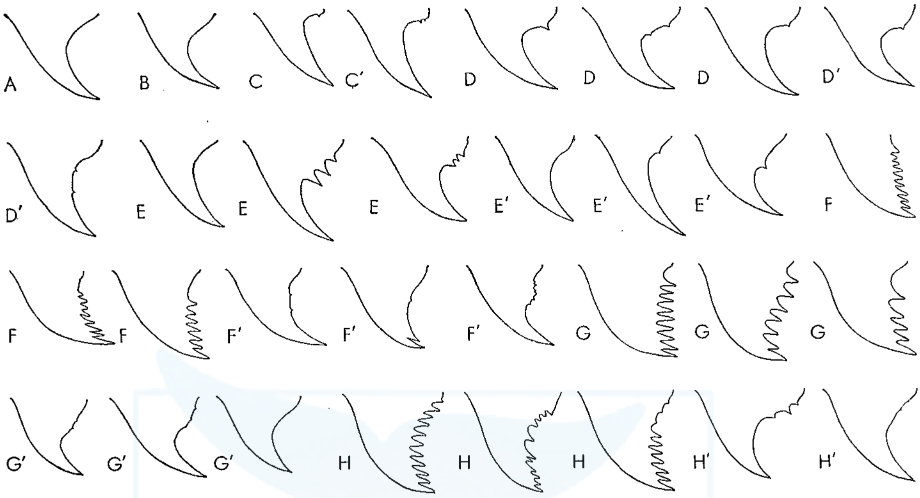

Fig. 20. Preanal spines of *Thysanoessa* euphausiids. A-*T. longipes:* B-*T. inspinata:* C-*T. spinifera:* D-*T. raschii:* E-*T. inermis:* F-*T. gregaria:* G-*T. vicina:* H-*T. macrura.* Males are illustrated with dots.

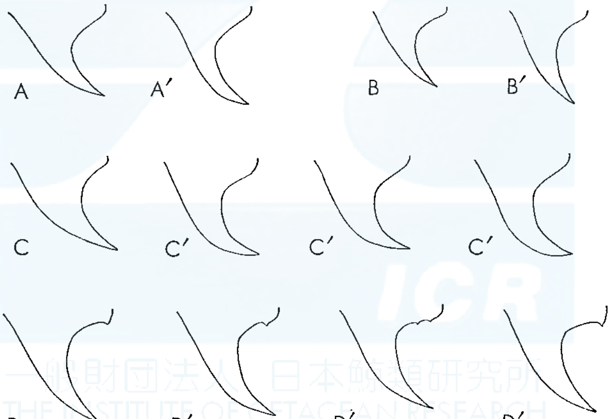

Fig. 21. Preanal spines of *Thysanoessa* euphausiids. A-*Thysanoessa longipes:* B-*T. inspinata:* C-*T. longicaudata:* D-*T. spinifera.* Males are illustrated with dots.

Typical sexual dimorphism present	*T. macrura*, *T. gregaria*, *T. vicina*
Slight sexual dimorphism present	*T. inermis*, *T. raschii*, *T. spinifera*
Sexual dimorphism nearly absent	*T. longipes*, *T. inspinata*, *T. longicaudata*

In a strict sence, the sexual dimorphism is existing also in the third group. As it is illustrated in Fig. 21, the male *Thysanoessa longipes* has rather acute and thick spine. On the other hand, females have rather long and curved spines.

In all species in which the sexual dimorphism is observed, females have the deep denticulations in the concave part of the edge of preanal spines. Males have rather simple spines with a few small denticles along the same part.

This group includes *T. gregaria*, *T. macrura* and *T. vicina* possibly including *T. parva*.

Thysanoessa raschii and *T. inermis* show slight sexual dimorphism, but *T. inermis* shows more distinct differences.

In other euphausiids, these sexual dimorphism is also observed. *Euphausia vallentini* in the southern hemisphere has heavy denticulated preanal spines in females and small denticles along the inner margin of the preanal spines in males. Another example is given by Boden, Johnson & Brinton (1955) on *Nematobrachion flexipes*. They stated the preanal spine is simple in males and bifid in females, and the male preanal spine is also simple in *Nematoscelis difficilis* (Mclaughlin, 1965).

THORACIC LEGS

The general arrangement of *Thysanoessa* is illustrated in Table 6. Three species of *Thysanoessa*, have non-elongated second legs and thoracic legs are similar in structure of setae and spine as the skimming apparatus for foods. Other seven species have elongated second legs, and rather degenerated fifth and sixth thoracic legs. The former group may be connected to genus *Euphausia* and the latter may resemble to the other groups in the thoracic legs, such as *Tessarabrachion*, *Nematoscelis*, *Nematobrachion* and *Stylocheiron* species. Of course, there is not enough data for the feeding mechanism of euphausiids, it seems that euphausiids which have elongated thoracic legs are carnivorous more or less or polyhagous as *Thysanoessa* species. Especially *Nematobrachion* species are considered as typical carnivorous euphausiids mainly feeding on copepods in the deeper layer of the sea. The possible relation between the eyes and feeding apparatus for the living environment is now under

TABLE 6. ARRANGEMENT OF THORACIC LEGS IN *THYSANOESSA*

Species	Number of functional legs	Similarity even	Similarity uneven	Elongated legs	Reduced legs Male	Reduced legs Female
Thysanoessa raschii	6	+		—	7, 8th	8th*
,, *inermis*	6	+		—	,,	,,
,, *spinifera*	6		(+)	(2nd)	,,	,,
,, *longipes*	6		+	2nd	,,	,,
,, *inspinata*	6		+	2nd	,,	,,
,, *gregaria*	6		+	2nd	,,	,,
,, *parva*	6		+	2nd	,,	,,
,, *macrura*	6		+	2nd	,,	,,
,, *vicina*	6		+	2nd	,,	,,
,, *longicaudata*	6		+	2nd	,,	,,

* Distal three or four segments are lacking in 7th leg.

examination, and here the allomorphosis in *Thysanoessa* euphausiids in thoracic legs and morphology of dactylus of first and second legs which have special feeding character are investigated.

Allomorphosis in the total length of legs

The first legs show three allometric tribes when they are plotted against carapace margin length. *T. macrura*, *T. longipes*, *T. inspinata*, *T. vicina*, *T. longicaudata* and *T. gregaria* are making one allometric tribe, which closely corresponds to the shorter spine group in the dactylus of the first logs.

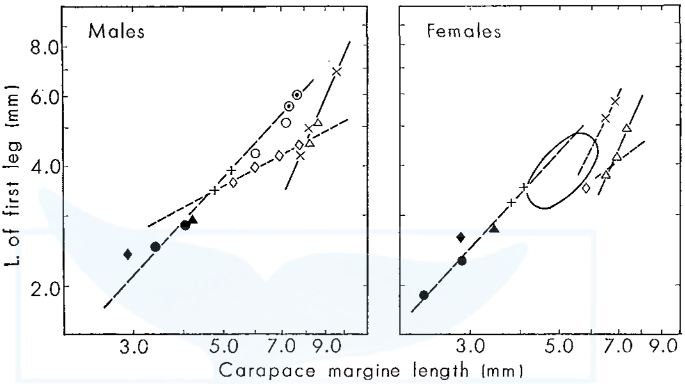

Fig. 22. Allomorphosis in leg of *Thysanoessa* euphausiids. Relation between length of total first leg and carapace margin length.

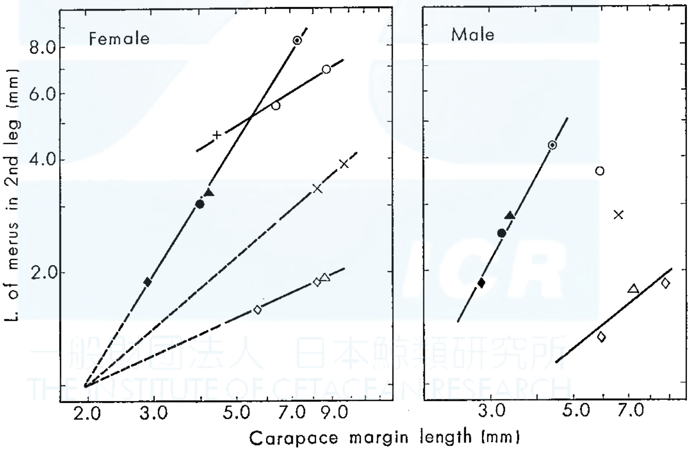

Fig. 23. Allomorphosis in merus in second leg of *Thysanoessa* euphausiids. Relation between length of merus of second leg and carapace margin length.

The next group is *T. spinifera* which form the tribe by itself both in males and females. *T. raschii* and *T. inermis* are considered to form the same allometric tribe although *T. raschii* shows some vague points in females.

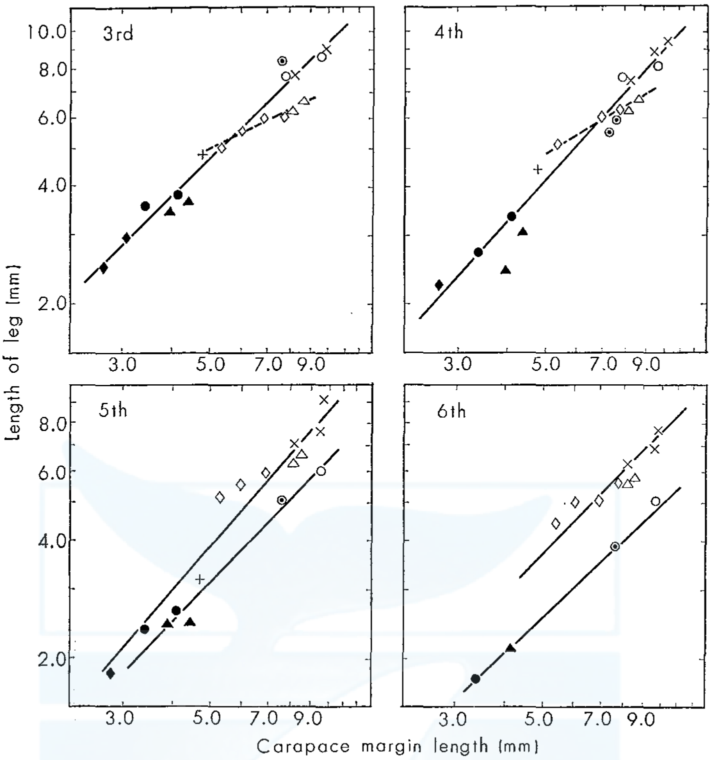

Fig. 24. Allomorphosis of leg in *Thysanoessa* euphausiids. Relation between length of carapace margin length and total length of thoracic legs.

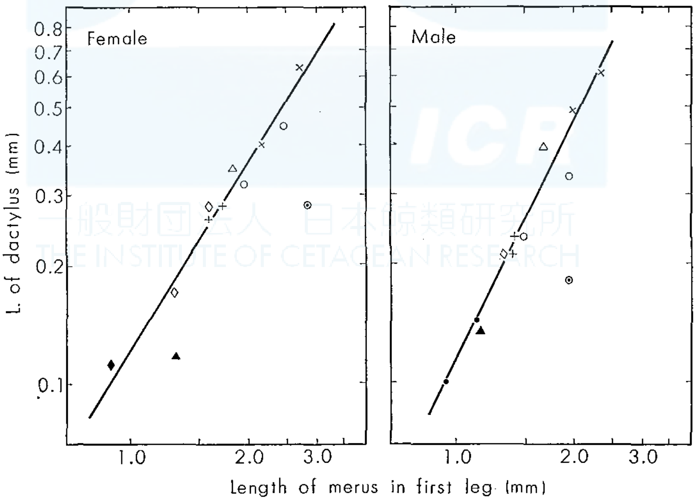

Fig. 25. Allomorphosis in *Thysanoessa* euphausiids. Relation between the length of merus in first leg and length of dactylus.

In second legs, the allometric tribes are given for the length of merus. Although *T. longipes* stands a little apart from the main line of the shorter group of the dactylus in the first leg, they fairly well coincide with the allomorphosis in the first dactylus.

In third and fourth legs, the wide band includes all species of *Thysanoessa* as illustrated in Fig. 24. In these figures, *T. inermis* and *T. raschii* form the oblique line which cross the main line. This is the same tendency in the first leg, and *T. inermis* and *T. raschii* form the distinct allometric tribes in fifth and sixth legs by themselves. But *T. spinifera* shift the tribe in fifth and sixth legs as illustrated in Fig. 24. It makes allometric line with *T. inermis* and *T. raschii* in sixth and fifth legs. These are confirmed by the skimming structure with well developed setae in those legs. On the other hand, *T. macrura T. longipes*, *T. gregaria* and *T. vicina* have shorter and poorly developed setae in those legs.

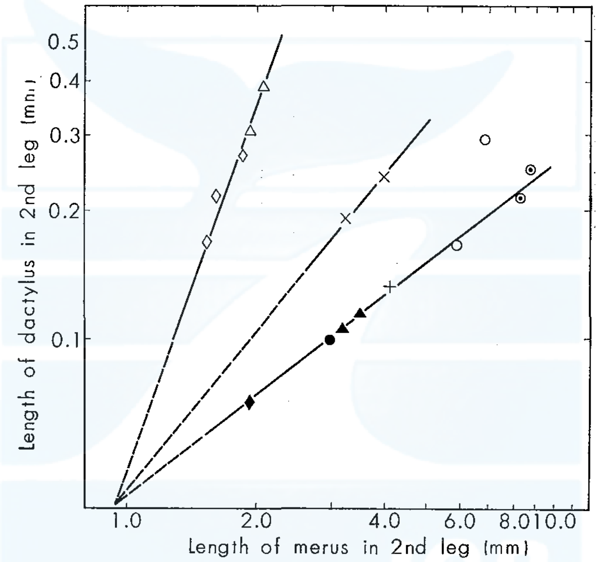

Fig. 26. Allomorphosis in legs of *Thysanoessa* euphausiids. Relation between length of merus and dactylus in 2nd leg.

The allomorphosis in thoracic leg joints in *Thysanoessa* euphausiids are also very characteristic. The length of dactylus of the first legs are plotted against the length of merus of the first legs in logarithmic chart. They form only one allometric tribe except *T. macrura*. The structure of dactylus of those species bearing somewhat peculiar characters as discussed. The position of *T. vicina* may shift from the main group if more data were obtained as it is basing rather small number of data.

The length of dactylus of other legs are also plotted against for the length of merus. They are shown in Fig. 26, and 27. In second leg, three allometric tribes are observed. *T. inermis* and *T. raschii* form the same tribe as the first leg, but *T. spinifera* differs considerably from the group. The oceanic group, *T. macrura*, *T. inspinata*, *T. vicina*, *T. gregaria* and *T. longicaudata* form one tribe and position of

T. longipes is somewhat vague as shown in Fig. 26. *T. longipes* also show some shift from those species in the relation between length of merus in second leg and carapace margin length. The length of dactylus is very variable in second legs of *Thysanoessa* euphausiids, and its variation in length is closely connected with the length of other joints of legs. *T. inermis* and *T. raschii* has shorter merus and longer dactylus. *T. spinifera* has somewhat longer merus and shorter dactylus than the former two species. It should be noted that *T. spinifera* differs in this point because it belongs to the *T. inermis* group in many other characters.

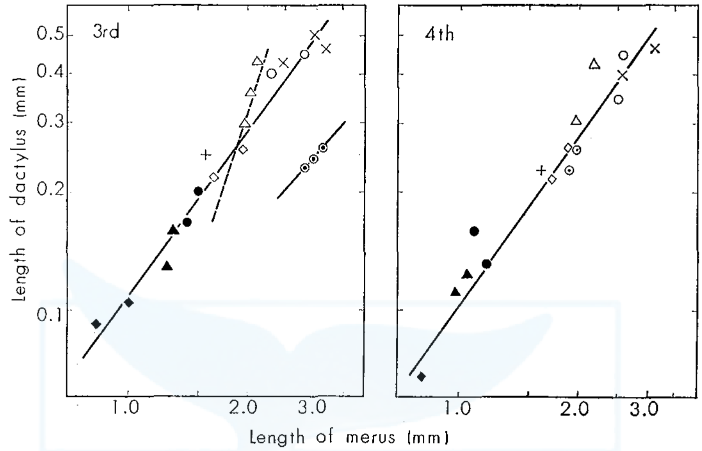

Fig. 27. Allomorphosis of leg in *Thysanoessa* euphausiids. Relation between length of merus and length of dactylus in 3rd and 4th legs.

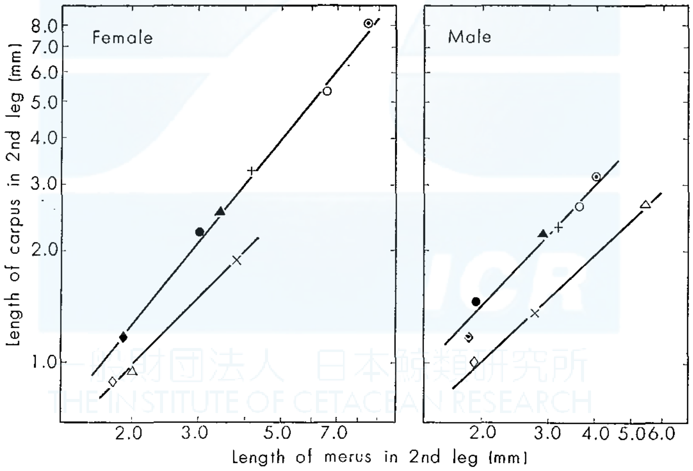

Fig. 28. Allomorphosis in legs of *Thysanoessa* euphausiids. Relations between length of merus and carpus in 2nd leg.

In the third legs of *Thysanoessa* euphausiids, the dactylus length against the length of the merus of the same legs form one allometric tribe except *T. macrura* which has rather shorter dactylus still in the third leg.

From fourth legs to sixth legs, all *Thysanoessa* euphausiids run the same line in allometric tribe in the relation between length of merus and length of dactylus. And setae in merus and carpus are developed in *T. inermis*, *T. spinifera* and *T. raschii*. The setae of *T. longipes*, *T. gregaria* and other pelagic species have rather rigid spines and number of setae are small.

The characteristic position of *T. macrura* in the allomorphosis in the dactylus of first and third legs may suggest the relation to the related species *Tessarabrachion oculatus* which has elongated second and third legs and shorter dactylus in those legs. The allomorphosis in the relation between length of carapace margin length and total second legs, *Tessarabrachion oculatus* stands the same line with *T. longipes*, *T. gregaria*, and *T. macrura* (Nemoto, 1962). In the allomorphosis in the relation between dactylus and merus of third legs, it shifts from the group of *T. longipes* with *T. macrura*.

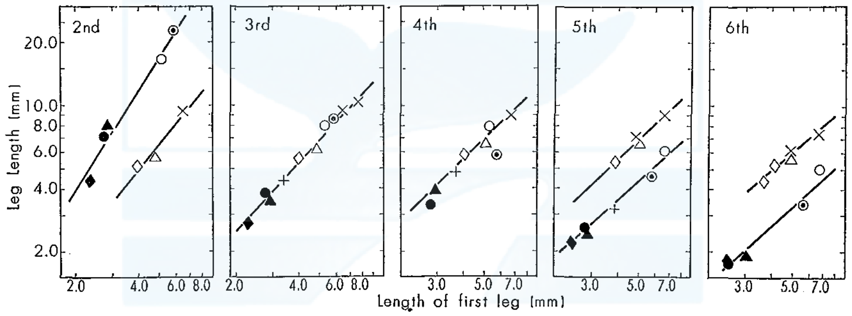

Fig. 29. Allomorphosis in legs of *Thysanoessa* euphausiids in the world ocean. Relation between first leg and other legs.

The relation between carpus and merus in second legs in *Thysanoessa* euphausiids is as follows. Both in males and females, there are two allometric tribes in *Thysanoessa*. *T. inermis*, *T. raschii* and *T. spinifera* form one line and other six species form another one. It clearly seems that *T. spinifera* belongs to the same tribe with *T. inermis* and *T. raschii*, although it belongs to the different tribe alone in dactylus.

The total leg length of each species are plotted against the length of the first leg. In the second legs, *T. spinifera*, *T. raschii* and *T. inermis* form one allometric tribe and other *Thysanoessa* species having longer second legs form another group. The third and fourth legs show no difference between above two groups in the total leg length, but *T. macrura* shifts slightly in fourth leg. In fifth and sixth legs, the general degeneration is observed in *T. macrura* group which has elongated second legs. The degeneration is heavy in sixth legs as illustrated in Fig. 29.

Dactylus of the first legs

The shapes of the dactylus of the first legs are very various in each species. *Thysanoessa inermis* and *T. raschii* have rather long dactylus and shorter top spines. The spines along the inner margin of the dactylus are ranging 5–8 in *inermis* and

8–12 in *raschii*. *T. spinifera* has also long dactylus and the spines of inner margins are ranging 8–14 and has shorter top spines.

T. longipes has somewhat shorter dactylus and longer top spines, but it has many spines in the inner margin of the dactylus. It should be noted *T. longipes* often has a half size spine along the inner margin at the most basic position as illustrated in Fig. 30.

The fringes in the spines are different in *T. spinifera* and *T. gregaria* groups. *T. spinifera* and *T. inermis* have fringes of the same length even in the top of the spines although they curve to the acute point. In *T. gregaria* and related speciees, the fringe are uneven in length and the top fringes are comparatively short as illustrated. The fringe of *T. macrura* has small number of spines along the inner side, but type of the fringes is seemed to be *inermis* type. The closely related species, *T. vicina* is gregaria type dactylus which has few spines in the inner margin of the dactylus. But it has short and pecurial fringes differing from those of *T. inermis* and *T. gregaria*.

TABLE 7. NUMBER OF SHORT SPINES IN INNER MARGIN OF DACTYLUS OF THE FIRST LEG IN *THYSANOESSA* EUPHAUSIIDS

Species	Male	Female	Type of fringe
T. spinifera	8～14	8～14	Inermis
T. raschii	8～12	8～12	"
T. inermis	5 or 6	6～ 8	"
T. longipes	5～ 7	7～ 9	Gregaria
T. inspinata	4～ 6	5 or 6	"
T. longicaudata	3～ 5	3～ 5	"
T. gregaria	1	1 or 2	"
T. macrura	2 or 3	2 or 3	(Inermis)
T. vicina	1	1	Vicina

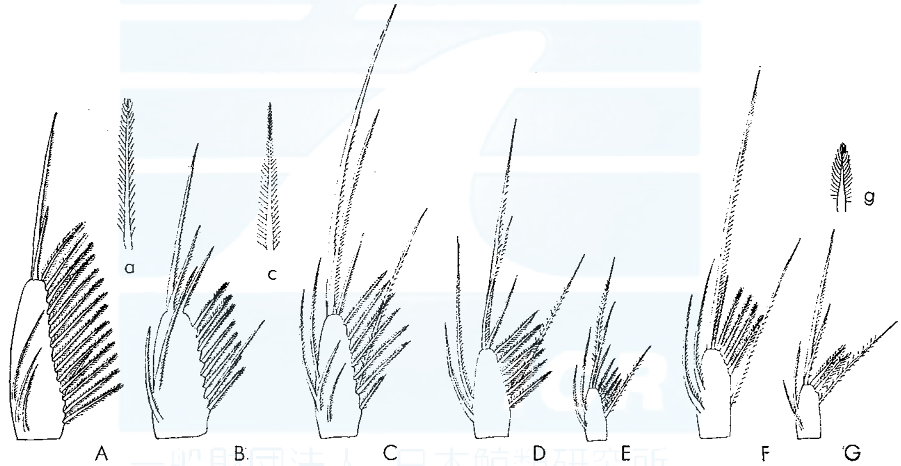

Fig. 30. Dactylus of first leg of *Thysanoessa* euphausiids. A-*T. spinifera:* B-*T. raschii:* C-*T. longipes:* D-*T. inspinata:* E-*T. longicaudata:* E-*T. macrura:* G-*T. vicina.*
a- spine of dactylus in *T. spinifera:* c- spine of *T. longipes:* g- spine of *T. vicina.*

Shape of the dactylus in the second legs

T. inermis and *T. raschii* have slender dactylus which bears the long spines along the margin of the dactylus. The number of the side spines in *T. raschii* are ranging 4 to 6 in one row, and *T. inermis* has 2 to 4 spines. These two species are considered as the same group also in the allometric tribe. *T. spinifera*, however, is considered to belong to another group. The dactylus is not so slender, rather short and the side row of spines is not observed. Those spines are growing in the distal edge of the top as illustrated. Other *Thysanoessa* have also shorter dactylus, but the arrangement of spines are the same with *T. spinifera.* There are two rows of small setae in the spines.

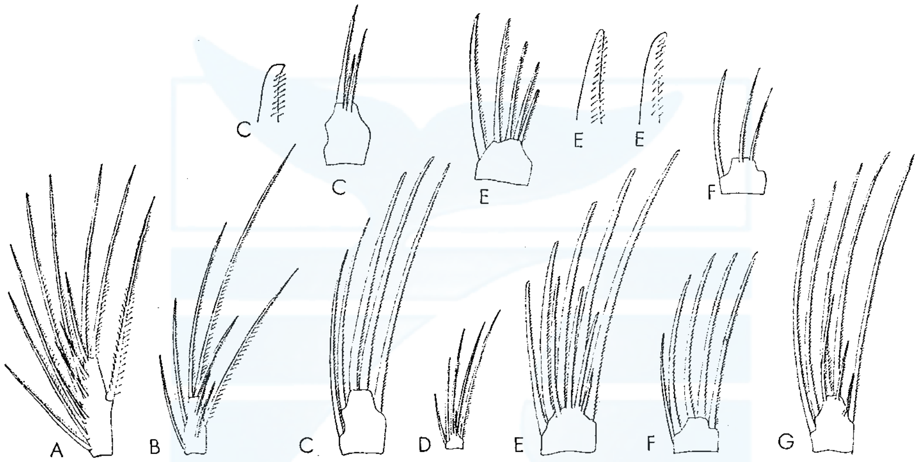

Fig. 31. Dactylus of second, and third legs in *Thysanoessa* euphausiids. A-*T. raschii;* B-*T. inermis;* C-*T. spinifera;* D-*T. longicaudata;* E-*T. macrura;* F-*T. inspinata;* G-*T. macrura*, third leg. Upper figures show the shorter spines.

These shapes of the dactylus are closely connected with the relative growth, allomorphosis of dactylus against the merus and carpus in the elongated second legs.

The shape of dactylus in second legs are discussed on *Euphausia superba* by Barkley (1940) and pecurial spines (Putzborsten according to Zimmer, 1927) are found in the inner side of the dactylus. These spines are yellowish or red in the living condition, and easily observed in their activity. But the sweeping or cleaning for their legs or setae is not observed by Barkley (1940).

None of this peculiar spines is found in *Thysanoessa* euphausiids. In *T. gregaria* group, the dactylus is shorter and the corresponding series of spines or setae become strong spines in the margin or inner edge of the dactylus.

It is very interesting that not only hervivorous *Euphausia* species but it is also found in the carnivorous euphausiids such as *Nematobrachion* species, although the second leg of *Nematobrachion* species is not elongated.

MOUTH APPARATUS

Here *T. gregaria* and *T. inermis* are mainly examined which are belonging to different type respectively comparing with other *Euphausia* and *Nematobrachion* species according to structures of thoracic legs.

Upper lip

The general shape and function of the upper lip in *T. gregaria* is almost the same with *Euphausia superba* and *T. inermis* which have also nearly the same shape of upper lip.

Lower lip

The lower lip of *T. gregaria* and *T. inermis* are also nearly the same with that of *E. superba* but having edge spines in the outer margins of the false jaws. These spines are characteristic denticles in *Thysanoessa* euphausiids but they may not have special mechanism in feeding.

Mandible

The general shape of mandible of *Thysanoessa* seems not to be so different from other euphausiids, however, the number of furrows in the mill-like process are not so much as *Euphausia superba* (Barkley, 1940).

First maxilla

The first maxilla has very strong processes along the edge of basis. *T. gregaria* has about seven tough processes. *Euphausia vallentini* and *E. superba* (Barkley, 1940) have much more processes along the basis of the first maxilla. These processes are accompaied with other small spines. The coxa has also processes and many spines. But these processes and spines reduced in carnivorous euphausiids, *Nematobrachion boopis*. Other euphausiids, *Euphausia superba*, *E. vallentini* have considerably many spines and processes. It is considered *Thysanoessa* euphausiids stand the intermediate position between carnivorous and hervivorous euphausiids from the structure of those maxilla.

Second maxilla

The second maxilla is long and covers the first maxilla. The general shape of the second maxilla is different between *T. inermis* and *T. gregaria*. *T. inermis* has longer segment in the last endopodite which corresponds to *Euphausia* species. (*E. superba*, 1940 Barkley: *E. vallentini*, Nemoto). But the shape of the last segment of *T. gregaria* is rather short and rounded. The carnivorous *Nematobrachion boopis* has also rather short and rounded segment, and setae are long but fragile and sparsely scattered. The mechanism of those second maxilla is considered to collect and move the odds which congregated in front of the mouth from the outer side to the opening of lower and upper lip and then to the mandible. The spines and setae of the coxa and the first ishium of the endopodite are the most important for the action, but the long spines and setae in the last segment of the endopodite are also usefull for the collection and not to miss the food. The carnivorous animals use the long sparse spines bearing special structure which is very effective to seize those food such as copepods and other active animals.

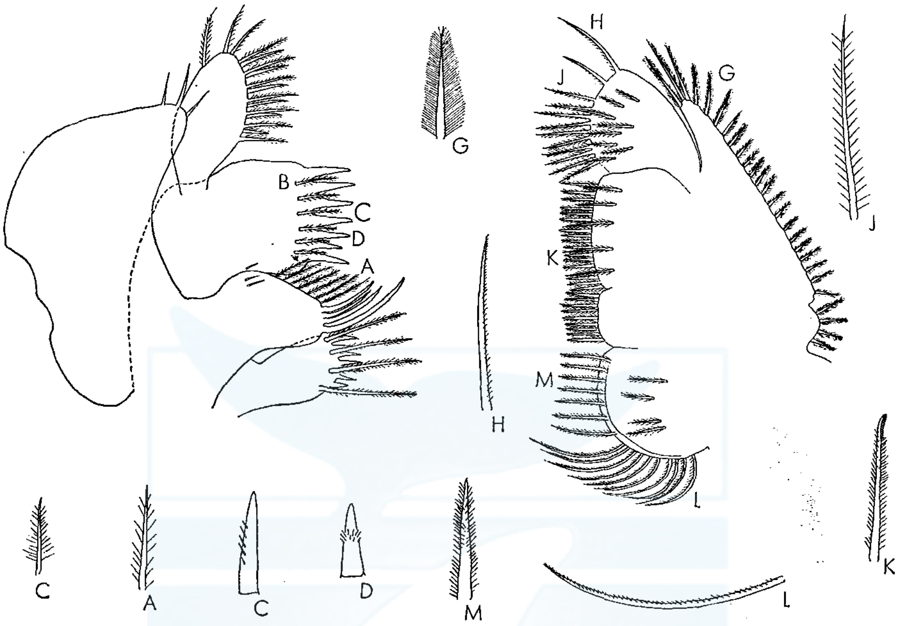

Fig. 32. First (Left) and second (Right) maxilla of *Thysanoessa gregaria* and spines of maxilla.

INNER STRUCTURE OF STOMACH

The inner wall of euphausiids are constructed to crash the foods of them such as diatoms, foraminfera, other zoo-planktons and phyto-planktons. The preliminary figures are given in the previous book on foods of whales and another paper (Nemoto, 1965). The food organisms are described by Ponomareva (1955). According to her list, *Thysanoessa* generally feeds on zooplanktons especially in *T. longipes* as well as phytoplanktons.

The stomach structure of *T. inermis* is given in Fig. 33. The general pattern of structure is the same with other euphauiids. It has, however, peculier bunch of spines in the middle of the lower margin of the side plate of the stomach wall. They may be called ' cluster spine ' of the euphausiids. This type of the cluster spine is characteristic in *Thysanoessa* euphausiids and related species *Tessarabrachion.* Every species of *Thysanoessa* euphausiids have row of cluster spines ranging from 10 to 40 in the middle of the side plates. The number of the cluster spines is small in *T. vicina* and *T. macrura*, and other *Thysanoessa* have 20 or more number of spines. The general shape of spines are not different among each species. *T. raschii* and *T. inermis* have about 20–25 cluster spines, *T. longipes* and *T. inspinata* have about 30 spines, and *T. spinifera* has about 40 cluster spines. *Thysanoessa* euphausiids have other spines to crash in the anterior part of the side plates as illustrated in Fig. 33. Especially *T. inermis*, *T. longipes* and *T. inspinata* and *T. vicina* have strong spines in the anterior edge parts of the side plates. These spines have some taxonomical characters as given in *T. longipes* and *T. spinifera*. In *Euphausia* genus, these spines congregate and form the circle bunch of spines as illustrated in a former report (Nemoto, 1965, Fig. 8). This type of cluster spines are characteristic in *Euphausia*, but they lack the row of cluster spines in the low or middle part of the side plate of the stomachs. The cluster spines in circles and isolated spines in *Thysanoessa* euphausiids are made to crash foods with the spines in upper side plates in the stomach walls. The circle cluster spines are fit for the porpose to crash hard wall cell of diatoms and related organisms. So *Thysanoessa* euphausiids lacking this circle cluster spines show good adoptation to catch zooplankton or other animals without hard shells. In the central part of the side plates, there are many isolated spines as illustrated in Fig. 32. These spines are also considered to crash their foods, and are most dominant in the central part of the side plates in the *Thysanoessa* and *Euphausia* species. In some species in the deep sea living *Thysanopoda* such as *Thysanopoda monacantha* has this type of spine, but other *Thysanopoda*, *T. tricuspidata* has one row of spines in the middle of the side plates. And *Nematobrachion boopis* completely lacks those spines in the side plates. All *Thysanoessa* euphausiids have central row of spines in the bottom plates. This row of spines is clear in *Thysanoessa longicaudata*, and *T. inermis*, but it is not so strong in other *Thysanoessa*.

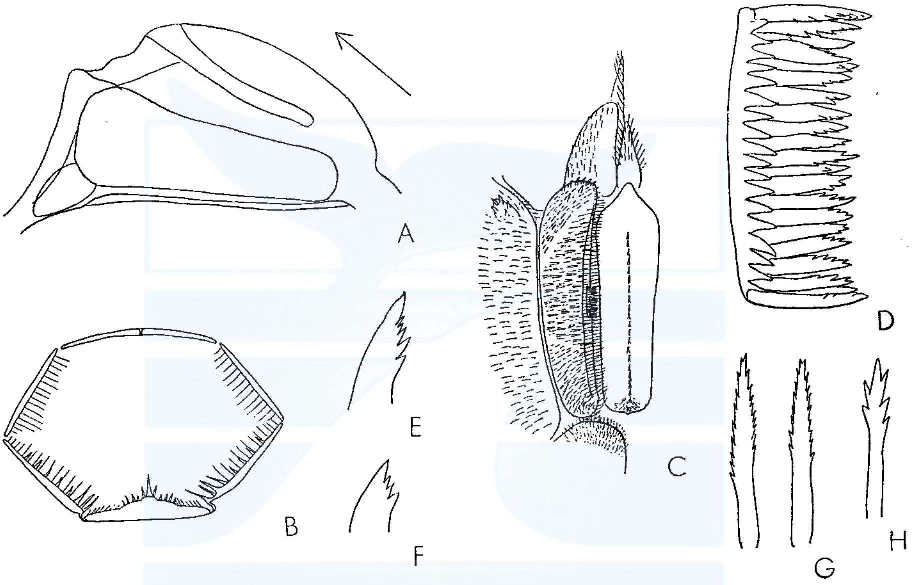

Fig. 33. Stomach of *Thysanoessa inermis*. A-Lateral view: B-Cross section at middle: C-Base part of the stomach: D-spine cluster in side plate of stomach: E,F,G,H,-Chewing spines in the stomach.

This central row of spines is also typical in *Thysanopoda monachantha*, *Nematobrachion* *boopis*, (Nemoto, 1965 Fig. 9.) and *Euphausia* species. But *Nematoscelis* has two branch rows and *Stylocheiron longicorne* and *S. abbreviatum* have only slight or no row of these spines.

The stomach of *Thysanoessa* is considered as a polyphagus type from the arrangement of cluster spines and isolated spines in the side plates. The side view of the stomachs of *Thysanoessa* shows no swell of the posterior portion of the stomach just above the pyloric region of the intestine. *N. boopis* has very swollen stomach in the posterior part (Nemoto, 1965 Fig. 9) which fit to take vast quantity of undigested foods such as copepods and other living zooplanktons at one occasion.

COPULATORY ORGANS

The male copulatory organs of euphausiids are considered one of the best specific characteristics and the female copulatory organs, namely thelycum, are also pointed out as one of the best character for taxonomy by Einarsson (1942). In some closely related euphausiids, *Thysanopoda aequalis* and *T. subaequalis* (Boden & Brinton, 1956), *Euphausia nana* and *Euphausia pacifica* (Brinton, 1962a), the copulatory organs do not exhibit so well their specific characters. In a former report, (Nemoto, 1963) I also discussed the possible difference in the relative growth of the length of the process and spines in the male copulatory organs in closely related *T. longipes* and formarly spineless form, *T. inspinata*. On *Euphausia nana* and *E. pacifica*, the microstructure of the male copulatory organs are considered as the taxonomic characters, however, the body length, horizontal distribution are also main discriminating points about two species (Brinton, 1962a).

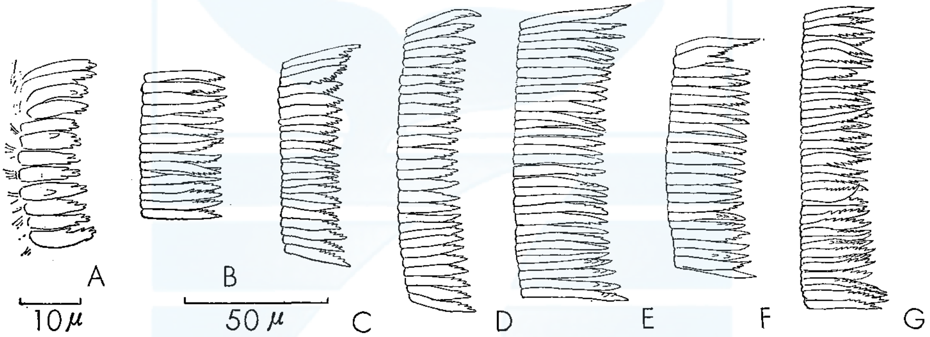

Fig. 34. Spine clusters of stomachs of *Thysanoessa* euphausiids. A-*Thysanoessa vicina:* B-*T. macrura:* C-*T. gregaria:* D-*T. longipes:* E-*T. inspinata:* F-*T. raschii:* G-*T. spinifera.*

The copulatory organs in *T. gregaria* group in males has terminal process distally expanded, but in the younger stages it is not so expanded as discussed in the previous report on *T. macrura* (Nemoto, 1958). The young *Thysanoessa macrura* has also broader base of terminal process but the tip is pointed.

The copulatory organs of *Thysanoessa* euphausiids are divided into four or five groups. *T. gregaria*, *T. macrura*, *T. vicina* and *T. parva* have rather related male copulatory organs as illustrated in Fig. 35.

The edge of the tip in terminal process of *T. gregaria* and *T. vicina* are serrated, and no clear serration is observed in *T. macrura* and *T. parva.*

T. raschii and *T. inermis* have similar male copulatory organs. Both species have two long menbranous wings or expansions from the tip almost to the bases. (Boden, Johnson & Brinton, 1955). The proximal and lateral processes are well developed but not expanded in the ends. *T. spinifera* has not the broad terminal spine. It has, however, the terminal spine of broad base and both proximal and lateral spines have acute ends. The broad base of a terminal spine is identical with *T. inermis* and *T. raschii* and it is considered as the original type of the copulatory organs of *Thysanoessa* euphausiids of *inermis* group.

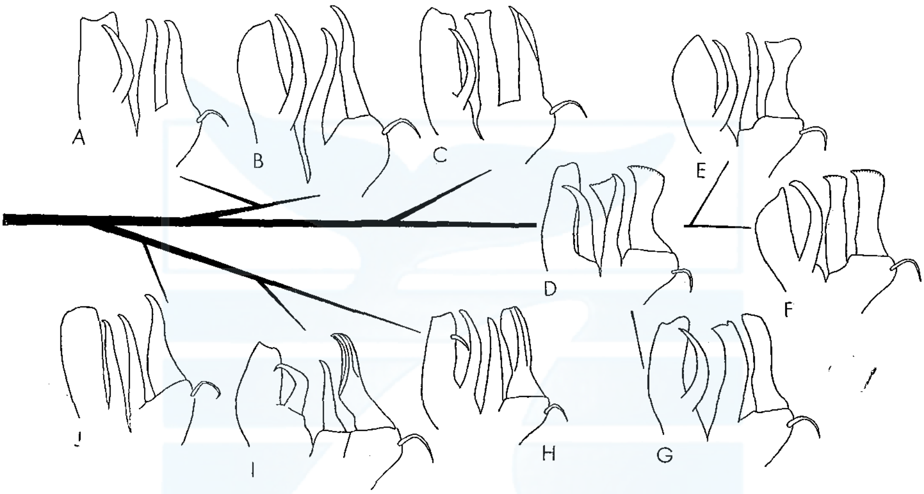

Fig. 35. Male copulatory organs and possible relationships in dendrogram in *Thysanoessa* euphausiids. A-*T. inspinata*, B-*T. longipes*, C-*T. longicaudata*, D-*T. gregaria*, E-*T. macrura*, F-*T. vicina*, G-*T. parva*, H-*T. inermis*, I-*T. raschii*, J-*T. spinifera*.

T. longipes and *T. inspinata* have three main processes which are not expanded in the tapered ends. But those are slender and the base is not broad as *T. spinifera.*

T. inspinata has short and robust processes and main characters are the same with those of *T. longipes*. The base of terminal process is not so broad as *T. spinifera.*

T. longicaudata has pointed terminal process, it has thin keel on the outer side. The proximal process flattens out considerably above the middle and forms somewhat spoon-shaped plate with an uneven upper edge. The terminal end of the proximal process is not serrated. This character is bearing a resemblance to *T. parva* or *T. gregaria*, but its base of terminal process is rather narrow and pointed end is quite different from those of *T. gregaria* group.

DISTRIBUTION

Three main distributions in the World Ocean contain following species listed in

Table 8 and 9. Two Arctic and boreal species *T. inermis* and *T. raschii*, are common in the Atlantic and the Pacific.

T. longicaudata is only found in the Atlantic and *T. longipes* and *T. inspinata*, *T. spinifera* are only distributing in the boreal region of the Pacific. Other two species *T. macrura* and *T. vicina* are Antarctic species, and two species *T. gregaria* and *T. parva* are distributing both in southern and northern temperate water regions.

T. spinifera is distributing only along the American side, the eastern part of the Pacific and *T. inspinata* and *T. longipes* are abundant throughout the boreal regions of the Pacific. The latter two species are rather rare in the shallow Arctic Sea. (Johnson, 1956) and the occurrence of *T. inspinata* in the sea of Japan is somewhat uncertain still in recent studies (Komaki & Matsue, 1958), although Ponomareva considered it also distributed in the Sea of Japan.

TABLE 8. OCCURRENCES OF *THYSANOESSA* EUPHAUSIIDS IN THE WORLD OCEAN

Species	North Atlantic	North Pacific	Southern Hemisphere
Thysanoessa raschii	+	+	—
„ *inermis*	+	+	—
„ *longipes*	—	+	—
„ *inspinata*	—	+	—
„ *longicaudata*	+	—	—
„ *spinifera*	—	+	—
„ *gregaria*	+	+	+
„ *parva*	+	+	+
„ *macrura*	—	—	+
„ *vicina*	—	—	+

TABLE 9. OCCURRENCES OF *THYSANOESSA* EUPHAUSIIDS IN THE NORTH PACIFIC

	Arctic Sea	Bering Sea West	Bering East	Okhotsk Sea	Japan Sea	North-west Pacific	Alaskan Gulf	American Coast
Thysanoessa raschii	+	+	+	+	+	+	+	±
„ *inermis*	±	+	+	+	+	+	+	—
„ *longipes*	±	+	+	+	+	+	+	+
„ *inspinata*	—	+	—	—	— ?	+	+	+
„ *spinifera*	—	—	+	—	—	—	+	+
„ *gregaria*	—	—	—	—	— ?	—	—	+
„ *parva*	—	—	—	—	—	—	—	—

T. spinifera shows pecurial distribution in the eastern part of the North Pacific. (Nemoto, 1962: Brinton, 1962b). It has not been recorded from the Arctic Ocean, north Bering Sea, Okhotsk Sea and the Sea of Japan. It is only distributing in the shallow neritic waters of the east coast of the North America. It is found dominantly in the stomachs of baleen whales in the coastal waters of the east Aleutian Is. (Banner, 1954: Nemoto, 1959). The most northern record is given in a former report (Nemoto, 1962) and the most western record is given by Hansen, (1915). The concentration of this species is also observed along the continental shelf of the Gulf of Alaska from the observation of the stomach contents of baleen whales. The southern range of the distribution is given by Banner (1949) and Brinton (1962b) along the California coast of North America.

The range of water temperature and salinity is considered slightly different from other neritic *T. raschii* and *T. inermis*. *T. spinifera* occurres in a little wamer temperature and lower salinity and T-S diagram chart for *T. spinifera* is different from those euphausiids. (Nemoto, 1962).

Thysanoessa inermis is distributing in the boreal Arctic water in the Atlantic and the Pacific. In the Atlantic, general distribution is observed between the February ice limit and the surface isotherm for 10°C (Einarsson, 1945). And the Pacific distribution is also limited within the February surface isotherm 10°C (Brinton, 1962b: Nemoto, 1962) and the main distribution is found within 15°C in summer isotherm (Nemoto, 1962). *T. inermis* is considered to spawn in the shallow waters along the continental shelf, and Glover (1952) described *T. inermis* as the shallow water species. In one former report, I reported that *T. inermis* occurres in the stomachs of baleen whales as their foods very often in the coastal waters of Kamchatka peninsula and along the continental shelf of the Alaskan peninsula in the Bering Sea (Nemoto, 1962). *T. inermis* also found in the Okhotsk Sea and Japan Sea. But latter occurrence is restricted in the northern half waters (Komaki & Matsue, 1958: Ponomareva, 1957). The concentration of *T. inermis* is also observed in the southern edge of the shelf along the Alaskan peninsula and the Gulf of Alaska, and it goes down to the waters off Vancouver (Brinton, 1962b).

The possible relation between *T. inermis* in the Atlantic and the occurrence of it in the western part of the Pacific is expressed in the two and one spine forms of *T. inermis*. In recent investigations, Johnson (1956) reported it from the Chukchi Sea but only few specimens. The main range of the *T. inermis* distribution is limited the line of continental shelf of the Bering Sea, and the ice limit in summer in the shallower Atlantic north waters. Thus the interchanging of Atlantic and Pacific stocks in recent age may not occur to effect the main distribution and of two and one spine forms as shown in percentage occurrence of them.

T. raschii is uaully distributing along the shallow continental shelf or the neritic shore waters in the Arctic boreal regions. It plays the role of foods of balleen whales in the off waters of Anadyle Gulf, Bristol Bay and main occurrences are also observed along the Kamtchatka peninsula, Anadyl Gulf, and the shelf of the Gulf of Alaska. Other investigations prove that it also occurres in the Japanese coast of Okhotsk Sea (Nemoto, 1959), north shallow waters of Okhotsk Sea and northern part of the Sea of Japan (Ponomareva, 1955).

The main stocks of *T. raschii* in the Pacific and the Atlantic are living within ice covered waters in winter seasons. It is also more common in the North pole sea than other euphausiids (Johnson, 1956). The interrelation between the Pacific and Atlantic stocks may be closer than other euphausiids, and possible continuity of distribution through the north pole waters is considered.

The southern range of *T. raschii* is restricted to the cold current and summer concentration of this species is found even in the low salinity (Einarsson, 1945: Nemoto, 1962). This position may be compared with the Antarctic *Euphausia* *cristallorophias* along the Antarctic continental shelf.

T. longipes is differeing from other neritic *Thysanoessa spinifera*, *T. inermis* and *T. raschii*, considered as pelagic form. Its main distribution is given by Brinton (1962b) and Nemoto (1962) in the northern part of the North Pacific. *T. longipes* is transported to the north American secter of the Arctic sea (Johnson, 1956), which coincides with the flow of the Arctic water current from the southern waters through Bering strait (Johnson, 1956). Considering from the occurrences in the stomach contents of baleen whales (Nemoto, 1959: 1962) and plankton net investigations (Banner, 1949: Brinton, 1962b), *T. longipes* concentrations are observed in the eastern Bering Sea (Nemoto, 1962: Brinton: 1962b) in the off waters of Alaskan continental shelf and mid waters along the Bowers Bank. The former occurrences are found in company with *T. inermis* and dominant occurrences are found in a little more off waters in the north waters of Unimak Is. The heavy concentrations are also observed in the southern waters of Aleutian Is. along the latitudinal belt of 50°N (Brinton, 1962b) by plankton investigations.

The closely related species *T. inspinata* (Nemoto, 1963) or the spineless form of *T. longipes* (Banner, 1949) is found in more southern waters. It consitutes the smaller part of the food of baleen whales in the southern Bergin Sea (Nemoto, 1959) which is possibly the northern limit of this species. The general distribution of *T. inspinata* is given by Brinton (1962b) as the unspined form of *T. longipes*. The southern limit of this species is considered in the western side of the Pacific coincide with the range of cold current Oyashio. Brinton gave the most southern record 34–17N, 156–11E, where the submergence at the southern margin of the range is observed (Brinton, 1962b). The present data collected by Tansei-maru in KT-64–17 cruise, *T. inspinata* occurred from 33°–50N and 138–30E as the more western waters in the southern waters of Japan.

T. macrura and *T. vicina* are only distributing in the southern hemisphere. Those two Antarctic species have been found in the circumpoler belts from the subantarctic to the Antarctic. From the external characteristics, they are considered to come from *gregaria-parva* relatives not *longipes* or *inermis*, and its distribution suggests also phylogenetic speciations like the relation between *T. longipes* and *T. inspinata*.

The distribution of *T. gregaria* is well discussed by Brinton (1962b) with some phylogenetic consideration in view of biantitropical panoceanic distribution of this species in southern and northern hemispheres.

The vertical and latitudinal distribution of *Thysanoessa* euphausiids is given in Fig. 36. In both Arctic and Antarctic seas, *Thysanoessa* euphausiids extend to the deeper waters following to the equator. *Thysanoessa raschii*, the most northern species is living in shallow water usually upper than 200 metre, and *T. inermis* upper than 300 metre in the North Pacific. The southern waters species, *T. macrura* and *T. vicina* are also living in the layers upper than 300 metre (Hardy & Gunther, 1935). *T. longipes* is generally considered to live in the layers upper than 500 metre, and deeper waters in the southern waters near 40N latitudes. The closely related species *T. inspinata* which is living more southern waters (Brinton, 1962) is considered to distribute into deeper waters (Nemoto, 1962). The deep water species *T. parva* is usually found from 750 to 2000 metre depth in the waters. The vertical zones of euphausiids distribution are illustrated by Brinton (1962b) as the mid Pacific profile in the North Pacific. The Arctic and subarctic species of euphausiids found in the surface layers often found in the middle layers of temperate waters of lower latitudes.

The deep sea living *T. parva* has far reduced spine and setae in the thoracic legs, although *T. gregaria* and other species have also reduced setae in thoracic legs especially in second legs.

This tendency is also observed in carnivorous euphausiids *Nematobrachion* species. But the remarkable point in *T. parva* is the lack of strong fringes in setae as well as the reduction of setae. As a taxonomic character in *T. parva,* these fine fringes in setae in legs are described. These fine fringes may be also adoptation to the deep sea living where the small food organisms such as diatoms are comparatively scarce as compared with surface layers.

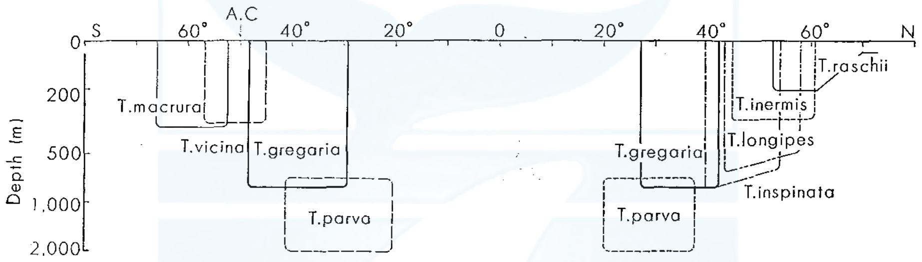

Fig. 36. Profile of the vertical and latitudinal distribution of *Thysanoessa* euphausiids along the section approximately 160E.

Among *Thysanoessa* euphausiids, *T. inspinata* is found by KT-64-17 cruise from the south waters of Japan by deep oblique haul, where *T. gregaria* possibly distributes from the surface to about 1000 m deep. The Pacific boreal species *Tessarabrachion oculatus* is also collected by this cruise in the same position. This submargence of boreal species in temperate waters is observed in other groups of plankton such as chaetognata *Sagitta elegans* in the south waters of Honshu (Marumo, 1965).

Brinton considered the biantitoropical panoceanic distribution of *Thysanoessa gregaria* may be explained by Pleistocene cold waters distribution. The 7°C and 11°C isotherms at 200 m are associated with the limitation of the recent range of *T. gregaria.* and *T. gregaria* crossed the equater by this cooling of 2 1/2° to 3°C at 200 m in Pleistocene age.

At this circumstance, the North Pacific subarctic species, *T. longipes* may still occupy the coastal fauna in the region 20–30N where the colder California current runs and it never has the chance of transgressing the equator.

From above explanations for the distribution of *Thysanoessa* euphausiids two hypotheses may be derived.

One is the trespass of *T. vicina* and *T. macrura* or their ancestor in the Antarctic waters is earlier than the transgression of the equator by *T. gregaria,* and speciation of *T. inspinata* from *T. longipes* or its relatives is possibly later than that age.

The second hypothesis is that *T. parva* is also specialized into southern and northern hemisphere at about the same age of *T. gregaria* or a little later age, and it also transgressed the equator after the specialization as *T. parva*, not the age of the original type of *T. parva* in the older ages.

DISCUSSION

The allometric study and comparative morphology explain fairly well the taxonomic and ecological positions of each species in *Thysanoessa* euphausiids.

TABLE 10. CHARACTERISTICS IN COMPARATIVE MORPHOLOGY AND ECOLOGY IN *THYSANOESSA* EUPHAUSIIDS

	EYE		ANTENNULE		CARAPACE			ABDOMINAL SEGMENTS		LEGS			PREANAL SPINE	COPULATORY ORGAN			STOMACH		LIVING DEPTH			
	constriction	sexual dimorphism	flagellum	sexual dimorphism	rostrum	denticle	eye hole spine	keel present	spine present	1st dactylus	2nd dactylus	3rd dactylus	sexual dimorphism	inermis type	longipes type	gregaria type	cluster spine	central spine	0– 300	300– 500	500–1000	1000–2000
T. inermis	−	−	◇	+	◇	−	−	−	+	◇	◇	◇	±	+			+	±	+	−	−	−
T. raschii	−	−	◇	−	△	+	−	−	−	◇	◇	◇	±	+			+	±	+	−	−	−
T. spinifera	−	−	◇	+	×	−	+	+	+	◇	×	◇	±	±	±		+	±	+	±	−	−
T. gregaria	+	+	●	−	△	+	−	−	−	●	●	◇	+			+	+	(±)	+	+	±	−
T. macrura	+	±	●	−	⊙	+	−	−	−	●?	●	⊙	+			+	+	(±)	+	+	−	−
T. vicina	+	+	●	−	⊙	+	−	−	−	●?	●	◇	+			+	+	(±)	+	+	−	−
T. longicaudata	+	±	◆	−	◇?	−	−	±	−	○	●	◇	−		±	±	+	+	+	+	+	−
T. longipes	+	±	●	−	◇?	+	−	+	+	○	●	◇	−		+		+	(±)	+	+	±	−
T. inspinata	+	±	●	−	◇?	+	−	+	−	○	●	◇	−		+		+	(±)	+	+	±	−
T. parva	+		?			+	−	−	−		?		?			+	?		−	−	+	+

The similarity in morphological characters of *Thysanoessa* euphausiids is listed in Table 10. In general consideration *T. inermis* and *T. raschii* resemble each other. *T. inermis* differs in the sexual dimorphism in the first antenna, presence of spines in the posterior abdominal segments, shape of the rostrum and the absence of the carapace denticle in the lower margins. But other main characteristics are the same with *T. raschii*. The arrangement of thoracic legs resembles to *Euphausia* species.

T. spinifera shows the first characteristic point in the sexual dimorphism in the first antenna. The rostrum of the carapace has also specific difference among these three species. The most peculiar point is that the eye hole spine along the carapace margin is present in *T. spinifera*. None of other *Thysanoessa* has this spine. The shape of dactylus in thoracic legs approximately the same among those *T. inermis*, *T. raschii* and *T. spinifera*. Only the dactylus of *T. spinifera* in the second leg differs from other two species. It bears the intermediate characteristics between *T.*

raschii group and *T. gregaria* and other species which have elongated second legs. Third dactylus does not differ among every species except *T. macrura* as it is discussed in the former part. And no special difference is given in other dactylus in posterior legs.

Preanal spines in those Inermis species show slight sexual dimorphism, and other two groups also divide themselves from those species as fairly clear dicisions. The group of *T. parva* is still unknown, but it may possibly belong to *T. gregaria* group. The Atlantic *T. longicaudata* has non-sexual different preanal spines in denticulation and belongs to *T. longipes* group. Longipes group species have the same character in the dactylus of the first legs and shape of the rostrums, but *T. longicaudata* lacks the lateral denticle of the carapace. The second leg of *T. spinifera* stands peculiar intermediate position between *T. inermis* group and *T. gregaria* group. And this tendency is also observed in the relation between merus and dactylus in the second leg. These characters show that the second leg of *T. spinifera* becomes elongating and the dactylus shortening which is more relating to *T. gregaria* group. *T. gregaria* group is considered off shore living species and they are now developing to more carnivorous feeder in selection of the food. The short and bearing tough spines in the dactylus of the elongated legs are also often observed in other carnivorous euphausiids. And a little elongated second leg in some younger forms of *T. inermis* (Hansen, 1911, Einarsson, 1945) is noted already, especially in *T. neglecta* form in the Atlantic. According to the Einarsson's consideration, *T. neglecta* is only a transitory form in the developmental history of *T. inermis*. It has longer second legs and shorter dactylus from the figures by Einarsson, (1945 Fig. 19) and constricted eye. The illustrated specimens stand clearly in the *gregaria* group from the length of each joint. The larval forms of *T. inermis* usually have eyes longer vertically, which is almost the same as *T. longipes* eyes in those stages. Thus *T. inermis* sometimes shows in its developmental stages the different pattern of allomorphosis in second leg, and it is considered as the one explanation for the different group of allomorphosis in *Thysanoessa* euphausiids is originated from the above different developmental stages.

Another neritic species *T. raschii* has non-elongated second leg, and non-constricted eye in adults, and it has no clear form of elongated second leg in furcilia stages like *neglecta* form of *T. inermis*. But it has lateral denticles in the anterior part of the margin of the carapace, although the denticle is situated far posterior part of the lateral margin of the carapace in the furcilia stages of *T. raschii*. This would suggests full development in this character if the speciation is attributable to excessive growth. There are three main types are observed in *Thysanoessa* euphausiids in male copulatory organs. One is *inermis* type which includes *T. raschii* and *T. inermis*. *T. spinifera* has this character, but it bears also *longipes* type as discussed in the former part. *T. gregaria* is considered to belong the same group with *T. macrura*, *T. vicina* and *T. parva*. *T. longicaudata* is standing in the intermediate position between *T. longipes* and *T. gregaria*. This is also one of the expression of the phylogenetic position of *T. longicaudata* that it does not belong to the *gregaria* group. The position of *T. longicaudata* is also confirmed by the presence of central spines in the base plate of the stomach structure. This central spine is clear also in some other euphausiids. *Thysanopoda*, *Nyctiphanes*, and *Nematobrachion* species have well developed central spines in the base plate. Only *T. longicaudata* among *Thysanoessa* has well developed central spines and *T. inermis* group has vague spines. *T. longipes* and *T. gregaria* have trace of central spines but sometimes they have spines like *T. inermis*. The type of cluster spines in the anterior part of the side plate of the stomachs are nearly the same in *Thysanoessa* species, but some difference in related species such as *T. longipes* and *T. inspinata* is observed.

The bilobate eye of seven *Thysanoessa* euphausiids in adult may directly be connected to the broader living range in the depth of the sea at present or their ancestors (Brinton, 1962b).

TABLE 11. LIST OF SIMILARITY IN ALLOMORPHOSIS IN *THYSANOESSA* EUPHAUSIIDS

	CARAPACE M. L.	CARAPACE M. L.						TOTAL 1ST LEG					MERUS : dactylus					MERUS	CARAPACE M. L.		SIX ABD. SEGMENT	
	: Denticle l.	: 1st leg	: 2nd merus	: 3rd leg	: 4th ,,	: 5th ,,	: 6th ,,	: 2nd	: 3rd	: 4th	: 5th	: 6th	: 2nd	: 3rd	: 4th	: 5th	: 6th	: 2nd carpus	: Antennule	: 6th abd. segment	: 5th segment	: Telson
T. inermis	–	◇?	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇
T. raschii	△	◇?	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	◇	△	△	◇
T. spinifera	–	×	×	◇	◇	◇	◇	◇	◇	◇	◇	◇	×	◇	◇	◇	◇	◇	◇	◇?	×	×
T. gregaria	●	●	●	◇	◇	●	●	●	◇	◇?	●	●	●	◇	◇	◇	◇	●	●	●	●	●
T. macrura	⊙	●	●	◇	◇	●	●	●	◇	◇?	●	●	●	⊙	◇	◇	◇	●	●	⊙	⊙	⊙
T. vicina	⊙	●	●	◇	◇	●	●	●	◇	◇	●	●	●	◇	◇	◇	◇	●	●	⊙	⊙	⊙
T. longicaudata	–	●	●	◇	◇	●	●	●	◇	◇	●	●	●	◇	◇	◇	◇	●	◆	⊙?	◆	⊙
T. longipes	○	●	●	◇	◇	●	●	●	◇	◇	●	●	●	◇	◇	◇	◇	●	●	△	◆	○
T. inspinata	+	●	●	◇	◇	●	?	●	◇	◇	●	●	●	◇	◇	◇	◇	●	●	△	◆	○

The similarity in allometric tribes are illustrated symbolically in the Table 11. As the general aspects of the list, those tribes are also divided into two main groups. In the relative growth of the lateral denticle and carapace length, however, each species demonstrates respective tribe except *T. vicina* and *T. macrura*.

It is suggested the same allometric tribe of *T. macrura* and *T. vicina* in the position of lateral denticle means they closely related each other and position of *T. vicina* is larval stage of *T. macrura* in this relation. Because the position of lateral denticle of the carapace is situated in the posterior part and goes up to forward with the body development especially in the furcilia stages. The body size of *T. vicina* is smaller than *T. macrura* and lateral denticle is situated a little posterior position. These characters are the larval characteristics. The general distribution of those species show that the adult form, namely the lateral denticle of the carapace situating in the anterior position, of each group is found in the colder waters. The body size of *T. inspinata* is smaller than *T. longipes*, and *T. vicina* is smaller than *T. macrura*. Thus those specific differences are connected with the body development in those species. The wamer water type may be the larval type, which has the posterior carapace denticles, and having smaller body length. The phenomena like this have been found on American fresh water fish as a consideration of the evolution of those fish (Hubbs, 1940).

The legs of euphausiids are generally considered as the feeding and swimming apparatus and legs vary very much among euphausiid species.

The general allomorphosis in legs of *Thysanoessa* euphausiids shows also two main groups. The total leg length against carapace margin length and total first leg are both the same in third and fourth legs, but it differs in first, second, fifth and sixth legs. As for the relation of total length of the first legs for carapace length, *T. inermis*, *T. raschii* and *T. spinifera* form one allometry group and other six and possibly *T. parva* form another group.

T. spinifera stands itself in the second leg aparting from *T. inermis* but it forms the same allometric tribes in fifth and sixth legs with *T. inermis* and *T. raschii*.

The allometric group of second legs are also divided into two groups. These groups coincide with also groups of fifth and sixth legs. From the observations on structure of legs, the reduction in the posterior thoracic legs is considered as the steps to the carnivorous feeding type. *Thysaneossa* euphausiids have even in the *gregaria* group, rather long and skimming setae in sixth and fifth legs. But other carnivorous *Nematobrachion* species have none functional setae and reduced fifth and sixth legs. The surface feeding and hervivorous euphausiids, such as *Euphausia*, have functional and long sixth and fifth legs in general. Thus it may be considered some of *Thysanoessa* euphausiids bear both types of feeding and omnivorous feeding type. Among them, *T. inermis*, *T. raschii* are surface feeder type. The general features of setae in thoracic legs as the feeding apparatus are discussed by Barkley (1940). *T. inermis*, *T. raschii* and *T. spinifera* resemble to *E. superba* in the arrangement of those setae in ishium and merus and in the allomorphosis relationship of every leg length.

In the allomorphosis in the relation between merus and dactylus of each legs shows also two main allometric tribes as in the relation between merus and carpus in second legs. But *T. macrura* shows peculiar position in first and third legs which occupys the independent allometric tribe. *T. spinifera* occupys also the tribe itself in second leg.

Although the different allometric tribes are observed in second legs, no difference is found in the allomorphosis from fourth to sixth legs in the relation between merus and dactylus. Thus the speed in the development in each joints from small and oceanic species to large neritic species is the same for each species. Only second legs, and first and third legs partly, show the significant allomorphosis difference, which also have special means for ecological and morphological structures. The allomorphosis in the relation between carapace margin length and abdominal segments varies considerably in each species. It is very interesting that *T. raschii* forms the same tribe with *T. longipes* and *T. inspinata*. *T. macrura*, *T. vicina* and *T. longicaudata* form one tribe and *T. gregaria* forms itself one tribe. In the relation between the length of sixth and fifth abdominal segment, *T. gregaria* also forms tribe only itself. *T. gregaria* is only one species living in the tempeate surface waters, and posterior parts of the abdominal segments are considered as the swimming apparatus of euphausiids. If it is true, *T. raschii* takes somewhat curious position to form the same allometry line with other two oceanic species. *T. vicina* and *T. macrura* form the same tribes not only in the denticle length but also the legs and abdominal segments relationship in general. The former relation in lateral denticles is considered as the close interspecific relation and the latter are partly the similarity in ecological characteristics such as feeding and swimming in the sea.

The preliminary phylogenetic development in *Thysanoessa* euphausiids is in considered as follows. The original form of *Thysanoessa* is possibly belonging to the group of *Nematoscelis* and *Tessarabrachion* relatives.

From the ancestor of *Thysanoessa*, two branches are considered which comparatively earlier times developed to the different directions. Those are *T. longipes* and *T. gregaria* group, and *T. inermis* and *T. spinifera* group. The former stem is developing along the *Thysanoessa* line, that is oceanic and wider vertical range of distribution. The later stem is developing to the different neritic inhabitance such as *T. inermis*, *T. raschii* and *T. spinifera.*

In the Antarctic, *Euphausia crystallorophias* is living as the real neritic species. Its colonization of Antarctic waters is considered by John (1936) as the series of *E. lucens—E. vallentini—E. frigida* and this series is divided into two branchs, those are *E. superba* and *E. crystallorophias.* And the transgression of the ancestor of *E. frigida* series from the south as the *E. pacifica* series is possibly at the same time that the genus *Thysanoessa* become antitropical (Brinton, 1962b). At these time, the later stem became developing as neritic and surface living species.

T. longipes or its ancestor is considered coming from the stem different *T. inermis*-ancestors and *T. gregaria*-ancestors as it bears the male copulatory organs and preanal spines of different forms. Further the distribution of *T. longipes* and *T. inspinata* is fixed in only North Pacific. This shows the transgression of equator of these *T. longipes* group did not occur at the age of transgression of *T. gregaria* group. They possibly occupy the northern colder waters already at that times, and they shift the postulated distributions of transgression of equator at the cooling age discussed by Brinton (1962b).

Thysanoessa inermis and *T. raschii* are common in the north Atlantic and Pacific, and they had possibly contact through North pole sea still in later ages. This may be endorced by the distribution of one and two spine forms of *T. inermis* and neritic species *T. raschii.* Before the differenciation between *T. inermis* and *T. raschii*, *T. spinifera* or its ancestor is fixed as the neritic and shallow water species from the consideration on the structure of male copulatory organs and the allomorphosis of body parts. The restricted distribution of *T. spinifera* along the west coast of North America may contradict this assumption. But it is generally accepted that it is closed in Aleutian and California current, and the cold North Bering Sea and general water transport from the west to the east in the North Pacific drift may be the barriers for the extension of *T. spinifera* to the west Pacifiic (Nemoto, 1962). The position of Atlantic *T. longicaudata* is very characteristic. It is considered it comes from the way between *T. longipes* stem to the ancestors of *T. gregaria* or directly from ancestor of *T. longipes*. *T. longicaudata* completely lacks the carapace denticle but it is sometimes absent in many species which usually have carapace denticles and some species have two forms which have denticles and none (*Nematoscelis difficilis*, Mclaughlin, 1965). It is apparent that the external characters such as male copulatory organs and carapace denticles and preanal spines, the *T. gregaria* ancestor has four other present *Thysanoessa* species, *T. macrura T. vicina*, *T. parva* and *T. gregaria* at least.

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SUMMARY

Thysanoessa euphausiids are investigated under the comparative morphology and allomorphosis studies, to get general considerations on morphological and taxonomical characters as well as ecological peculiarities. The main results are summarized as follows.

1. Modified and simple key for the taxonomy of *Thysanoessa* genus is given.
2. Three main groups, namely longer, intermediate and shorter forms are found on the first antenna. *T. inermis*, *T. spinifera* and *T. raschii* form the longer group, and they run also the same allometric tribe in allomorphosis in the relation between carapace length and length of the flagellum. *T. vicina*, *T. macrura*, *T. inspinata*, *T. longipes* and *T. gregaria* form the shorter group and also the same allometric tribe. *T. longicaudata* forms different tribe apart from those two groups.
3. The shape of the rostrums, lateral denticles are examined. The position of the lateral denticle have very important taxonomical characters especially in closely related species under the evolution of the neoteny-like speciation.
4. Shape of eyes of *Thysanoessa* are very various. Neritic and shallow water

species have round and none constricted small eyes which show no sexual dimorphism. The allometric tribes in eyes are very various among each species and sex, which is possibly due to the reflection of the complex ecological characteristics.

5. Arrangement of dorsal keels and abdominal spines are examined. One and two spine forms of *Thysanoessa inermis* show the geographical cline in the North Pacific in occurrences of each form. One spine form occurrence is high in western Pacific especially in the sea of Okhotsk, in which it is ranging about 80 to 90 percent like the Atlantic specimens. But it decreases following to the east and only about 25 percent in the waters of the Gulf of Alaska. Three spine form of *T. inermis* is again described from the North Pacific.

6. *T. gregaria* stands in peculiar position among *Thysanoessa* species in the allomorphosis in telson, fifth, and sixth abdominal segments. It is possibly due to the wamer water habitat in the transition zone apart from other *Thysanoessa*. *T. macrura* and *T. vicina* have close relations also in those points, which shows the ecological and phylogenetic similarities are very close also in these body parts.

7. In *T. spinifera* and *T. longicaudata*, the allomorphosis in each sex is different in the relation of abdominal segments and other body parts. The dalay in the development of the carapace in males may bring this variation, and these sexual differences among allometric tribes are considered as one of speciation of the direction from the female type to the male type.

8. Preanal spines of *Thysanoessa* euphausiids are divided into three groups, according to the sexual dimorphism. It is present in *T. macrura*, *T. gregaria*, *T. vicina* and possibly in *T. parva*. Only slight dimorphism is observed in *T. inermis* and *T. raschii*, and nearly absent in *T. longipes*, *T. inspinata* and *T. longicaudata*. These sexual dimorphisms are already found still in younger adlescents.

9. Allomorphosis and structures of thoracic legs especially dactylus of them are examined. In the relation between carapace length and second thoracic legs, three allometric tribes are observed. *T. inermis* and *T. raschii* run the same line, and *T. longipes*, *T. inspinata*, *T. gregaria*, *T. macrura*, *T. vicina* and *T. longicaudata* form another tribe. *T. spinifera* forms one tribe itself. These tribes are nearly the same with the first legs, and *T. longipes* group is corresponding to the shorter dactylus group. There is no difference in the allomorphosis in third and fourth legs, but *T. inermis*, *T. raschii* and *T. spinifera* form another tribe apart from *T. gregaria* group which has shorter and poorly developed setae in those legs.

The characteristic positions of the dactylus in the first and third legs of *T. macrura* are observed.

10. The structures of the dactylus of first and second legs are investigated. The number of the spines along the inner margin of the dactylus of the first leg varies in each species, and corresponding to the shorter and longer groups of the dactylus. *T. spinifera* and *T. raschii*, the longer group, have 8 to 14 spines and *T. inermis* has 5 to 8 spines. The shorter group has less than 9 and *T. gregaria*, *T. macrura* and *T. vicina* have only 1 to 3 inner spines.

The dactylus of second legs is long in *T. inermis* and *T. raschii*, and *T. spinifera* has rather shorter dactylus. Other *Thysanoessa* euphausiids have shorter dactylus and elongated merus and carpus, which may be the simpton of carnivorous habit.

11. The first and second maxilla of *Thysanoessa* species show the carnivorous and hervivorous characters, which stand the intermediate position between the carnivorous euphausiid, *Nematobrachion* and the mainly hervivorous euphausiids *Euphausia* and other species.

12. The inner structure of the stomachs of *Thysanoessa* euphausiids has special row of spines which is named as ' Cluster spines '. This row of cluster spines is found along the base part of the side plate of inner wall of the stomach. The isolated tough spines are also found along the anterior part of the side plate, which also very effective for the crashing their foods such as diatomes and other hard shell organisms. But *Thysanoessa* euphausiids have no circle ' cluster spines ' in the anterior part of the side plate.

13. Male copulatory organs of *Thysanoessa* prove also *T. macrura T. vicina* and possibly *T. parva* are belonging to the relative of *T. gregaria*. *T. longicaudata* stands peculiar position, and *T. inspinata* shows close similarity to *T. longipes*.

14. The similarity and difference in allomorphosis and morphological study are compared to get characteristics and phylogenetic considerations.

From the morphological observations, three main types are found. *T. longipes*, *T. inspinata* and *T. longicaudata* form one group, *T. raschii*, *T. inermis* and *T. spinifera* second group, and *T. gregaria*, *T. vicina* and *T. macrura* (possibly *T. parva* is included in this group) third group. The most typical difference among those three groups is the sexual dimorphism in preanal spines. The characteristics expressed in preanal spine and male copulatory organs of *T. longicaudata* suggest that it comes from the *T. longipes* ancestors rather than *T. gregaria* group.

15. General distribution of each species shows the possible correlation between the evolution and present distributions, suggesting that *T. vicina* and *T. macrura* are fixed in the Antarctic before the transgression of the equator by *T. gregaria*, and the speciation of *T. inspinata* from *T. longipes* is possibly later than that age in the North Pacific.

16. The preliminary consideration of the phylogeny of *Thysanoessa* is stated. *T. longipes* and *T. gregaria* groups are developing along the *Thysanoessa* line, which is oceanic and wider vertical range of distribution, in which *T. longipes* and *T. inspinata* or their ancestor is coming not through the *T. gregaria* or *gregaria* ancestor, although some morphological characters are related to it. *T. longicaudata* also comes from the way between *T. longipes* and the ancestors of *T. gregaria* or directly *T. longipes* group but possibly not from *T. gregaria* group. The close relations between two groups, *T. longipes* and *T. inspinata*, *T. macrura* and *T. vicina* may be explained as the neoteny type evolution.

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一般財団法人　日本鯨類研究所

THE INSTITUTE OF CETACEAN RESEARCH

FISHERY OCEANOGRAPHIC STUDY ON THE BALEEN WHALING GROUNDS

KEIJI NASU

INTRODUCTION

A Fishery oceanographic study of the whaling grounds seeks to find the factors controlling the abundance of whales in the waters and in general has been a subject of interest to whalers. In the previous paper (Nasu 1963), the author discussed the oceanography and baleen whaling grounds in the subarctic Pacific Ocean. In this paper, the oceanographic environment of the baleen whaling grounds in the coastal region of Japan, subarctic Pacific Ocean, and Antarctic Ocean are discussed. Japanese oceanographic observations in the whaling grounds mainly have been carried on by the whaling factory ships and whale making research boats using bathythermographs and reversing thermomenters. Most observations were made at surface. From the results of the biological studies on the whaling grounds by Marr (1956, 1962) and Nemoto (1959) the author presumed that the feeding depth is less than about 50 m. Therefore, this study was made mainly on the oceanographic environment of the surface layer of the whaling grounds.

In the coastal region of Japan Uda (1953, 1954) plotted the maps of annual whaling grounds for each 10 days and analyzed the relation between the whaling grounds and the hydrographic condition based on data of the daily whaling reports during 1910–1951. A study of the subarctic Pacific Ocean whaling grounds in relation to meteorological and oceanographic conditions was made by Uda and Nasu (1956) and Nasu (1957, 1960, 1963). Nemoto (1957, 1959) also had reported in detail on the subject from the point of the food of baleen whales and the ecology of plankton.

Numerous physical, chemical and biological studies of the Antarctic have been described by the Discovery Committee. Studies of the physical and chemical oceanographic environment of the whaling ground based on the data obtained by the Japanese surveys were made by Shimomura (1947), Sugiura (1949), Tsuchida (1952), Nasu (1959), Kumagori (1963), Ishino (1963), Uda (1963) and Ishino & Nasu (1965). The biological study was made by Nemoto & Nasu (1958) and Nemoto (1959).

The present paper gives the oceanographic structure of these whaling grounds and the physical environment connected with the distribution of baleen whales, using data obtained by whaling research, operation ships and other survey ships.

DISTRIBUTION OF BALEEN WHALING GROUODS OF THE WORLD IN THE PAST 10 YEARS

COASTAL WHALING GROUNDS

Coast of Japan

The sea regions from Sanriku* to Hokkaido are the most representative whaling grounds in the North Pacific, and the whale species caught consist mainly of sei and Bryde's whale. The sei whale is the most important species and its catch average about 600 in a year. Generally the favourable seasons are from May to June off Sanriku and from September to October off Hokkaido.

The catch of Bryde's whale in the Sanriku region is primarily influenced especially by the fluctuation of the Kuroshio water mass because the distribution of Bryde's whales depends on water with about 20°C or more in surface temperature Omura & Nemoto 1955, Omura 1959). The total catch of whales caught in the most abundant years in the Sanriku was 400 and the average number in a year was about 120. On the other hand, the catch off Hokkaido was less than 10 in a year, because of colder sea region than Sanriku. Sometimes the fin, blue and humpback whales were caught in this sea region, too. The catch of fin whale in the Okhotsk sea was reduced recently and a catch of few sei and humpback whales was observed. The favourable seasons being from July through August.

Whaling in the East China sea commenced in 1955. The fin whales are most important baleen whale species there. About 250–300 animals are caught in abundant catch years, Bryde's whales also were caught here.

The main whaling grounds of Bryde's whale were located off Kii Peninsula, and the total number of whales caught reached more than 200 in plentiful years.

In waters adjacent to Okinawa Island in the Ryukyu Islands humpback whales mainly were caught. More than 200 animals were taken during January to March in rich years (the catch in 1958 reached 240 animals). The catch of Bryde's whales also was observed on the coast of Formosa, but the number of whales caught was very few compared with Ryukyu Islands. The whaling operation in these waters have closed from 1963 in Ryukyu Islands and 1960 in the coast of Formosa, respectively.

Coast of North America

The most important whaling grounds in this area was located off British Columbia and the catch during April to October in 1963 were 30 blue, 220 fin, 24 humpback and 154 sei whales, the favourable whaling season for each whale species is as follows: blue whale: May-July; fin whale: May-August; himpback whale: May-June; sei whale: June-August. The coast of California is also an important baleen whaling ground, that is, the catch in 1963 are 6 blue, 16 fin, 55

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* Sanriku includes the waters to the northeast of Honshu, Japan.

humpback and 97 sei whales and the favourable whaling seasons are April-May for humpback whale and July- August for sei whale, respectively.

Coast of South America

The whaling off the Chilean coast was operated for long seasons except August and September. The chief whale species was sperm whale (the total number of whole caught in 1963 was 1494). However, Clark (1962) reported that unexploited baleen whaling grounds were located in the waters of 30°–35°S latitude in the vicinity of Humbolt current. After that, 378 blue, 138 fin and 190 sei whales were caught by the operation from November of 1964 to March of 1965, and so it may be considered that the results of the survey by Clark were justified. The favourable whaling seasons are for fin : November, December and for sei and blue : after January, respectively.

In addition, according to the composition of body length and shape of baleen plate, the blue whales in this area seem likely to pigmy blue whales which were observed in the sea regions from Kerguelen to Marion Island (private information from Dr. Ichihara). The baleen whale catch in the waters of Brazil consists mainly of sei whale. The sei whale catch, recently has decreased motably.

Coast of Australia and New Zealand

In the coast of New Zealand and Australia mainly humpback whales were caught and whaling seasons are May-July in New Zealand and June-October in Australia. The number of whales caught in good years amounted to about 300 in New Zealand, and about 2,000 in Australia. The catch, however, in 1963 decreased to 9 animals in New Zealand and 87 in Australia. On the other hand, the catch of sperm whales in these waters has increased considerably recently.

Coast of South Africa

In south African waters whaling was carried on from the coast of Natal and the coast of Cape Province. The baleen whale species in these waters consists mainly of fin and sei whales. On the coast of Cape Province, 50 or less, Bryde's whales are also taken in a year. The favourable whaling seasons are May to October in both waters. In 1959. 160 humpback and 6 sei whales were caught in Gabon on the west coast of South Africa.

North Atlantic and Arctic

The representative whaling grounds in this region were Iceland and the Norwegian coast. The main species of whale was fin whale in both regions. The average catch of fin whale in a year from Iceland was more than 250. The sei whales also were caught, averaging 70 animals in a year, but the catch of sei whale has decreased notably recently (the catch in 1963 decreased to 20 animals). The whaling grounds off Norwegian coast are located near Steinshamn in the southern district of Norway and near Skjelnan in the northern district of Norway. The main whale species (fin whale) caught and the favourable whaling seasons (June to Aug.) are quite same in both grounds. The total annual catch average in these regions reached about 160 animals.

The catch in Færoe Islands consists mainly of fin whales and reached 141 animals in 1957, but the annual average (less than 80 animals) was less than Norway and Iceland. The catch in these waters was also strongly reduced in recent years, and was only 3 fin whales in 1963.

In the west coast of Greenland the annual number of whales caught was more than 200 animals up to 1957, but the catch in recent years can not observed. The catch in Newfoundland also can not observed from 1960.

Some baleen whales also were caught in Spain and Madeira, where the high number of sperm whales were caught.

PELAGIC WHALING GROUNDS

Subarctic Pacific

The Japanese operations with floating factories in the subarctic Pacific Ocean were resumed in 1952, and the whaling grounds covered the Bering Sea the northern part of North Pacific and the Gulf of Alaska. The baleen whale catch in these waters consists mainly of fin whales, but the catch of sei whales have increased notably in recent years.

The fin whaling grounds were located from the southern region of the Aleutian Islands to the Bering Sea, but no blue or sei whaling grounds were located in the Bering Sea.

Antarctic

The locality of baleen whaling grounds operated by the Japanese floating factories varied in the recent 10 years. That is, the grounds during the seasons in 1954/55–1956/57 covered the waters of 170°W to 80°W, and the western end of whaling grounds reached to 50°E in 1960/61, 10°W in 1962/63 and 60°W in 1964/65.

The latitudinal positions of grounds also varied abruptly, that is, the whaling operations have been carried on near the Antarctic Convergence, and the northern border reached in 47°S latitude. Pigmy blue whales were caught in the adjacent waters to Marion, Crozet and Kerguelen Island in 1959/60. In 1964/65 the baleen whaling grounds operated by Japanese floating factors completely shifted to the Antarctic Atlantic sector, and the northern border reached in about 45°S which corresponded to the vicinity of Sub-tropical Convergence which was characterized by the comparative high temperature with 13°–14°C as surface temperature.

OCEAROGRAPHIC STRUCTURE OF BALEEN WHALING GROUND

IN THE WATER TO THE NCRTHEAST OF JAPAN AND OFF HOKKAIDO.

The oceanographic analysis of baleen whaling ground in this area were made on the sei whale whose catch was the most abundance. The whaling grounds were divided as Fig. 1 by the land station. In addition, the catch statistics used in this paper were those 1955–1963. Fig. 1 shows the locality of land station from 1955 to 1963.

Moreover, the data used in this chapter are as follow.
1953 1954: Nihon Hogei Senpaku Sobikaizen Iinkai
Meteorological Agency,
1962 : Whale chaser

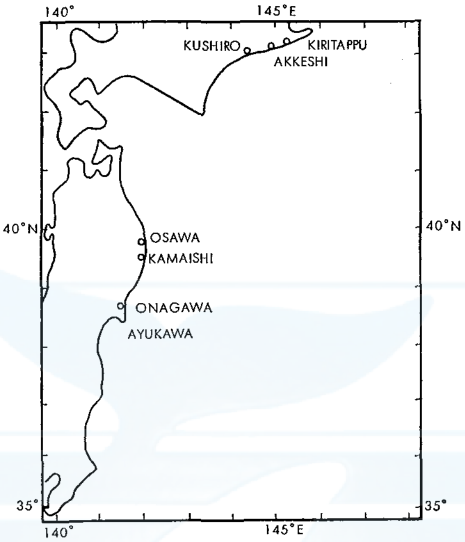

Fig. 1. Locality of land station.

Oceanographic conditions of sei whaling ground

The coasta lwhaling of Japan is operating from May to October, and the favourable whaling ground is generally moving from the northeast of Japan to Hokkaido.

Figs. 2–1, 2, 3 show the relation between the distribution of surface temperatures and sei whaling grounds in 1953, 1954 and 1962 respectively.

May: 1953—The favourable whaling grounds are located in the waters with 13°–16°C surface temperature which lie in mixing area*) and the edge of the branch of Oyashio.

1954—Oceanography in relation to whaling ground was not clear, because of few data of catch distribution, but the oceanographic condition was characterized by

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* The waters to the northwest of Japan was divided into Kuroshio, Oyashio and Transition areas, and those surface temperature are as follows (Kawai 1959).

	Area		
Season	Kuroshio	Transition	Oyashio
Feb.–Mar.	14°–19°C	5°–16°C	0°– 7°C
May	17°–23°C	10°–19°C	2°–12°C
Aug.	25°–29°C	20°–27°C	10°–22°C
Nov.	20°–25°C	13°–22°C	4°–15°C

the cyclonic eddy between Oyashio (O) and Kuroshio (K).
1962—The whaling ground was located in the waters with temperatures of 13°–15°C at the surface which correspond to the colder part in the mixing area.

June: 1953—The maximum catch of sei whales which generally is in June was in May in this year. The whaling ground was located in the mixing area, and es- pecially was formed around the oceanic front consists of the northwardly flowing warm waters and southwardly flowing cold waters. In addition to the warm water mass in 1953 was located more easterly than in normal years.
1954—The kuroshio water mass in 1954 was located in a more western area than 1953. The surface temperature generally was higher than in 1953 and the main whaling ground was formed in the waters of 18°–20°C (especially the most favourable whaling area is at the west side of warm water mass towards north).

July: 1953—The main whaling ground was located in the domain of 21°–23°C near the frontal zone of northwardly flowing warm water mass which corresponds with the oceanic front by the warm and cold water mass.
1954—The distribution of sei whales extends to the northeast direction, and the locality of main whaling grounds are found near the frontal zone of Oyashio which is characterized by 12°–14°C at surface temperature, too. Therefore, it seems that the whaling ground moves to the northeast of Japan to the Hokkaido area in this season.
1962—The whaling ground was located in the mixing area, and the most favourable area was found in oceanic front between the Kuroshio and Oyashio water mass near in 146°–144°E lat. which is characterized by 22°–25°C at surface temperature.

August: 1953—The distribution of temperature appears roughly similar to July, but it was supposed by the catch of whale that the amount of migrating whales was increased. The main whaling grounds were found in the mixing area between the warm and cold water mass and were divided into cold area where is near the front of Oyashio 19°–22°C (at surface temperature) and warm area where is near the front of Kuroshio (23°–26°C at surface temperature).
1954—From the locality of favourable whaling grounds which are situated in the waters with temperatures of 17°–20°C at surface. Evidently the main group of whales had moved toward the cold area to the north of Oyashio front. Morever the favourable whaling ground in the north of 42°N was located to the west of southwardly the 2nd Branch of Oyashio, and it was supposed that the whaling ground near 40°30′N, 148°E corresponded to the southern border of the 2nd Branch of the Oyashio (See Fig. 2–2).
1962—The favourable whaling grounds were in the Oyashio area (17°C–20°C at surface temperature) and bordered the Kuroshio front (23°–27°C at surface temperature), and such phenomena seemed to be a moving seasonal whaling ground.

September: 1953—The whaling grounds are similarly located in the two areas as in August and generally existed to the north. That is, the whaling ground lay in the water of 10°–18°C near 43°N in the Oyashio area and near 39°N in the warm waters, where owing to the condition of the surface temperature field, must be formed of the cyclonic eddy between the southwardly 2nd Branch of the Oyashio and the

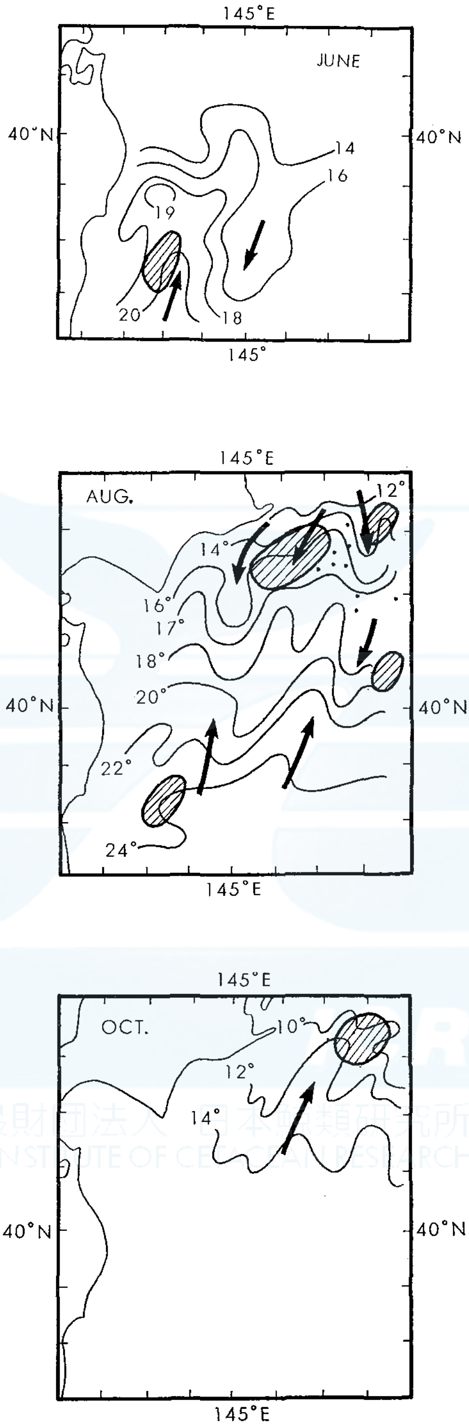

Fig. 2. Distribution of surface temperature and sei whaling ground in 1954.

warm waters.

1954—The southern whaling ground in 38°–39°N lie in the waters of 21°–26°C at surface temperature, which may be considered that the cyclonic eddy was formed between the southwardly cold and northwardly warm waters.

1962—The whaling ground in September was found far north of the previous month's, an especially favourable area located in front of tongue shaped warm waters near 42°N, 148°E. According to this phenomenon it must be presumed that the northward moving structure of whaling grounds participate in the situation of tongue shaped warm water mass.

October: 1953—The favourable whaling ground was located in the west area of the 2nd Branch of Oyashio near 42°N, 147°E, and in the oceanic front between the cold and warm waters near 40°N, 144°E, too.

1954—The whaling ground was in the Oyashio area to the north of about 43°N, which is characterized by 10°–12°C at surface temperature (Fig. 2–3).

Consideration of the sei whaling grounds

According to the reports of whale chasers, the sei whales off Sanriku coast in last of April were sighted in waters of 8.5°C–13.1°C surface temperature. The area having the highest whale density existed in water of 12.2°–13.0°C where corresponds to the southern area in the Polar Frontal Zone.*

In May through June, as shown by Fig. 9, the number of sei whale in the Sanriku area abruptly increases. As already stated the whaling grounds locate in the adjacent waters to southerly Oyashio waters within the mixing area which consists of Oyashio and Kuroshio waters, and the main grounds were formed in the northerly warm waters area (Kuroshio waters). The most favourable whaling grounds exists in the extreme area of warm waters. In July, the northward flow of Kuroshio water mass predominates (In 1982, in spite of the notable predominant Kuroshio, the whaling grounds were located considerally southwards) and the whaling grounds move from Sanriku area to Hokkaido area with the northerly movement of the Kuroshio.

In August of 1953 and 1962, the whaling grounds were formed considerablly southwards, and the general character of oceanographic conditions are that the northwardly flowing warm water mass (Kuroshio system waters) became located in the waters adjacent to the Sanriku coast in these respective years. In 1954 the main whaling ground moved off Hokkaido, and the northwardly flowing warm water mass became located further from Sanriku coast than in 1953 or 1962. In addition, the surface temperature of whaling grounds in August reaches 26°C by influence of Kuroshio waters.

In September some of the main whaling grounds are located in the Sanriku sea region as 1954, but these are generally located off the Hokkaido sea region.

By above mentioned phenomena the whaling grounds off Sanriku and Hokkaido are formed in the southern part in the transition area at beginning of whaling season, and moving towards the north with the increase of Kuroshio waters. It

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* The Polar Frontal Zone is a general term for the Kuroshio and Oyashio front.

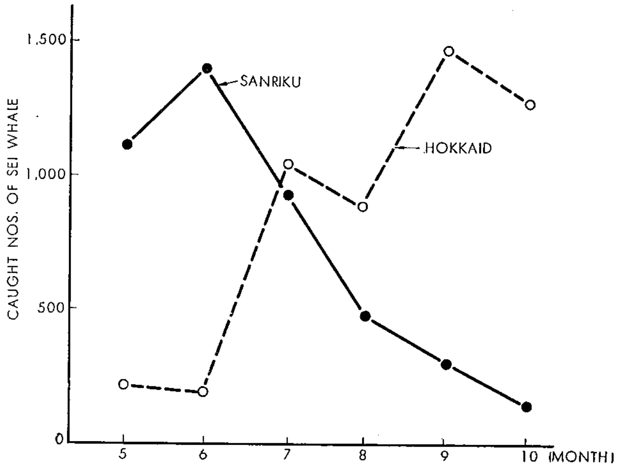


Fig. 3. Monthly catch of sei whale at Sanriku and Hokkaido in the years 1955 to 1964.

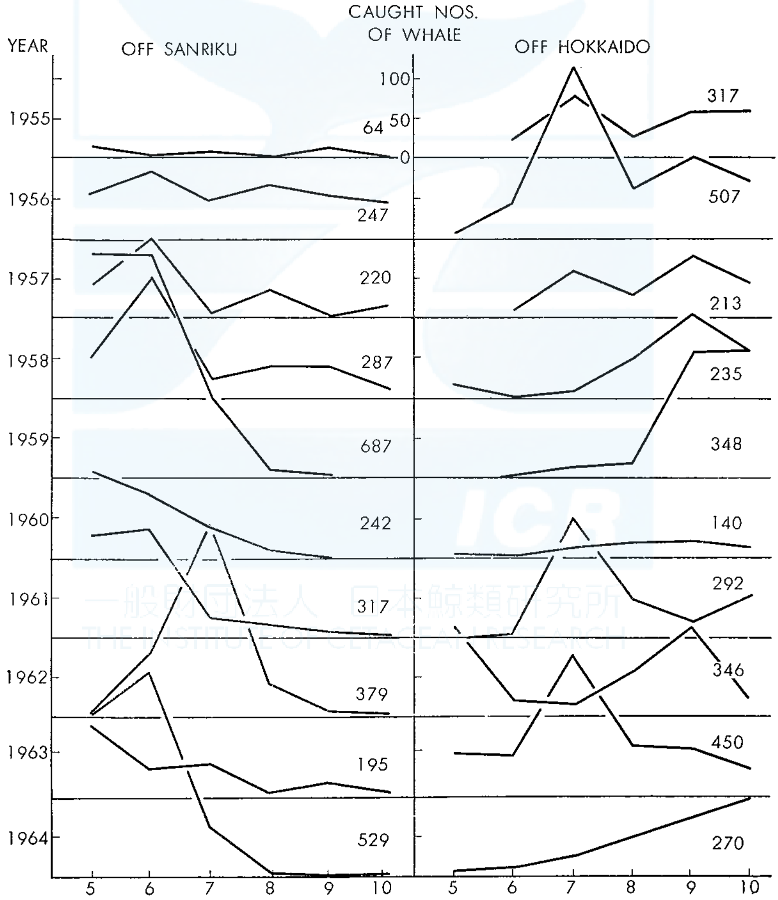


Fig. 4. Monthly and yearly catch of sei whale.

may be considered that the moving mechanism of the whaling grounds were influenced by the conspicuous tongue shaped Kuroshio waters which project towards the north.

Fig. 3 shows the monthly catch of sei whale of Sanriku and Hokkaido in the years 1955 to 1964. Judging from the monthly fluctuation we can find that the prosperous whaling times generally are in June off Sanriku and in September off Hokkaido, and it seems that the whaling grounds move from Sanriku area to Hokkaido area in July to August.

Fig. 4 shows the monthly and yearly catch of sei whale was drawn to study the moving mechanism of whaling grounds.

From Fig. 4 we can to two ground whaling condition types, the character of which are as follows.

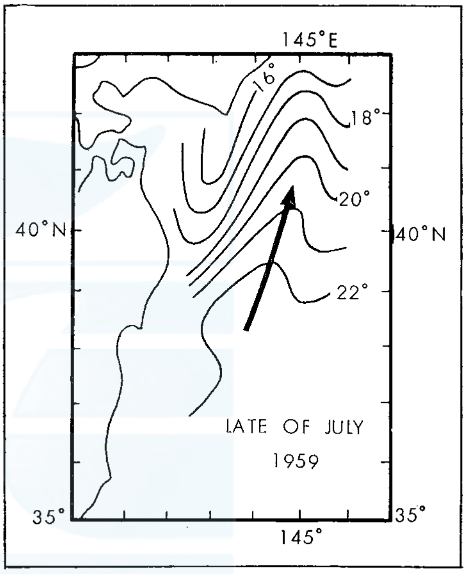


Fig. 5. Oceanographic conditions of good catch year in Sanriku.

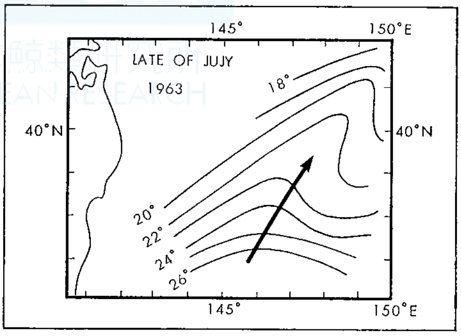


Fig. 6. Oceanographic conditions of good catch year in Hokkaido.

1) Good catch off Sanriku

It is of the general type, namely, the prosperous whaling times are in June off Sanriku and September off Hokkaido respectively. Further, the catch of sei whale off Sanriku is better than Hokkaido.

2) Good catch off Hokkaido

The prosperous whaling time off Hokkaido is early that is, it is generally in July, and the catch of sei whale off Hokkaido is better than Sanriku. Then the oceanographic character have been analyzed on the situation as of the last of July in each whaling condition year in which a close correlation can be shown between the catch of sei whale and the oceanographic pattern (especially, the fluctuation of Kuroshio waters).

As shown by Fig. 5 the oceanographic conditions of good catch year in Sanriku area as 1958, 1959 and 1963 are characterized by that the Kuroshio waters flow towards the north close to the Sanriku coast.

Further, as already stated on previous chapter, the main whaling grounds located to the west of the northwardly flowing warm waters, and tend to move towards the north along with the warm waters.

Therefore it must be considered

that the rich catch of sei whale in the yeasrich in the Sanriku area are caused by following.

1) The distribution density of whales increase because of the constriction of whaling ground area in Sanriku area.

2) The whaling grounds are located near the Sanriku land stations.

On the other hands, the catch off Sanriku area is generally poor in the years which show the good catch in Hokkaido area as 1955, 1956 and 1963 (see Fig. 6). The oceanographic character in these years is that the northward Kuroshio waters was located more easterly than good catch year off Sanriku.

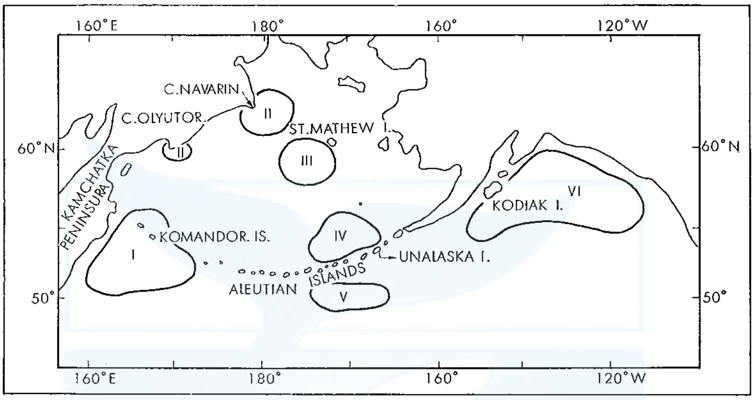


Fig. 7. Locality map of baleen whaling grounds.

Therefore it must be considered that the catch of sei whale in these years are poor in Sanriku area by following cause.

1) The distribution density of whales decrease because of the expansion of whaling area.

2) The whaling grounds are located further from the Sanriku land stations.

In addition, the whaling conditions in Hokkaido area are as follows:

1) The prosperous whaling time is early in these years.

2) The catch of sei whale is better than Sanriku area.

Their causal explanation must be summarized as follows:

1) The locality of whaling grounds which is formed near the northing tongue-like extension of Kuroshio waters become close to Hokkaido land station; because the Kuroshio waters flow northing far out from the Sanriku.

2) The catch availability of sei whale in the Hokkaido area is larger than Sanriku in these years.

SUBARCTIC PACIFIC AREA

The main baleen whaling grounds in the Subarctic Pacific area were divided as follows by the geographic distribution of Aleutian Islands, Alaskan continent and Siberia continent.

That is,

I) East area off Kamchatka Peninsula.
II) Off Cape Navarin and Olyutorski.
III) St. Mathew Island area.
IV) North area off Unalaska Island.
V) Southern area of Aleutian Islands.
VI) Gulf of Alaska.

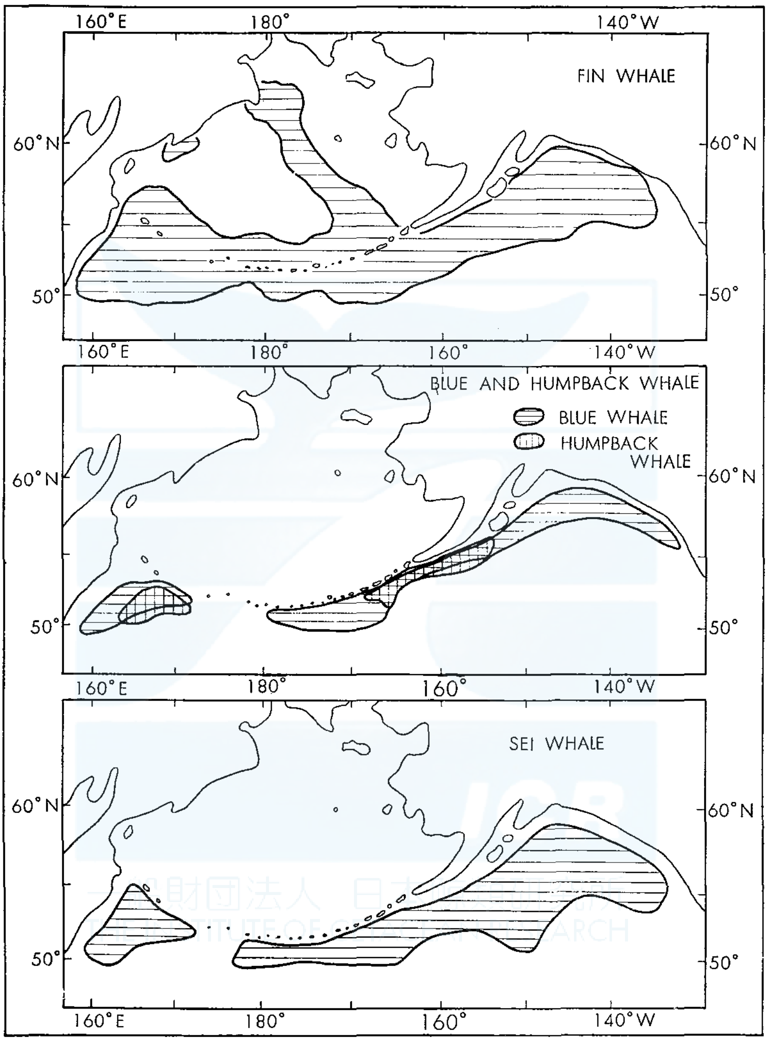


Fig. 8. Distribution of whaling grounds by species.

The locality map of baleen whaling grounds shown in Fig. 7 based upon the catch distribution of fin whale. Consequently, in here the author discussed the fin whaling grounds, but the distribution of whaling grounds by species in 1952 to 1964 also were shown in Fig. 8.

East area off Kamchatka Peninsula

The whaling grounds in this area were formed to the south and north of Komandorskii Islands and the beginning season of the whaling is most early, late in May, because of the geographic relation to Japan and migrational season of whales. Moreover the killed whale species consist of blue, fin, humpback and sei whale as shown in Table 1.

TABLE I. WHALING RESULT IN THE SUBARCTIC PACIFIC AREA IN THE YEARS 1952–1964

	Species of whales caught				
Years	Blue	Fin	Humpback	Sei	Total of Whales
1952	55	213	37	14	319
1953	90	470	42	98	700
1954	28	961	16	82	1087
1955	23	148	18	20	209
1956	1	595	35	47	678
1957	—	280	0	64	344
1958	5	269	24	60	358
1959	1	694	0	7	702
1960	0	167	0	0	167
1961	0	169	0	0	169
1962	0	3	0	0	3
1963	0	0	0	0	0
1964	0	55	0	2	57
Total	203	4024	172	394	4793

In order to obtain the center of whaling grounds the author (1963) used following formula which was shown by Uda (1930), and discussed the annually fluctuation of it. The annual fluctuation of the number of whales caught in 1 degree of latitude and longitude were discussed, too.

$$\bar{X} = \frac{n_i x_i}{n_i} \qquad \bar{Y} = \frac{n_i y_i}{n_i}$$

where x and y are the location of caught whale. n is number of whale caught. $\bar{X}$ and $\bar{Y}$ is the center of wahling ground.

That is, in the years 1952 to 1960, on the longitudinal fluctuation, two peaks were found in 1952, 1953 and 1954 during which the operation were carried out over an extended period (the operations in 1956 and 1959 were carried mainly out at the northern region of the Komandorskii Islands). These peaks are generally near 164°E and 174°E, and the highest peak of the longitudinal catch was found near 164°E. The peaks of the latitudinal catch were found 52°N to 53°N. Next, the mean position of the center of whaling grounds in the years 1952 to 1960 locate near 52°N, 165°–30'E, but the annual fluctuations of it were comparatively large.

Figs. 9 to 14 show the distribution of sighted fin whales and surface temperature obtained by whale chaser in May and June.

May: 1955 (see Fig. 9).—The isotherms run roughly paralled to Kamchatka Peninsula, but the 3.5°C-line extend to the north and south with some meander. Fin whales were found in the waters of less than 3.8°C in surface temperature and the greatest concentration of whales was located in the waters which were characterized by 3.5°–3.8°C. Whaling grounds were also located in the cold waters of less than 2.5°C in surface temperature. It seems to author that the whaling grounds which are located near 2.5°C are minimum temperature are as for whaling in the Subarctic Pacific Ocean.

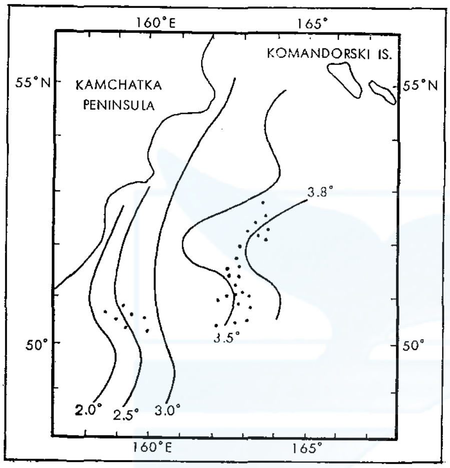


Fig. 9. Distribution of sighted fin whales and surface temperature (°C) in May of 1955.

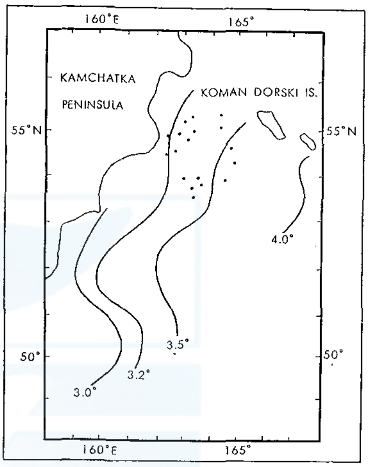


Fig. 10. Distribution of sighted fin whales and surface temperature (°C) in May of 1959.

1959 (see Fig. 10)—The distribution of isotherms generally run parallel to Kamchatka Peninsula similar to 1955, but the temperatures in the vicinity of Peninsula are higher than 1955. According to Fig. 9 and 10 the whales were sighted in the waters of 3.2°–3.5° surface temperature and were not sighted in the cold waters of less than 3.0°C, as in 1955. The surface temperatures in the area from the east of Kamchatka Peninsula to the south of Komandorskii Islands in 1959 generally were higher than 1955 and the fin whales were distributed further to the north as compared with 1955.

1960 (see Fig. 11)—The oceanographic character of this area in 1960 that the isotherms of 2.6°C to 3.0°C meandered in the vicinity of 52°–54°N, and the cold water mass near the Kamchatka Peninsula extended to the east. In general the surface temperatures were colder than in 1959 being similar to 1955. The fin whales were sighted more south to the region than in 1959.

June: 1955 (see Fig. 12)—The temperature at surface rised remarkably, and generally were more than 3.0°C as compared as in May. The isotherms run parallel to the Kamchatka Peninsula like May, but the disposition of them differed greatly. That is, the patterns of temperature are summerized as follows,

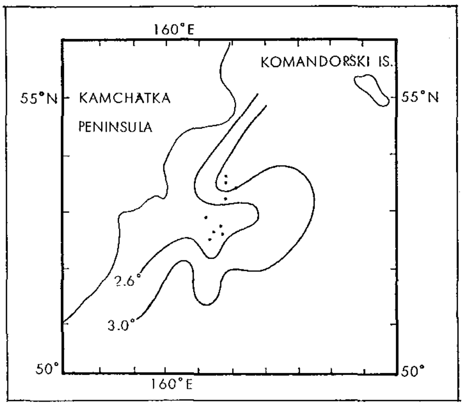
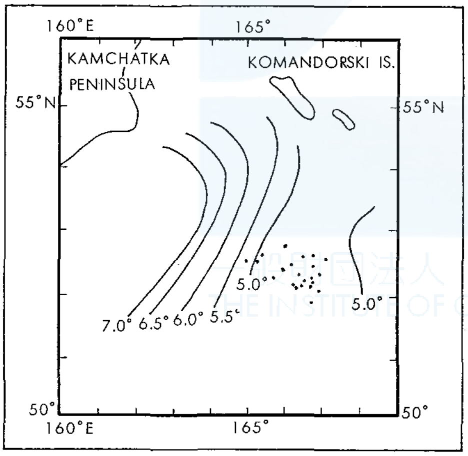


Fig. 11. Distribution of sighted fin whales and surface temperature (°C) in May of 1960.

May: lower in west and higher in east
June: higher in west and lower in east.

And it also differed in that during May the cold area which was characterized by less than 5.0°C in surface temperature was located near the Komandorskii Islands. The areas where fin whales were moved from the adjacent waters of the Kamchatka Peninsula in May to the waters south of the Komandorskii Islands where, as stated above, was found cold area of less than 5.0°C in surface temperature which proved to be the most productive whaling grounds of this season.



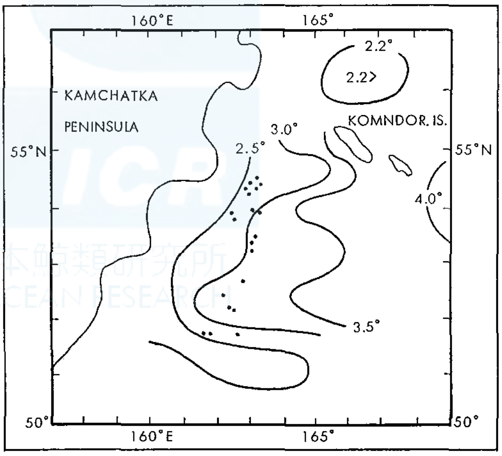


Fig. 12. Distribution of sighted fin whales and surface temperature (°C) in June of 1955.

Fig. 13. Distribution of sighted fin whales and surface temperature (°C) in June of 1958.

1958 (see Fig. 13)—The temperatures in this year were especially low, and the waters with less than 3.5°C at surface covered extensive areas to the south of Komandorskii Islands as May in 1955, 1959 and 1960. The pattern of temperature distribution was lower in the west and higher in the east as in May of ordinary years. The notable cold area which was characterized by less than 2.2°C at surface was located to the north of Komandorskii Islands.

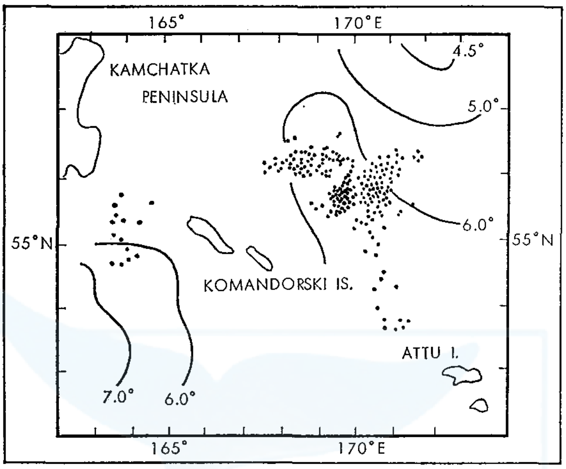


Fig. 14. Distribution of sighted fin whales and surface temperature (°C) in June of 1959.

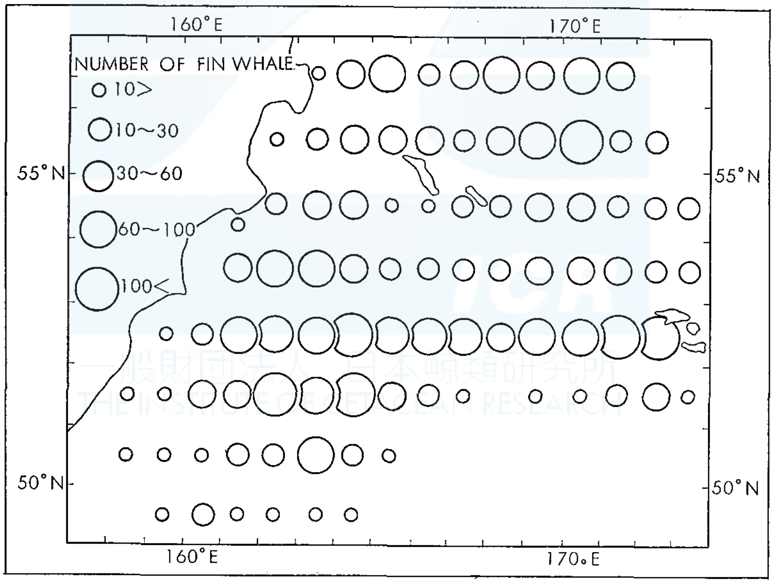


Fig. 15. Distribution of fin whales caught in the years 1952 to 1964.

Fin whales were sighted at the comparatively south sea region with 2.5°–3.0°C at surface temperature as similar to 1955 which was a colder year.

1959 (see Fig. 14)—As already evident from the distribution of temperature in May, this was warmer year and especially the warm water mass with temperatures higher than 6.0°C conspicuously extended to the northeast of the Komandorskii Islands.

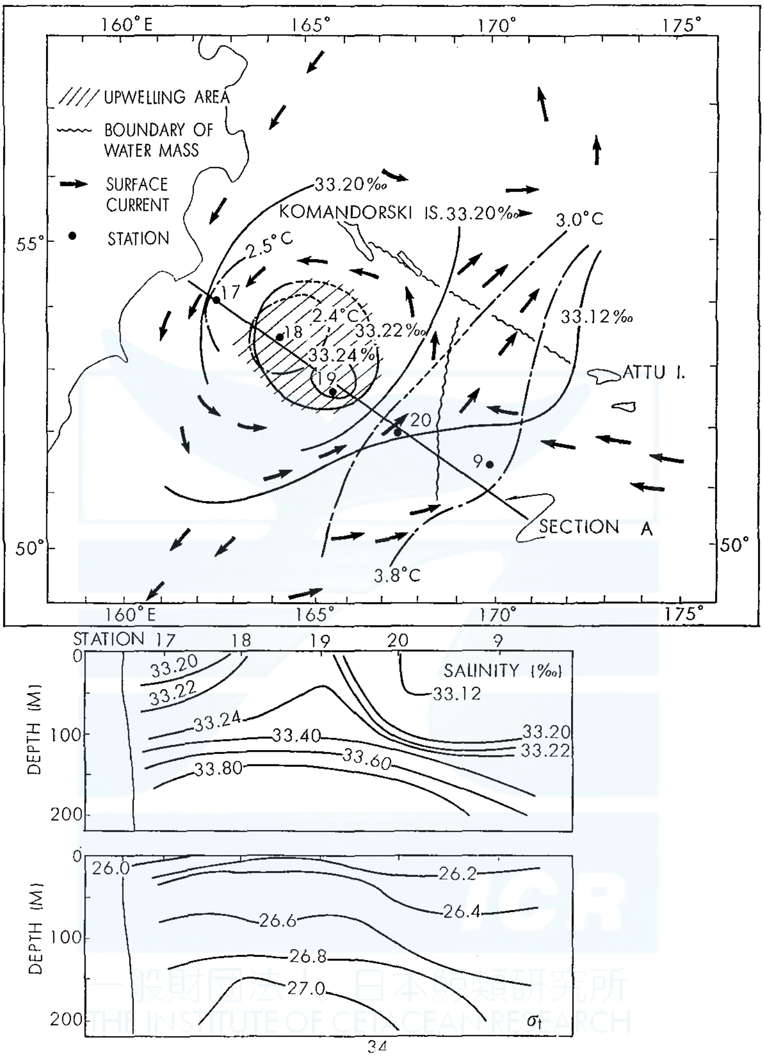


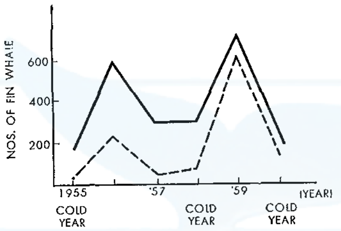
Fig. 16. Oceanographic structure in the east area off Kamchatka Peninsula.

The concentration fin whales were sighted in the warm sea region which was located to the northeast of Komandorskii Islands and was not sighted in the region east of the Kamchatka Peninsula.

Fig. 15 shows the distribution of caught fin whales in the years 1952 to 1964. As already reported by Nasu (1963), it is well known that the center of fin whaling grounds were located in the region of 51°–54°N, 162°–166°E. In order to analyze the oceanographic structure of this sea region. Fig. 16 was drawn by use of the oceanographic data obtained by NORPAC survey.

The distributions of temperature and salinities are shown at 50 m of depth. The author presumed that the feeding depth of baleen whale is less than 50 m, because of the papers of Marr (1957, 1962) and Nemoto (1959). The surface currents which are shown by arrows were based on the current map by Taguchi (1956), Uda (1963) and Dodimead *et al.* (1963).

From these figures it was evident that the favourable fin whaling grounds coincided with the isolated cold area which formed the anticyclonic eddy. The lower figures in Fig. 16 show the profile of salinity and σt along the section A. As Koto (1958) already reported. Fig. 16 shows that the upwelling area was located near the center of anticyclonic eddy.



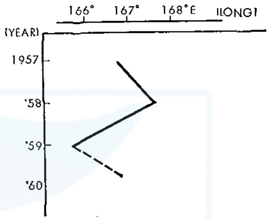


Fig. 17–1. Annual fluctuation of surface temperature and catches of fin whales.
Fig. 17–2. Annual fluctuation of intensity of Alaskan stream (After Koto 1964).

Consequently it may be considered that the whaling grounds south of Komandorskii Islands were formed by the dynamic upwelling which was caused by the anticyclonic eddy. As already shown, the whaling grounds in May, theearly season of whaling, were located in the waters with 2.0°—3.8°C surface temperatures.

To analyzed the salmon fishing grounds in this sea region, Taguchi (1956) divided to coastal and offshore waters in May and June by surface temperature as follows:

Water mass	temperature (°C)
Coastal waters	> 4.0°C
Offshore waters	< 3.0°C

According to this division, the whaling grounds in May were located at the mixing area between the coastal and offshore waters, and shifting to the east with the progress of thewhaling season. The author has analysed the situation in this region for the years 1955 to 1960. A close correlation was found between the water tempterature and fluctuation of fin whale catches. That is, from Figs. 9, 10, 11, 12, 13, and 14, the tendency are summarized as follows.

The colder year (1955, 1958, 1960).
Whaling grounds were located towards the south.
The warmer year (1956, 1959).
Whaling grounds were located towards the north.

Fig. 17—1 shows the relation between the annual fluctuation of surface temperature and fin whale catches. According to Fig. 17–2 it may be considered that the annual fluctuation of water temperatures were introduced by the intensity of the Alaskan stream. Namely, the western extension of the Alaskan stream in warm years was located more westerly than in colder years. As shown by Fig. 16 ,the warm water masses which extend from the region east of the Kamchatka Peninsula to the region north of the Komandorskii Islands are closely connected with the Alaskan stream.

Off Cape Navarin and Olyutorskii

The catch from these sea regions was only fin whales, and the whaling seasons were from late July to the middle of August. As shown by Table 2, the fin whale catch off Cape Navarin was greater than off Olyutorskii. The total number of whales caught off cape Navarm was compared to 128 off Cape Olyutorskii.

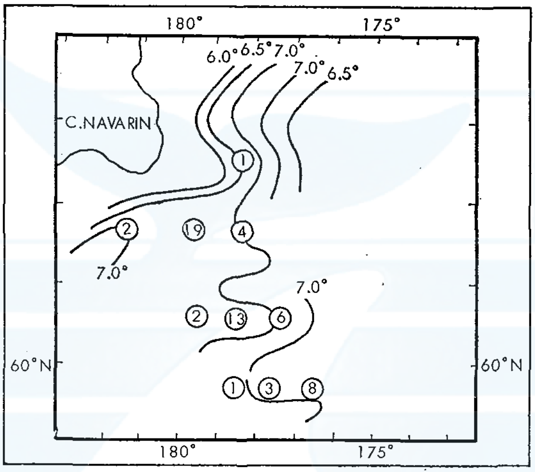


Fig. 18. Distribution of sighted fin whale and surface temperature (°C) in July of 1958.

TABLE 2. WHALING RESULT OFF CAPE NAVARIN AND OLYUTORSKII (FIN WHALE).

	Sea region		
Year	Olyutorskii	Navarin	Total
1957	6	175	181
1958	47	275	322
1959	0	0	0
1960	75	0	75
1961	0	0	0
1962	0	81	81
1963	0	0	0
1964	0	0	0
Total	128	531	659

July of 1958 *:* According to Fig. 18 which was drawn from the results of whale marking survey, the isotherms near 62°N extended towards the east. This can be considered the result of the cold water mass which was formed by the melted-ice in the vicinity of Siberia mainland. From the distribution of 7.0°C isotherm which meanders north and south, it was clear that there is oceanic front between the Bering water masses and the water masses covering the Alaskan continental shelf. The fin whales were sighted mainly along the oceanic front.

Augustof 1958*:* Fig. 19 shows the distribution of temperatures and salinities at the surface based on the data from the results of whales marking survey. The temperatures covered from off Navarin to the Gulf of Anadyr raised about 2.0°C over those July. The isotherms ran roughly parallel to Cape Navarin, and the cold water masses extended to the south. The fact that the cold water mass which extended to the south was caused by the melted-ice waters in the vicinity of Siberian continent is clearly shown by the distribution of salinity. That is, the distribution of cold water masses which were characterized by less than 8.0°C at surface corresponded to the waters with salinity less than 31.40‰.

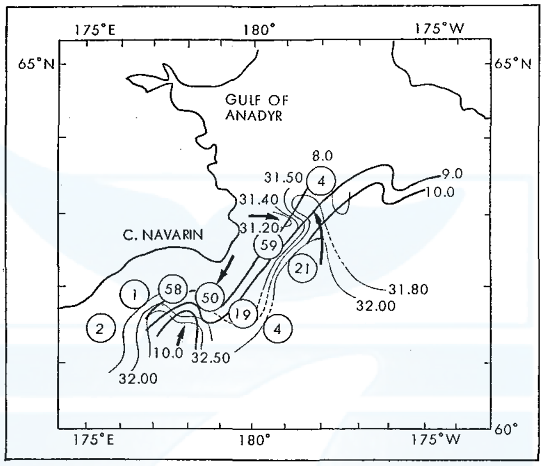


Fig. 19. Distribution of sighted fin whale and surface salinity (‰) in August of 1958.

Many fin whales were sighted near the mixing zone between the water mass of low temperature and salinity along the Siberian continent, and the Bering sea water mass of relative high temperature and salinity.

Fig. 20 shows the schematic map of the distribution of fin whales caught in the years 1957 to 1962. The oceanographic conditions, and the surface currents were drawn by use of the papers of Fleming (1955), Uda, (1963), Dodimead & Hirano (1963) and Nasu (1963). The main fin whaling grounds were located from the mixing zone to the south area. From the vertical section of temperature along the L-line as shown in Fig. 20, it can be found that there is the notable vertical boundary of the water masses.

Off Cape Olyutorskii

The catch from off cape Olyutorskii was small as shown in Table 2, and the

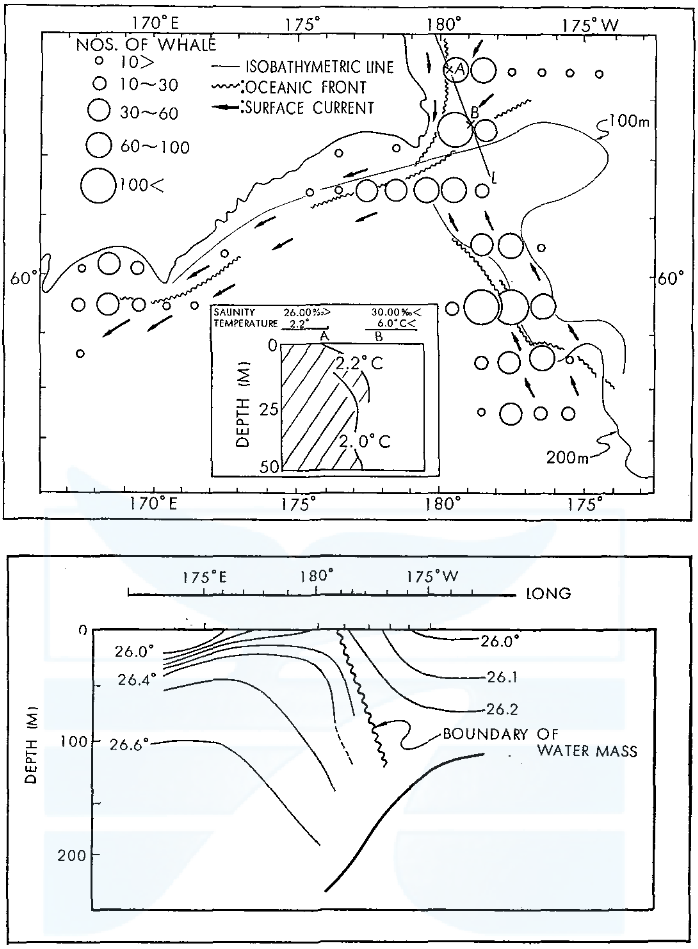


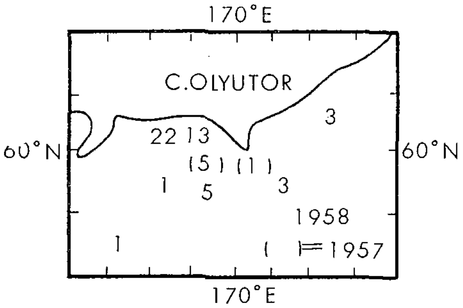
Fig. 20. Schematic map of the distribution of fin whales in the years 1957 to 1962 and the oceanographic structure.

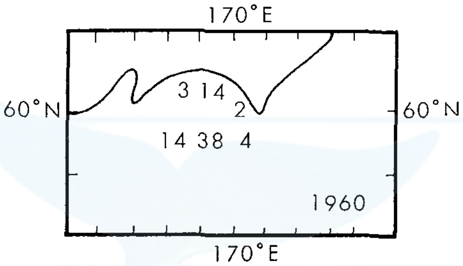
whaling seasons were short.

From the distribution of surface temperature in 1958, it may be considered that the zone of eddy was west of Cape Olyutorskii (see Fig. 21–3). Moreover, it was noted that the whaling grounds in 1958 and 1960 were located west of Cape Olyutorskii (see Fig. 21–1, 2). This can be summarized as follows: The formation of whaling ground was result of the topographic back eddy was located west of Cape Olyutorskii by the southward current along the Siberian continent.

St. Mathew Island area

Fig. 22 shows the distribution of fin whale caught in rich years (163 animals in 1957, 399 animals in 1959). The whaling grounds were located roughly same sea region, and the area of abundance of whales corresponds to the edge of continental shelf.





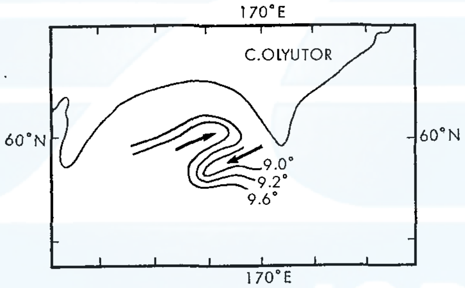


Fig. 21–1. Whaling grounds in 1958.
Fig. 21–2. Whaling grounds in 1960.
Fig. 21–3. Distribution of surface temperature in August of 1958.

From Fig. 22 the whaling grounds located at the oceanic frontal zones between the water masses covered the continental shelf to the Alaska and the water mass upwelled at the edge of shelf. The oceanic front was distributed nearly along the 200 m isobathymetric line. As already stated, the whaling grounds located nearly in the same area every year. It may be considered that the whaling grounds were at the oceanic front which was formed by the topographic upwelling.

Northern area off Unalaska Island

The whaling operations in the area north of Unalaska Island by Japanese ex-

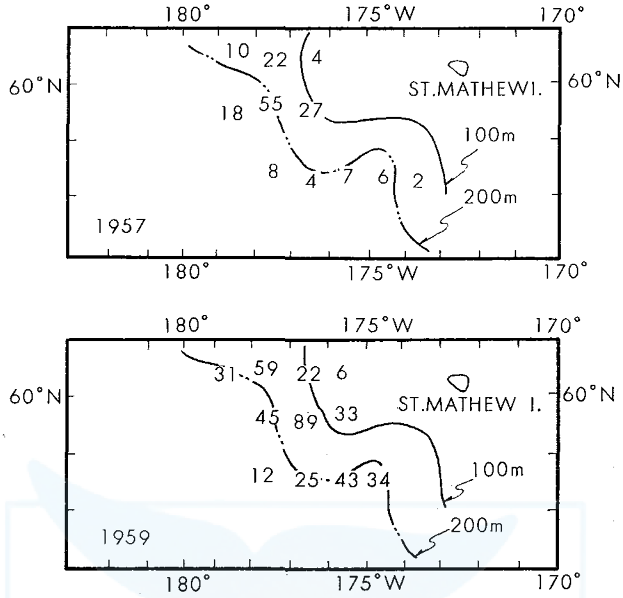


Fig. 22. Distribution of fin whale caught in rich years, 1957 and 1959.

peditions began in 1954. As shown in Table 3, the fin whale is the most important species of whale caught here. The catch from this region reached a maximum in 1955 with 1,177 animals. In 1963 and 1964, however, this catch decreased to 1 and 3 animals, respectively. A possible explanation maybe that the body lengths of whales taken in this area were smaller than other regions (see Table 11), and the whaling operations in the Gulf of Alaska has been carried on from 1961.

TABLE 3. NUMBER OF WHALE CAUGHT BY JAPANESE EXPEDITIONS IN THE NORTH AREA OFF UNALASKA ISLAND IN THE YEARS 1954 TO 1964

	Species of whales caught		
Year	Fin	Humpback	Total of whales
1954	584	6	590
1955	1,177	10	1,187
1956	744	0	744
1957	286	0	286
1958	298	0	298
1959	703	0	703
1960	670	0	670
1961	422	0	422
1962	115	0	115
1963	1	0	1
1964	3	0	3
Total	5,003	16	5,019

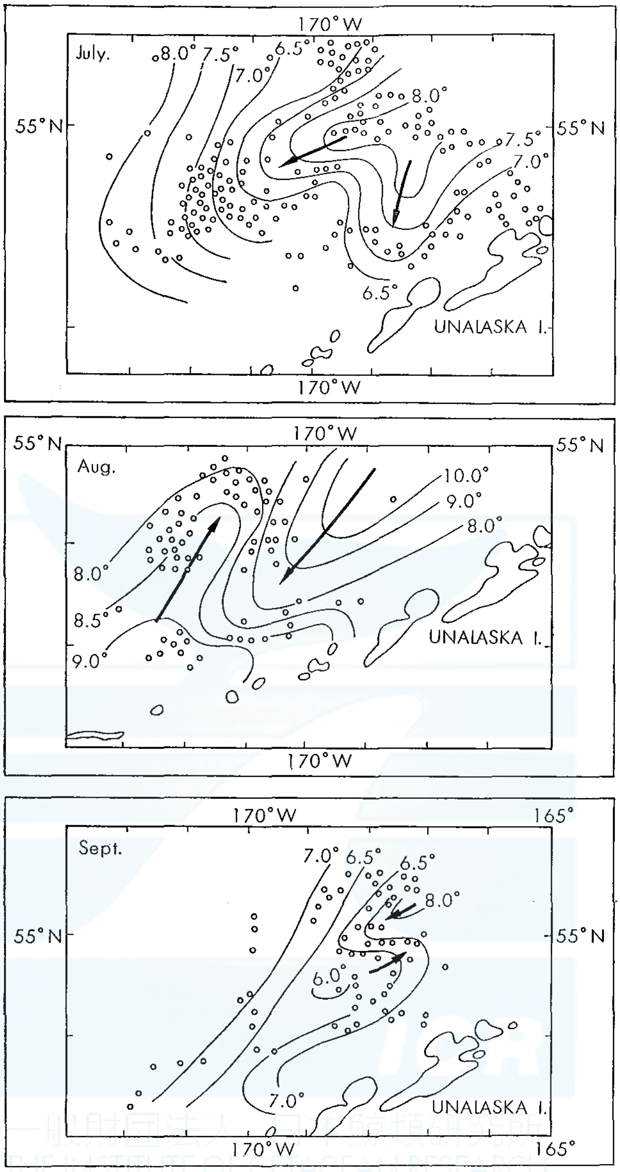


Fig. 23. Distribution of sighted fin whales and the surface temperatures in July, Augut and September of 1955.

The average center of whaling grounds in the years 1954 to 1960 were located at 54°N, 169°W. The greatest catch was found between 54°N and 55°N latitude. In general, the whaling ground north of Unalaska Island are smaller than those east of Kamchatka Peninsula (Nasu, 1963).

July of 1955 (see Fig. 23) : At 56°W, the warmer water mass* which was characterized by 8.0°C or warmer at the surface extended towards the east. The

6.5, 7.0 and 7.5 isotherms were parallel to each other with meandering to the west and the south. To the south of the warmer water mass, there was cold water region which was formed by the upwelling due to the effect of the submarine topographic conditions. The favourable whaling grounds located were in the cold region having surface temperatures of 7.0°C or less.

There was a mixing area between the warmer water mass which flows to the east on the northern side of Aleutian Islands and the warm water mass which extends to the west. In Fig. 23, the mixing area having surface temperatures of less than 6.5°C are shown to be favourable whaling grounds (Nasu, 1963).

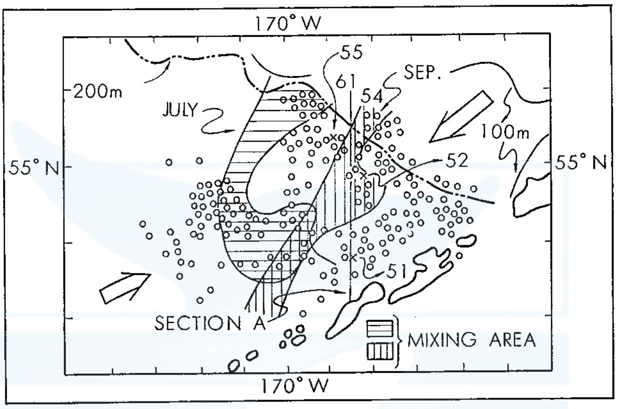


Fig. 24. Distribution of fin whales and mixing area.

August of 1955 (see Fig. 23) : The warmer water mass which was located near 56°N, 196°W in July showed temperatures higher than 10.0°C, and was strongly extended towards the southwest. The easterly-flowing water mass along the northern side of Aleutian Islands also extended tongue-like towards the northeast. More-ever, the mixing area are characterized waters with less than 8.0°C surface temperature.

September of 1955 *:* (see Fig. 23) : According to the distribution of surface temperature, the westerly edge of Bristol water mass retreated near 168°W, and the mixing area had temperatures of less than 6.5°C. Fig. 24 shows the distribution of fin whales and the mixing area. As already stated, the most fin whales were sighted from the mixing area to the Bristol water mass, and the position shifts month by month in accordance with the fluctuation of the two water masses, i.e. in July lying near 171°W and in September lying at near 169°W.

Fig. 25 shows the vertical distribution of σt along the section A. At isolines of σt St. 55 the water mass rise abruptly towards the surface, and St. 55 is located at just the edge of 200 m contour line. The bottom topography from this station to the west became suddenly deeper. Accordingly, the sudden rise of isoline of σt are probably caused by the bottom topography. From this phenomenon, it may be inferred that the whaling grounds of Unalaska Island are formed by the topographic upwelling and the mixing area.

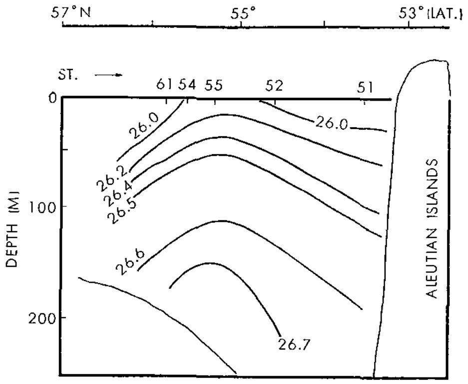


Fig. 25. Vertical distribution of σ_t along the section A (Fig. 24).

Southern area of Aleutian Islands

The main whaling ground in this area extends to the east and the west as a center to 50°–51°N. As shown in Table 4, the fin whale is the most important species of whale caught in this area, but some blue, humpback and sei whales also were captured.

TABLE 4. NUMBER OF WHALE CAUGHT BY JAPANESE EXPEDITION IN THE SOUTHERN AREA OF ALEUTIAN ISLANDS IN THE YEARS 1954 TO 1964

	Species of whales caught				
Year	Blue	Fin	Humpback	Sei	Total
1954	121	167	114	40	442
1955	47	39	89	1	176
1956	69	46	2	1	118
1957	70	500	0	102	672
1958	65	442	20	270	797
1959	69	53	0	25	147
1960	70	52	0	203	325
1961	39	273	9	4	325
1962	13	288	0	195	496
1963	0	7	0	0	7
1964	17	224	0	457	698
Total	580	2,091	234	1,298	4,203

Fig. 26 shows the distribution of sighted fin whales and the oceanographic conditions. The water mass which extended towards the southwest with tongue-shaped may be considered the Alaskan stream. On the other hand, the water mass which extended towards the northeast may be considered. From the distribution of these water masses the whaling ground seems to be closely associated with the oceanic front which is formed between the extention of Alaskan stream and the northerly branch of Kuroshio water mass. Morever, the fin whales in this ground generally were captured in the area where the upwelling exists from relatively deep layer, being especially plentiful near the boundary zone which exists between the sinking and upwelling area (Nasu 1963).

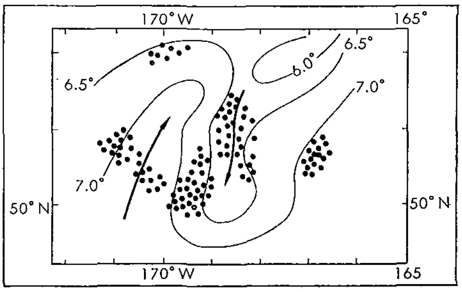


Fig. 26. Distribution of sighted fin whales and the oceanographic condition.

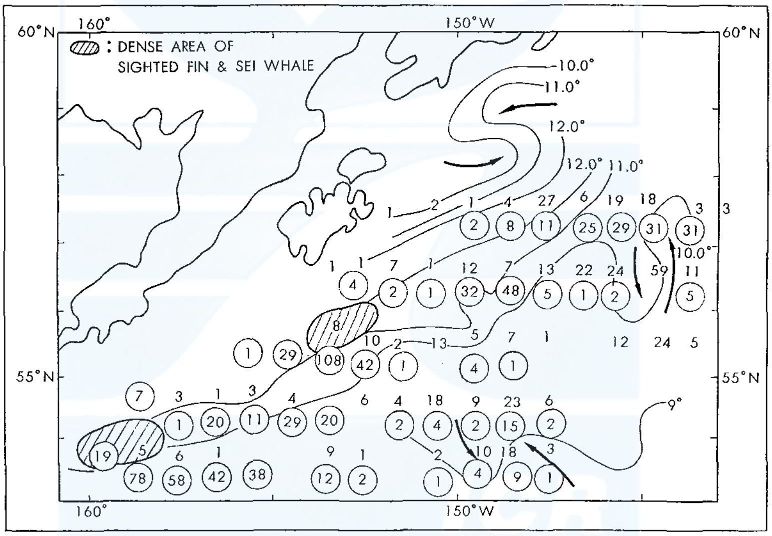


Fig. 27. Distribution of surface temperature and the number of fin and sei whale caught.

Gulf of Alaska

The Japanese whaling operations in this region were started in 1961. As shown in Table 5 the catch from this region consists to a great extend of fin and sei whales. The total number of whale caught in 1963 amounted to 1,037 fin and 945 sei whales which was the greatest catch ever recorded from this area.

TABLE 5. NUMBER OF WHALE CAUGHT BY JAPANESE EXPEDITIONS IN THE GULF OF ALASKA IN THE YEARS 1961 TO 1964

	Species of whale caught				
Year	Fin	Blue	Humpback	Sei	Total
1961	425	31	0	0	456
1962	587	35	13	61	696
1963	1,037	57	20	945	2,059
1964	728	25	0	1,082	1,835
Total	2,777	148	33	2,088	5,046

Fig. 27 shows the distribution of surface temperature and the number of fin and sei whale caught every 1 degree latitude and longitude in July. The cold water mass which is characterized by less than 10.0°C in surface temperature is located from near the Alaskan continent to the adjacent waters of the Aleutian Islands. It extends eastward to an area northeast of Kodiak Island, where the warm water mass extending towards the west exists.

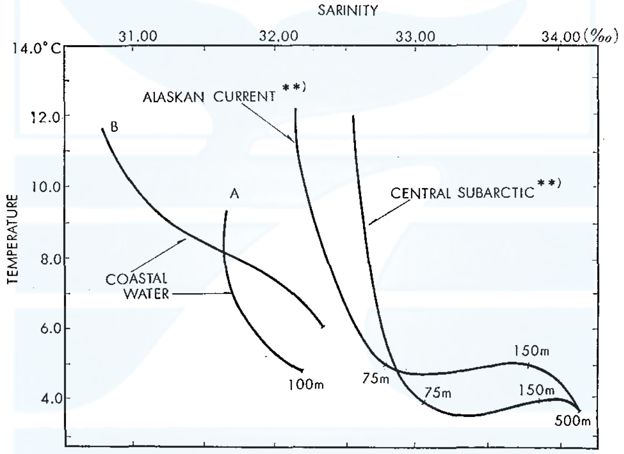


Fig. 28. Temperature and salinity diagram.

These water masses form the eddy in the east of Kodiak Island where the favourable whaling grounds was located in 1961 and 1963. The 2-isotherms of 11°C which extend towards the southwest from the eddy area must be influenced by the Alaskan stream. The distribution of fin and sei whale caught in 1964 covered the southern area of 11°C isotherms.

From the distribution of temperatures it has been found that the zone of eddy was located near 56°30′N, 144°30′W and 53°N, 149°W where the whaling grounds with fin and sei whales were formed. In addition, many sei whales were sighted in the water with 10°–12°C in surface temperatures near 56°N, 153°W and 54°N, 159°W respectively during the whale sighting survey in summer of 1964 (The regions where many sei whales were sighted were shown by the oblique line in Fig. 28).

Fig. 28 shows the temperature and salinity diagram based on the data obtained by Brown Bear in summer of 1955, and Fig. 29 shows the schematic map of water masses and the distribution of fin whales caught.

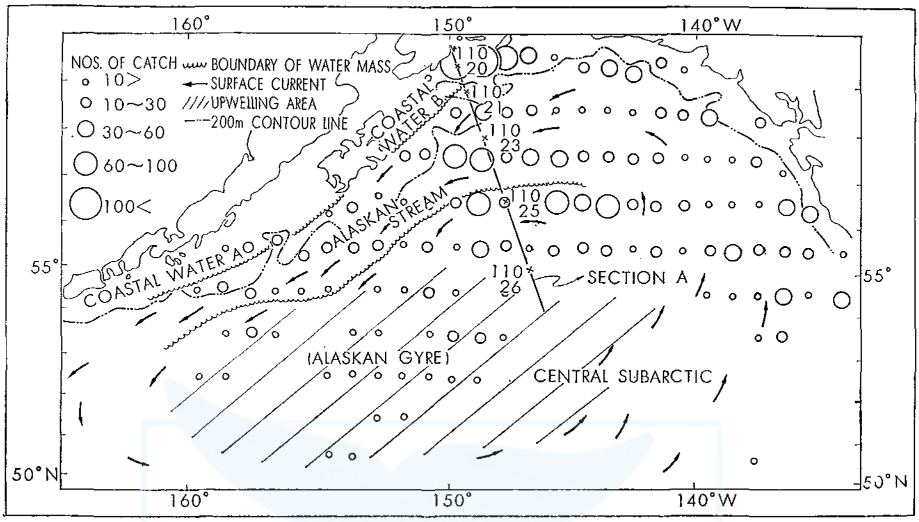


Fig. 29. Schematic map of water masses and the distribution of fin whale caught.

As already reported by Dodimead and Hirano (1963), the water masses in this whaling grounds are divided as follows;

1) Central subarctic
2) Alaskan stream
3) Coastal water (it can diveded to A and B)

Whaling grounds in 1961: The main whaling grounds were located in the Alaskan stream.

Whaling grounds in 1962: The main whaling grounds were located from the zone of eddy which situated in the northeast of Kodiak, near 59°N, 149°W to the coastal water B.

Whaling grounds in 1963: As already stated the catch of fin whale in this year was the highest. The whaling grounds covered an extensive area and were situated close to the continent compared with 1961, 1962 and 1964, and also were found near 59°N, 149°W to the northeast of Kodiak Island, similar to 1961 and 1962. The catch of sei whales in this year also increased, and the main whaling grounds, differ from that of fin whales being located in the zone of boundary between the Alaskan stream and the central subarctic water.

From the distribution of annual whaling grounds, the favourable grounds generally were found in the marginal zone of Alaskan stream. According to Fig. 30 which shows the vertical distribution of σt along the section A it can be seem that the upwelling area existed in the southern edge of the Alaskan stream. Consequently, the explanation of oceanographic structure in this whaling grounds may be summarized as follows: The whaling grounds in the southern marginal zone of Alaskan stream were formed by the convergence between the upwelling water mass which was influenced by the anticlockwise gyr and the Alaskan stream.

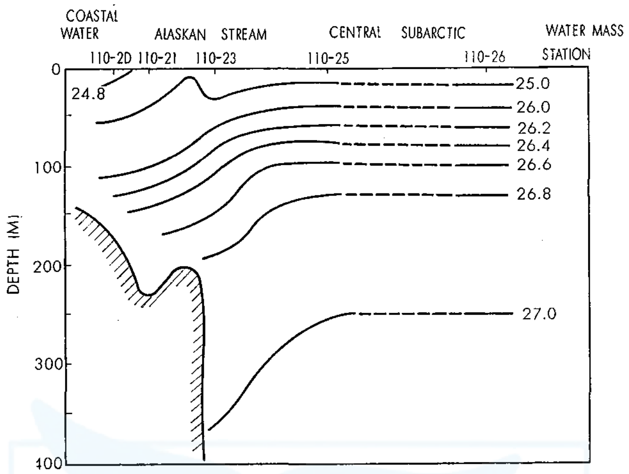


Fig. 30. Vertical distribution of σ_t along the section A.

The whaling grounds in the northern marginal zone of Alaskan stream were formed by the convergence between the coastal waters to the Alaskan continent and the Alaskan stream.

As above stated it may be assumed that the dynamic upwelling by the anticyclonic eddy and the Alaskan stream were the important factors in the formation of these whaling grounds.

ANTARCTIC OCEAN

Fig. 31 shows the rough map the whaling ground operatated by Japanese expeditions and the surface oceanographic condition cited from Marr (1964). In addition Table 6 shows the catch during the recent 10 years from the Antarctic region by world expeditions.

TABLE 6. BALEEN WHALES CAUGHT IN THE YEARS 1955/56–1964/65, BY SPECIES (AFTER THE INTERNATIONAL WHALING STATISTICS)

	Species of whales caught					
Year	Blue	Fin	Humpback	Sei	Total	B.W.U.
1955/56	1,611	25,102	1,425	274	28,412	14,779
1956/57	1,505	25,502	673	708	28,388	14,636
1957/58	1,682	25,067	396	2,375	29,520	14,770
1958/59	1,187	25,687	2,393	1,394	30,661	15,324
1959/60	1,228	26,271	1,332	3,219	32,050	15,421
1960/61	1,739	27,299	709	4,280	34,027	16,374
1961/62	1,116	26,364	309	4,716	32,505	15,228
1962/63	944	18,636	270	5,482	25,332	11,306
1963/64	112	13,583	2	8,256	22,223	8,448
1964/65	20	7,306	—	19,838	27,164	7,052
Total	11,144	220,817	7,509	50,542	290,282	133,338

Area of 105°W–135°W in 1957 season

Fig. 32–1 and 32–2 show the distribution of fin whales caught and the surface oceanographic conditions in January of 1957. Observation area covered from about 105°W to 130°W. The surface temperature in this area varies from 0.5°C to –0.9°C. The distribution of pack-ice is extended towards the east from the vicinity of 66°S, 117°W, and it is directed southward very sharply from 66°S, 110°W. To the west side of the south-western tongue region, the low temperature and salinity water mass is projected towards the north-east. This is probably caused by the of distribution of pack-ice.

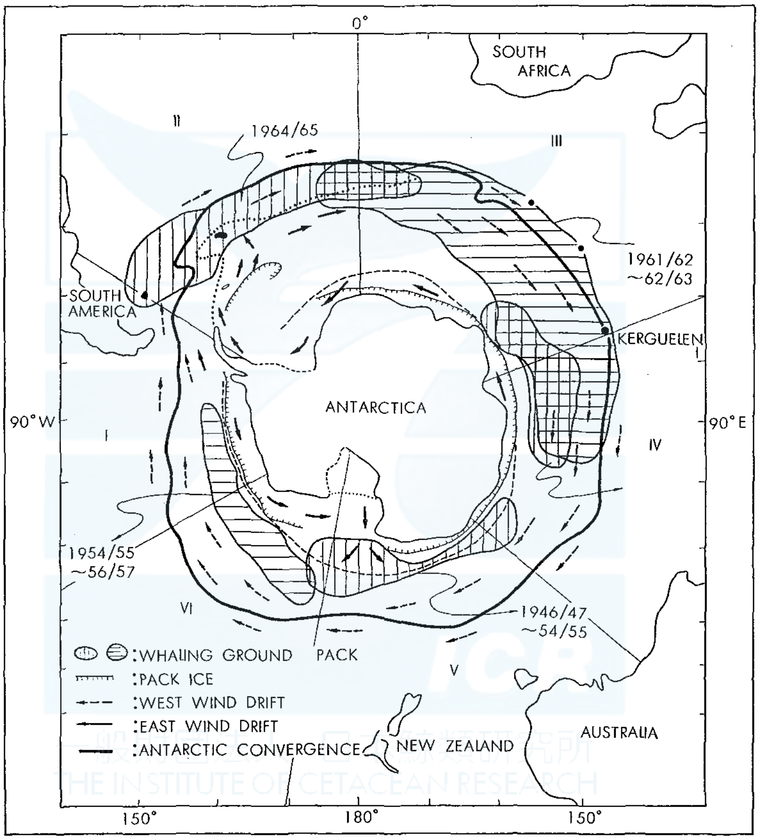


Fig. 31. Rough map of the whaling ground operated by Japanese expeditions.

It is clear that complicated sea conditions were formed in this region between the northern and southern moving water masses as evidenced by the map of isotherms and isohalines. The distribution of temperatures in this area varied abruptly.

The condition of pack-ice at the western part of 117°W is not clear, but it is assumed that the pack-ice is distributed towards southern direction from about

117°W. In the vicinity of 117°W, the high temperature and salinity water mass is found and at the west part of it, near 128°W, the definite shape running towards the south-west direction was recognized.

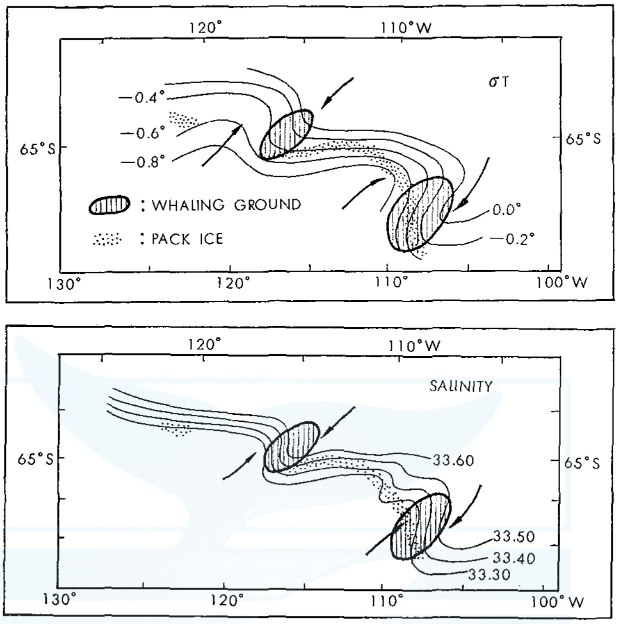


Fig. 32. Distribution of fin whales caught and the surface oceanographic condition in June, 1965.

It is clear from these phenomena that the favourable whaling ground are situated near the region of 65°S, 115°W and 66°–67°S, 108°W. In the neighbourhood of these two regions the eddies were developed on the oceanic fronts between the water mass of high temperature and salinity flowing towards the south and the water mass of low temperature and salinity flowing towards the north.

Area of 90°E–35°W in 1961/62 season

Fig. 33 shows the distribution of sighted whales by Umitaka-maru in December and January respectively in the regions east and west of 20°E. To the east of South Georgia Island, there was warm water mass which flowed towards the south and a cold water mass which flowed towards the north. In the vicinity of 65°S, 10°W the low salinity water mass with less than 33.0‰, was clearly influenced by the melting of ice, extended towards the northeast with definite shape. Fin whales were sighted near the pack-ice in the low salinity water area.

On the other hand, near 15°E, many fin whales were sighted in the area of high salinity water mass which projected towards the southwest. At 20°E fin whales were sighted in the neighbourhood of pack-ice (the area of less than −1.0°C) which was situated towards the north. Fin whales were also distributed in the waters of low temperature and salinity which were situated towards the north near 35°E.

Generally, it can be assumed from the distribution of temperature and salinity that the clockwise eddies in the vicinity of pack-ice play a very important role for the formation of the Antarctic baleen whaling grounds. According to Fig. 34 which shows the vertical distribution of temperature along the line-A (see Fig. 34), the sea region where many fin whales were sighted correspondeds to the upwelling area of the Warm Deep Water.

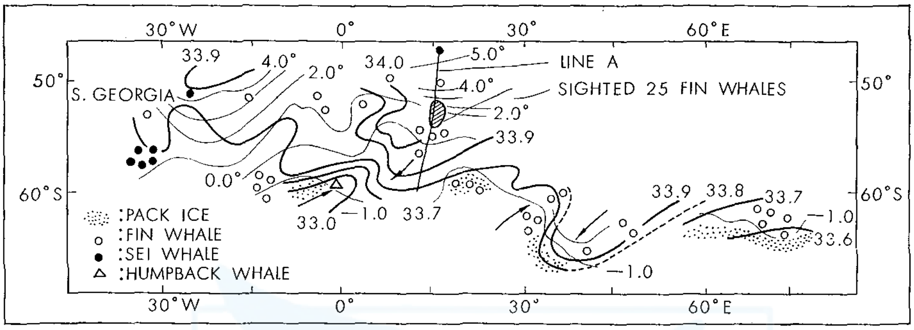


Fig. 33. Distribution of sighted whales by Umitaka Maru in December and January.

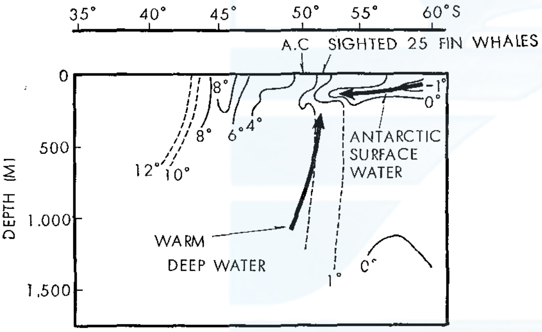


Fig. 34. Vertical distribution of temperature along the line A.

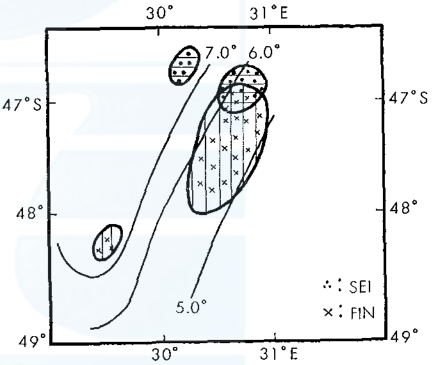


Fig. 35. Distribution of surface temperature and sighted fin and sei whale.

Area of 29°E–39°E in 1962/63 season

In the middle of January, the main whaling grounds consisting of fin and sei whales) were in the region of 47°–48°S and 30°–31°E (see Fig. 35). The oceanographic conditions in this area were characterized by a warm water mass (more than 7.0°C surface temperature) which extended toward the southwest. Most of fin whales are caught in the relatively colder region (less than 6.0°C) and the sei whales in the same grounds are caught in the relatively warmer region. The results of stomach content observed by the author are as follows: sei whales feed mainly on *Parathemisto gaudichaudi* and *Euphausia vallentini*, and fin whale feed only *E. vallentini*.

The fin whaling grounds in late of January shifted to the region of 48°–49°S, 37°–38°E. The surface temperature in the more favourable grounds was less than 4.0°C. The colors of the water were observed 4–6 (see Fig. 36). In addition the stomach content of fin whales consisted mainly of 2 years group of *Euphausia superba.* Fin whaling grounds also located in the sea region with 4.0°–5.0°C in surface temperature and with 5–6 in water color. The stomach contents of whales observed were mainly *Euphausia vallentini.*

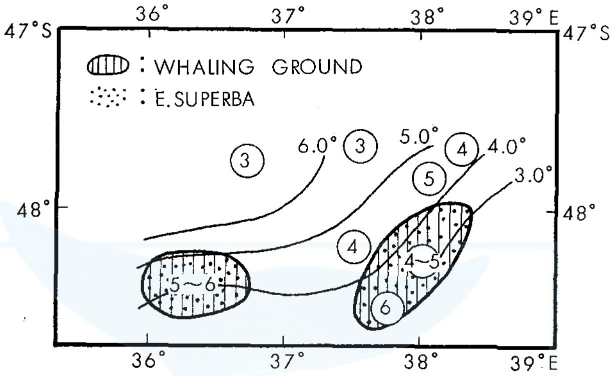


Fig. 36. Distribution of surface temperature (°C) and the color of water.

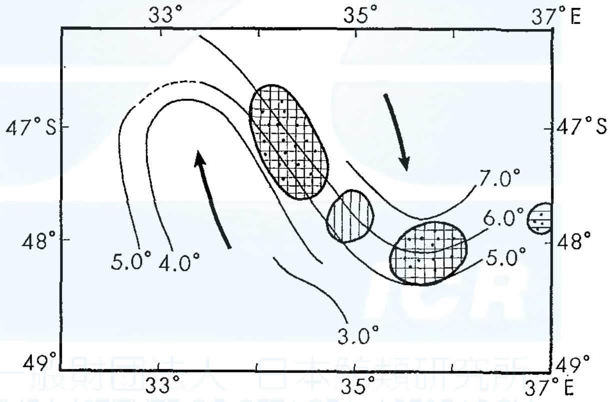


Fig. 37. Distribution of *Eaphausia superba,* sighted pigmy blue and fin whales, and surface temperature (°C). Dot: *E. superba,* Vertical line: Pigmy blue and Fin whale, Horizontel line: Fin whale.

Fig. 37 shows the distribution of pigmy blue and fin whales and the sea condition at surface in middle of January. According to the distribution of surface temperature, it indicated that there is the clockwise eddy between the warmer water mass with flowing towards the southeast and the colder water mass flowing towards the northwest. Many pigmy blue and fin whales were sighted in the area from the southern tops of the warm water mass to the oceanic front between the warmer and colder water mass. The stomach contents of fin whales caught were mainly *Euphausia vallentini.*

Fig. 38 shows the whaling grounds of pigmy blue and fin whales and the surface sea conditions in the waters of 30°E–34°E in early of February. In the vicinity of 32°E, the colder water mass having a temperature of less than 2.5°C was located towards the north. On the other hand, the warmer water mass flowing towards the south was found in the neighborhood of 33°E.

The fin whaling grounds were situated in the water with 2.5°–4.0°C surface temperature within the colder water mass. The stomach contents were observed with *Euphausia superba* from water of less than 4.0°C, and with *Euphausia vallentini* from water of more than 4.0°C.

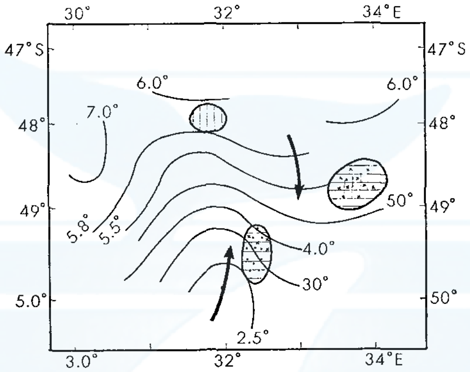


Fig. 38. Whaling ground of pigmy blue and fin whales and the surface temperature (°C), Vertical lines: Sighted pigmy blue whale, Horizontal lines: Sighted fin whale, Dot: *E. superba*, Cross ; *E. vallentini.*

The catch from the zone of the warmer water mass are pigmy blue and fin whales. The stomach contents of these whales were largely *Euphausia vallentini* from pigmy blue whales, and *Euphausia vallentini* and *Euphausia superba* from fin whales.

Area of 60°W–10°W in 1964/65 season

The whaling grounds of fin and sei whales and the distribution of surface temperature are shown in Fig. 39. The Antarctic Convergence and Subtropical Convergence in Fig. 39 were indicated by the 4.5°C and 14°C in surface temperature, respectively. As shown in the figure, to the east of South Georgia Island the cold water mass which has a northerly component of movement covered an extensive area. In the waters with a center at 22°–23°W the warm water tongue shaped mass extended towards the south. Favourable whaling grounds of fin and sei whales also were found in the sea region of 44–48°S, 55–60°W, where the extension of Brazil Current was located, and corresponded to the zone of Subtropical Convergence

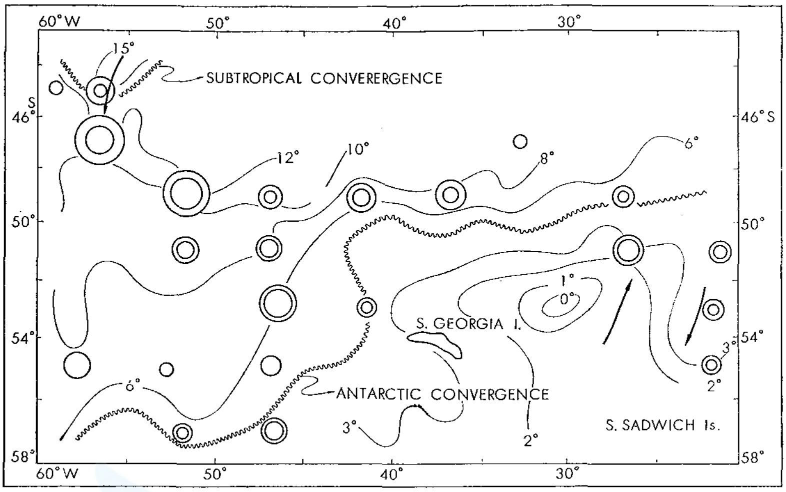


Fig. 39. Whaling ground of blue and fin whales, and the surface temperature (°C).

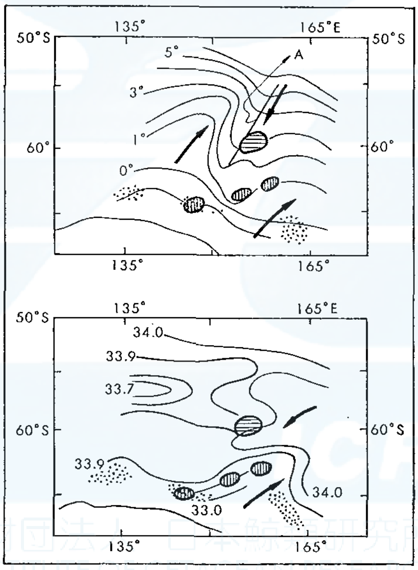


Fig. 40. Distribution of sighted fin and minke whale, and surface temperature (°C), Horizontal line: Fine whale, Vertical line: Minke whale, Dot: Pack ice.

which was reveiled assumed by 12–15°C in surface temperature.

Area of 135°E–165°E in 1965 season

Fig. 40 is drawn based on the data obtained by Umitaka-maru in January of 1965. The species of whales sighted are fin and little piked whale, or minke.

From Fig. 40 it can be seen that the fin whales were sighted in waters of high temperature and salinity, and the little piked whales were sighted in waters of low temperature and salinity.

Fig. 41 shows the vertical distribution of temperature along the line A of Fig. 40. In Fig. 41 the area of oblique lines shows that the denser region of sighted whales as observed in the area of 52°S, 15°E in January of 1962, coincided with the upwelling area of Warm Deep Water.

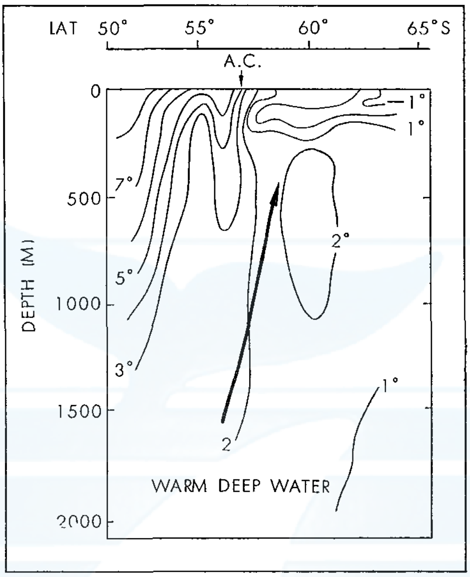


Fig. 41. Vertical distribution of temperature (°C) along the line A in Fig. 40.

As the analyses in the Antarctic whaling grounds mainly used the data obtained by Japanese expeditions, the author mostly discussed the relation between the surface sea conditions and the baleen whaling grounds.

It general can be assumed that the most favourable whaling grounds were situated in the oceanic front between the warm water mass and cold water mass with no relation to the latitude. Especially when the clockwise eddies develop along the oceanic front, the best whaling grounds were found from the top of the tongue shape of warm water which flowed towards the south to the east side of the cold water mass which flowed towards the north.

Fig. 42 is the schematic illustration of above-mentioned sea condition. Uda (1954) already analyzed the whaling grounds off Sanriku, and explained as follows: The cyclonic revolving pattern of the tongues of cold and warm currents corresponds to the centres of the most favourable whaling grounds. It may be due to the rich zone of the foods for whales. In the southern area of Antarctic Convergence, it may be considered from the vertical distribution of temperature that the favourable whaling grounds were located in the upwelling zone of warm deep water.

It is well known that the zone of high production is found in areas of upwelling. Uda (1963), Kumagori (1963) and Ishino (1963) already stated the relation between the Antarctic whaling grounds and the upwelling, Warm Deep Water.

The catch from the sea-region of 47°–51°S, 24°E–36°E where the whaling operations have been carried on since 1961/62, and the stomach contents of these whales were studied *Euphausia superba*, *Euphausia vallentini*, and *Parathemisto gaudichaudi* was found to be the primary food. Morever, the relations among the species of food predator (whales) and surface temperature generally are as follows:

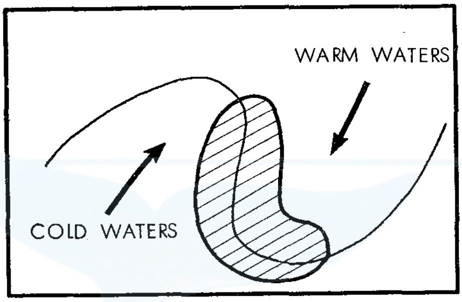


Fig. 42. Schematic illustration of sea condition in the favourable whaling ground.

Species of food	Predator (whales)	Surface temperature
Euphausia superba	Fin whale, Sei whale	<4.5°C
Euphausia vallentini	Pigmy blue whale, Fin whale, Sei whale	>4.5°C
Parathemisto gaudichaudi	Sei whale	>5.0°C

On the Antarctic whaling grounds in recent years

As shown in Fig. 31 the baleen whaling grounds in the Antarctic Ocean have been shifted from the Pacific sector to the Atlantic sector, and its latitudinal positions also moved from the vicinity of pack-ice region to the area of Antarctic and Subtropical Convergence. In order to analyze such a tendency the author discussed the fin whaling grounds which have been operated by the Japanese expeditions. Table 7 shows the whaling results in the individual areas and the catch rate of all areas during the period 1957/58–1964/65. The largest catch in the season 1957/58 was obtained in area VI with 4,107 fin whales, or 56.4 per cent of the all area. In the following two seasons the catch in the area IV varied between 42.1 in 1958/59 and 72.8 per cent of the entire area in 1959/60. In Area III the catch amounted to 8,865 fin whales, or 74.8 per cent of the entire area in 1961/62. Thus in the Antarctic season 1964/65, in Areas II and III (from 60° west and eastwards to 70° East) a total of 5,233 fin whales were obtained, or 99.2 per cent of all Area. In area I the result was only 44 fin whales, 0.8 per cent of all Area. In other areas there was no whaling activity in the latest season. Consequently, the recent Antarctic whaling by Japanese expeditions have mostly been operated in the Atlantic sector.

TABLE 7. THE NUMBER AND CATCH RATE OF ALL AREA OF FIN WHALE CAUGHT IN THE DIFFERENT AREAS OF ANTARCTIC*

Year	II	III	IV	V	VI	I
1957/58	—	832	584	1,130	4,107	628
		(11.4)	(8.0)	(15.5)	(56.4)	(8.7)
1958/59	—	53	3,314	2,395	2,103	—
		(0.7)	(42.1)	(30.5)	(26.7)	
1959/60	—	797	6,477	1,303	320	—
		(9.0)	(72.8)	(14.6)	(3.6)	
1960/61	—	4,761	2,044	236	1,861	—
		(53.5)	(23.0)	(2.6)	(20.9)	
1961/62	226	8,865	2,764	—	—	—
	(1.9)	(74.8)	(23.3)			
1962/63	2,066	7,705	699	—	—	—
	(19.7)	(73.6)	(6.7)			
1963/64	5,003	3,296	7	111	—	24
	(59.3)	(39.0)	(0.1)	(1.3)		(0.3)
1964/65	4,346	887	—	—	—	44
	(82.4)	(16.8)				(0.8)

( ) : shows the catch rate for the all area.
* : whaling area was shown in Fig. 32.

For the purpose of obtaining the meridional change of fin whaling grounds, the catch between each 5 degrees latitude is shown in Table 8.

From Table 8 will be seen that the whaling operations in the Antarctic in later years have been carried on farther north than earlier.

TABLE 8. CATCH BETWEEN EACH 5 DEGREES LATITUDE IN THE ANTARCTIC (CATCH FROM THE JAPANESE EXPEDITION)

Year	40°–45°S	45°–50°S	50°–55°S	55°–60°S	60°–65°S	65°–70°S
1961/62	—	1,009	6,138	4,008	547	153
		(8.5)	(51.8)	(33.8)	(4.6)	(1.3)
1962/63	9	2,964	6,605	854	43	—
	(0.1)	(28.3)	(63.1)	(8.1)	(0.5)	
1963/64	6.5	937	6,704	617	—	—
	(0.8)	(11.3)	(80.5)	(7.4)		

A causal explanation may be as follows:

1) Change of oceanographic environment
2) Fluctuation of whale population

In the paper, the author discussed the position of the pack-ice. This factor is important in the formation of Antarctic whaling grounds. Fig. 43 shows the average positions of pack-ice in the years 1929–1934 (Mackintosh & Herdman: 1940) and in recent year obtained from the data carried out by Umitaka maru (shown by U in Fig. 43) and whaling catcher boats (shown by W in Fig. 43).

Fig. 43 shows that the fluctuations of pack-ice in the meridional average position between the previous and recent years were about 1 degree or 60 sea miles towards the north or south and consequently, it seems that the positions of pack-ice have not a tendency to change towards the low latitude in recent years.

It has been well-known that the baleen whaling grounds in high latitude mainly were formed in the waters with 1.0°–0.0 in surface temperature, so that the meridional fluctuations of 0°C isotherm at surface was illustrated in Fig. 44 for comparison to the pack-ice. The data sources used in Fig. 44 were similar to those of Fig. 43.

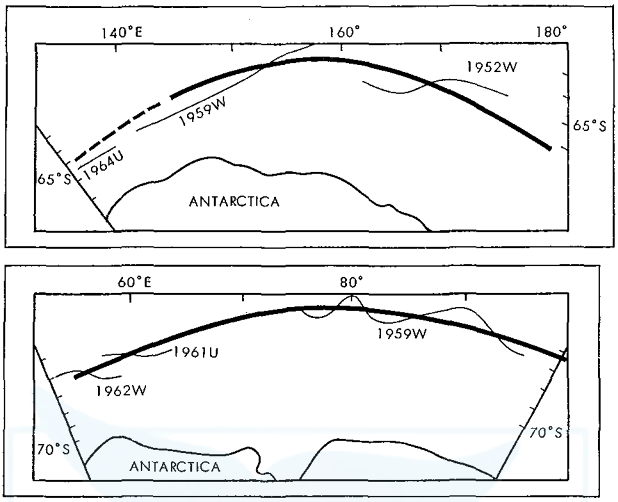


Fig. 43. Average position of pack ice in the years 1929–1934 (black line) (Mackintosh & Herdman 1940) and recent year (slender line).

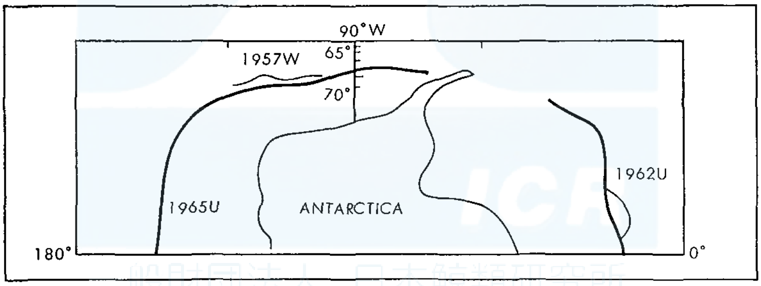


Fig. 44. Average position of 0°C-isotherm in the years 1926–39 (black line) (Mackintosh 1946) and recent year (slender line).

The maximum difference of meriditional position between the previous and recent years was about 1 degree in latitude, or 60 sea miles, and consequently, it seems that the position of 0°–isotherm have not a tendency to change towards the low latitude in recent years.

According to these phenomena it may be not considered that the change of whaling ground in recent years was influenced by the oceanographic environments such as pack-ice and surface temperature.

In next, the discussion on the fluctuation of fin whale population was made on the C.P.U.E. (Catch per unit of effort) in area III and IV, because the fin whales are the most important species, and occupied more than 80 per cent of the total catch. Table 9 shows the value of C.P.U.E. on the Antarctic fin whales caught by the Japanese expeditions. As seen from Table 9 it may be considered that the population of Antarctic fin whales have been decrease in recent years.

According to these phenomena as already stated by Ichihara (1962), it supposes that the shift of fin whaling grounds were influenced by the relation of demand and supply between the amount of available food and the number of whales.

TABLE 9. ANNUAL VALUES OF C.P.U.E. ON THE FIN WHALES IN AREA III AND IV (BY THE JAPANESE DATA)

Year	1958/59	1959/60	1960/61	1961/62	1962/63	1963/64
III	—	—	2.69	2.57	2.62	1.94
IV	2.46	2.21	1.64	1.77	1.52	—

MOVEMENT OF BALEEN WHALE AND OCEANOGRAPHIC ENVIRONMENT

Generally, the movement of animals was divided into 1) recurrent movement, or migration 2) none-recurrent movement, or mere movement (hereafter termed movement). As to terms migration and movement of whales. I would refer to the work by Mackintosh (1942) and Nemoto (1959). That is, the migration means the long annual journeys between the cold feeding area and temperate or tropical breeding area, and the movement is used in the case of the local movement or short journey in the feeding and breeding areas. In this paper, the movements of fin whales in the Subarctic Pacific region are discussed. The research on the movement of whales have been made by the whale marking directly, and by biological survey etc. in directly.

According to the results of biological and marking investigations on the whales, it is clear that the blue and fin whales in the southern hemisphere migrate between high latitude feeding area and low latitude, breeding area (Mackintosh and Wheeler 1929, Mackintosh 1942, Brown 1960). In a addition in the southern hemisphere, humpback whales also migrates with regularly period (Mathews 1937, Chittleborough 1953, Dawbin 1949, Mackintosh 1942).

In the northern hemisphere it is clear from the results of whale marking that humpback whales migrate between the Bering Sea in summer and the waters of the Ryukyus in winter. Current maps indicate that theimigrations of humpback between the Antarctic Ocean (Area IV and V) and the adjacent waters to Australia have no consist relationship to current conditions. Dawbin (1956) also reported that the direction of current flow appears to be unimportant as the known south-north movements of humpback whales in the southern hemisphere.

Ing eneral, the important factors for the migration of baleen whales are not explained, however, the moving mechanism in the feeding area was reported by some papers. In the Sanriku area Uda (1954) stated that the moving route of whales appears in the zone of abundant food. Nemoto (1959) also reported that the movement of baleen whales bears close relation with the abundance of food. And further, in the Antarctic Ocean the distribution of blue and fin whales was intimately related to the areas rich in *Euphausia superba* and other organisms (Kemp & Bennet 1932: Hardy & Gunther 1935).

MOVEMENT OF FIN WHALES IN THE SUBARCTIC PACIFIC OCEAN

The whale marking survey by Japanese vessels in the Subarctic Pacific has been carried on since 1953. The migration and movements of fin whales are indicated by the marking results (Kakuwa, Kawakami & Ito, 1955: Omura & Kawakami, 1956: Kawakami & Ichihara, 1958: Nemoto 1959).

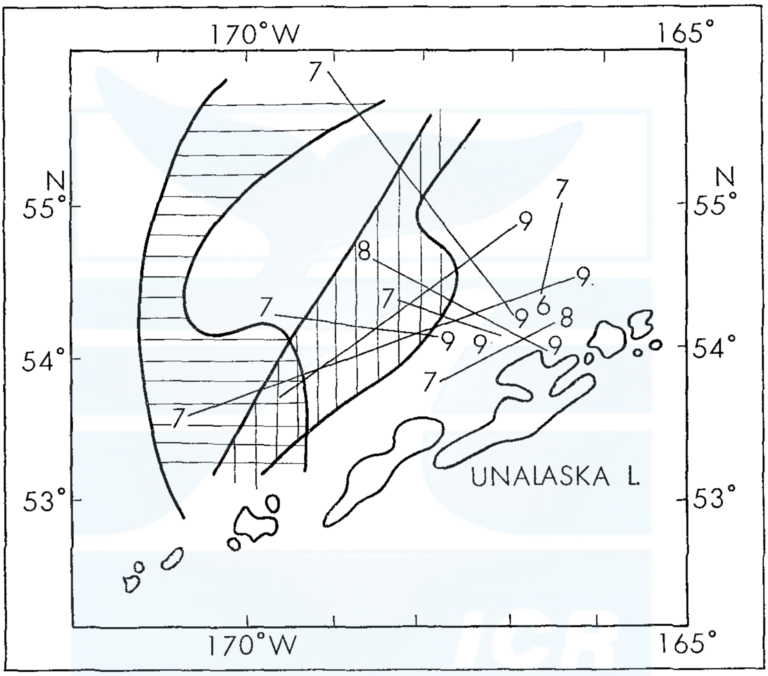


Fig. 45. Marking results by the Japanese marking research in the northern area of Unalaska Island, Horizontal line: Frontal zone in August, Vertical lines: Frontal zone in September.

Fig. 45 shows the marking results by the Japanese marking research in the northern area of Unalaska Island. In the earlier season, the fin whales which come to the nothern area of Unalaska Island may be divided into two groups, one of which moves towards the adjacent waters to Cape Navarin, while the other group approachs towards the Unalaska Island with the progress of the season. The latter seems likely to stay in the vicinity of the Aleutian Islands as will seen from the fact that the movement of fin whales in this region corresponds to the seasonal shift of oceanic front (see Figs. 23–1, 23–2, 23–3 and 45). It seems that the movement of whales in the feeding area generally is influenced by the oceanographic circumstances. For the purpose of analyzing the movement among the whaling grounds, the instances of comparatively long distances between marked and recaptured position are shown in Fig. 46. It must be considered that the distribution of the whales caught shows the movement of it, and so the map of whaling grounds and the monthly sighted whales show in Fig. 47 and 48, respectively. According to five instances in the Gulf of Alaska the fin whales which came from off Vancouver Island prior to June tend to move towards the Gulf of Alaska, and it will be seen from the distribution of whales caught that these moving routes run along the marginal zone of Alaskan stream. In addition Kellogg (1929) already stated that the fin whales may move between the Lower California and Bering Sea.

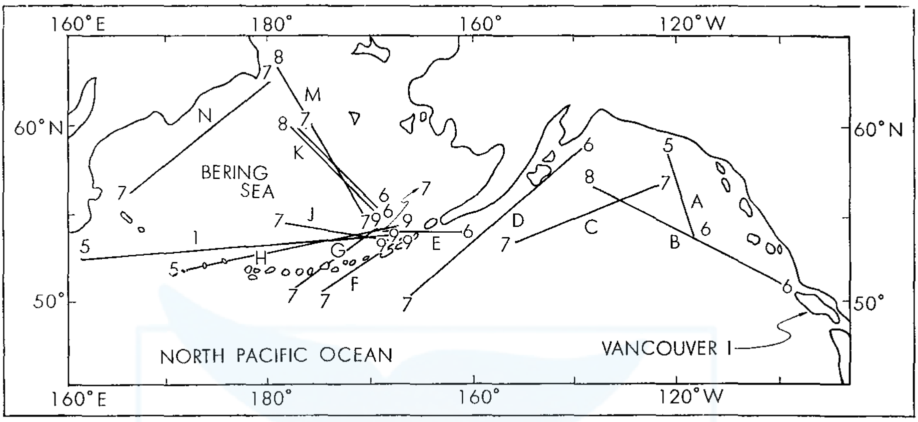


Fig. 46. Map of comparatively long distance between marked and recaptured position.

The fin whales which moved towards the west along the Aleutian Islands came to the northern area of Unalaska Island between the Islands (E.F.G. in Fig. 46), and the movement of these whales in general may be related to the eastward current along the northern area of Aleutian Islands.

The marking results indicate some fin whales which came to the east area off Kamchatka Peninusula move towards the east area, and those routes also may be related to the eastward current similar to case of E.F.G. in Fig. 46. Fin whales which came to the northern area of Unalaska Island must be divided into two groups. One group closely follows the oceanic front between the water mass covering the continental shelf of Alaska and the water mass upwelling at the edge of shelf in a north-westerly direction as far as near Cape Navarin. The other group must stay a long time in the northern area of Unalaska Island. In addition, as will be seen from Table 10 it seems that the staying group is characterized by the high percentage of young and lactating whales.

Therefore, it supposes that the group which moves towards the north consists comparatively of older whales.

The reasons why the whaling ground in the northern area of Unalaska Island was formed by the special biological group are obscure. Consequently, the author thinks that the analysis of the relationship between the physiology and ecology of whales and the oceanographic environment is a very important problem for the fishery oceanographic study of whaling grounds.

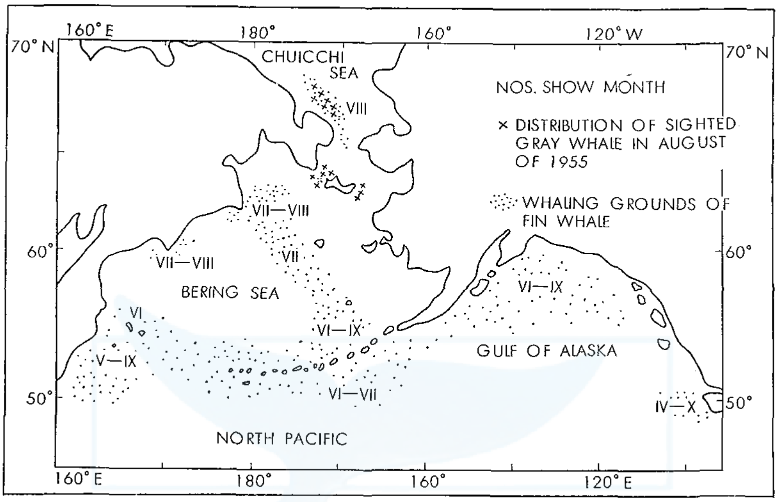


Fig. 47. Map of monthly whaling grounds.

TABLE 10. AVERAGE SIZE, IMMATURE RATE, AVERAGE OVULATION AND LACTATING RATE OF FIN WHALE CAUGHT IN THE SUBARCTIC PACIFIC OCEAN BY INDIVIDUAL AREA 1958 (AFTER NASU 1959)

Area*	Average size (feet)	Immature rate	Average Ovulation	Lactating rate*
I	60.5 63.1	18.8 27.6	8.1	5.6
II**	60.6 63.2	20.6 23.0	8.0	3.8
IV	59.4 60.8	41.5 54.6	5.6	12.5
V	60.8 62.6	25.0 32.4	6.3	3.2

* Shown in Fig. 8.

** Off Cape Navarin.

*** Lactating rate $= \dfrac{\text{number of Lactating whale}}{\text{number of female mature whale}} \times 100\%$

North-bound fin whales which travel up to the Bering Sea in summer season were seen in the Chukchi Sea, where few already were observed in July, and some of them were staying until October (Nikulin 1964). According to the results of survey in 1937 and whaling operation in 1940 by Japanese expedition it seems that the number of fin whales in the Chukchi Sea decreases from the middle of August, on the contrary the gray whales increase. Such a tendency also was indicated by the survey carried out on 16–20, August of 1958 (The number of the sighted whales during the survey were as follows: Fin whale: 1, Right whale: 2, Gray whale: 82, Unknown: 1, Total 86). Also most gray whales during the survey in 1958 were sighted in the fin whaling ground operated by Japanese expedition in 1940.

Furthermore, it is clear from the distribution of physical (temperature and salinity) and chemical (dissolved oxygen and hydrogen-ion concentration) element that the conspicuous oceanic front was formed in the dense concentration area of sighted whales, of which the marine productivity seems to be high.

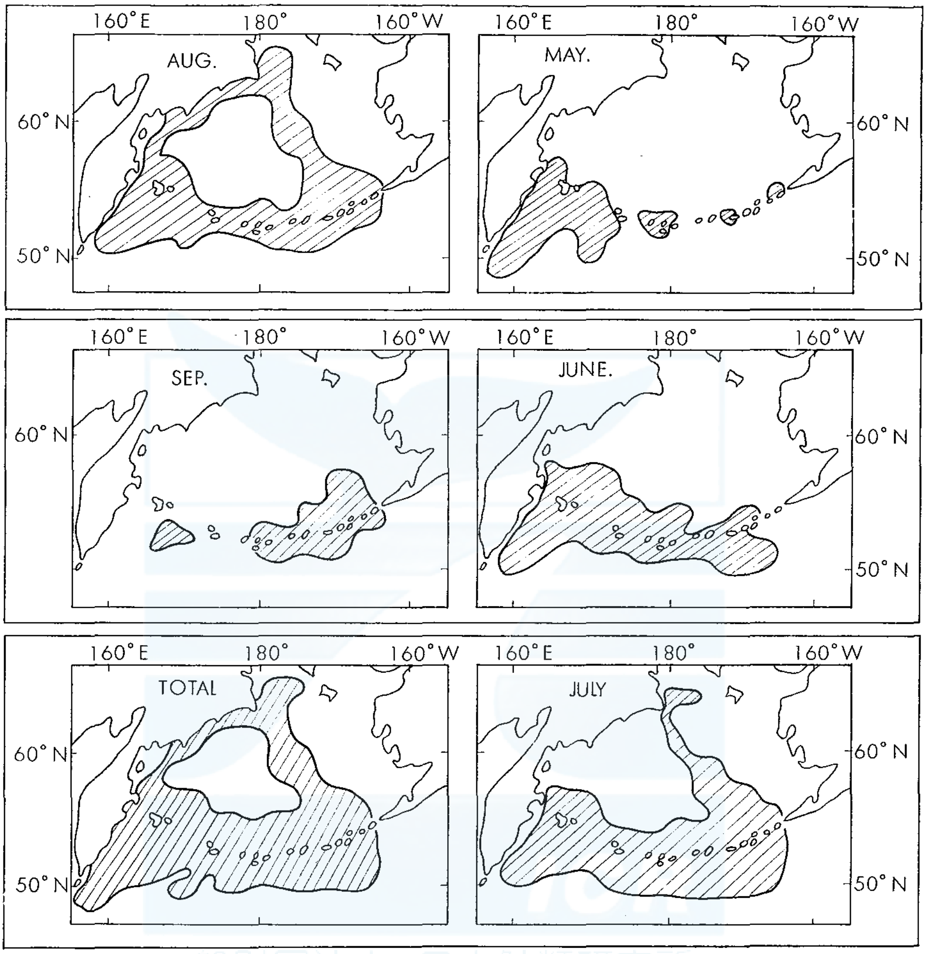


Fig. 48. Map of monthly distribution of sighted fin whale.

Fig. 49 shows the presumed moving route of fin whales, and the distribution of oceanic fronts and current pattern at surface in the Subarctic Pacific Area. In the Antarctic as already stated in previous chapter, the catch of fin and sei whales from near 47°S, 57°W were distributed along the southward tongue-shaped extension of the Brazil current. To the south of Antarctic Convergence, fin and sei whales near 54°S, 22°W were caught along the tongue shaped southward current indicated by the 2°–3°C isotherms.

In the waters to the north east of Japan, the northwards moving mechanism of sei whaling grounds were influenced by the conspicuous tongue shaped Kuroshio

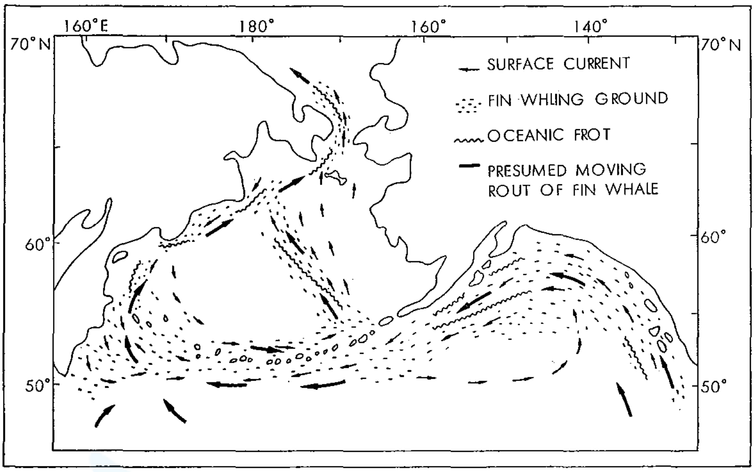


Fig. 49. Presumed moving route of fin whale and the oceanographic environment.

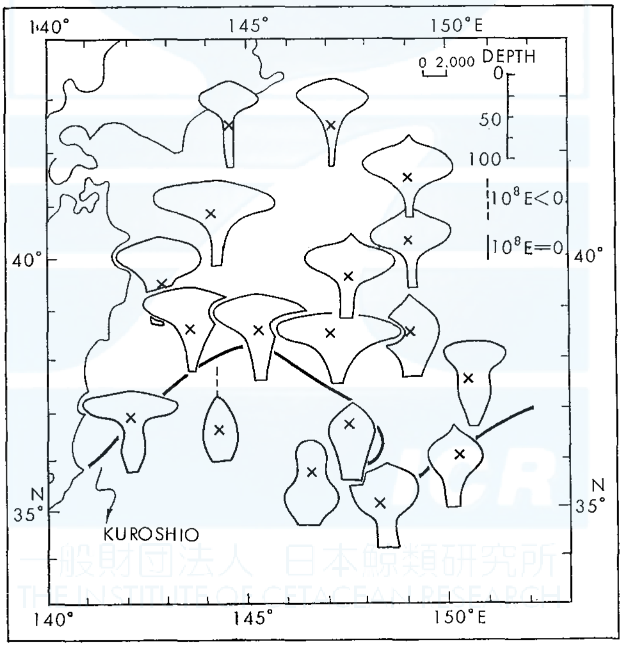


Fig. 50. Vertical stability in the northeast sea region of Japan, Sanriku to Hokkaido. Black line whows the Kuroshio current.

waters which projects towards the north. As stated in previous chapter, the distributions of the sei whales which came to the waters off Hokkaido correspond to the waters which the Oyashio Front projects towards south. Consequently, the baleen whales in the feeding area have a tendency to move along the oceanic front and the current which it developes in this region.

GENERAL CONSIDERATION OF THE BALEEN WHALING GROUNDS

Generally, the whaling grounds are divided into feeding and breeding grounds. There are breeding grounds such as humpback whales in the Ryukyu Islands which were investigated by Nishiwaki (1959). However, most whalings is done in feeding grounds (especially, in the pelagic whaling grounds). Favourable feeding grounds of whales are characterized by the special oceanographic structures such as the upwelling and vertical convection etc. Such oceanographic characters are found in the waters to the northeast of Japan, Subarctic Pacific Ocean and Antarctic Ocean.

That is, the vertical convection based on the increase of surface density in winter was recognized in the whaling grounds by the existence of intermediate cold water (Uda 1935, 1955, 1956, 1963, Nasu 1957, 1963). The upwelled deep waters in the euphotic zone form the notable spring layer of density by the increase of surface temperature or the melted-ice waters. For the purpose of obtaining the depth of spring layer, the vertical stability in individual sea region shown in Fig. 50, 51 and 52. As Elizarov (1963) also stated on the sea region at Newfound Banks, the vertical stability is a very imprtant element for the formation of fishing grounds. In the Antartic, Halse (1956) stated that the large phytoplandton populltions were confined to a surface large of 25–50 m, which coincided with the pronounced stable layer, Nasu (1963) also pointed out that the vertical stability is the important factor for the formation of whaling grounds.

Of course, the oceanographic analysis of whaling grounds must include the structure of deep water, however, from the results reported by Marr (1957, 1962) and Nemoto (1959) the author presumed that the feeding depth of baleen whale is less than about 50 m. Consequently, the vertical stability is within 100 m in Antarctic, Subarctic Pacific and Northeast area of Japan as shown in Fig. 50, 51 and 52. For the calculation of vertical stability the following approximate formula was used:

$$E = 10^{-3} \frac{d\sigma t}{dz}$$

Where E is vertical stability, σt is density of sea water, and Z is depth). As will be seen from these figures the maximum layer of E in the favourable whaling grounds generally existed at depth less than about 50 m which roughly corresponded to the maximum layer of dissolved oxygen. This may be explained by an upwelling water mass during the winter seasons supplying the surface layer, where phytoplankton increase. Halse (1956) stated that in the Antarctic zone, with its pronounced stability, the large phytoplankton populations were confined to a surface layer of 25–50 m.

According to Mackintosh & Wheeler (1929), Hardy & Gunther (1935), Mizue (1951), Peters (1955), Marr (1956, 1962) and Nemoto (1957, 1959, 1963), it is well known that the staple food of baleen whales is euphausiids. Kemp &

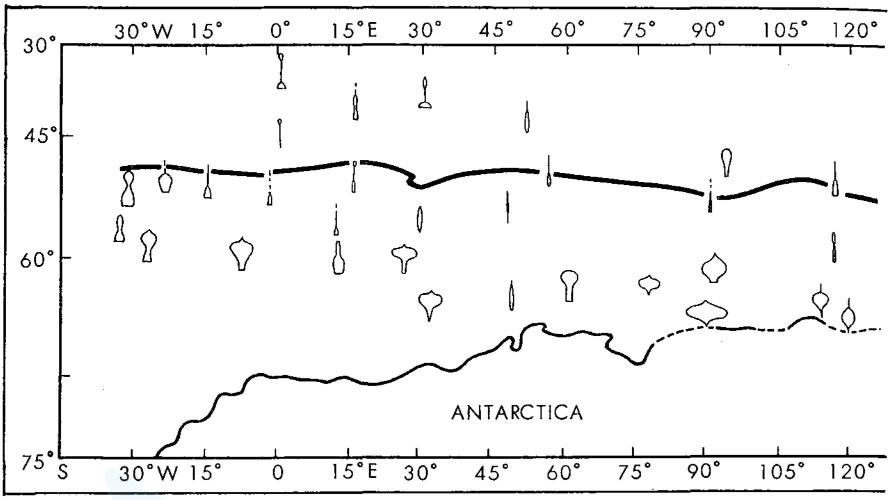


Fig. 51. Vertical stability

Bennett (1932) stated that the distribution of blue and fin whales in the Antarctic Ocean is closely correlated with the euphausia distribution. Euphausiids feed mainly on phytoplankton (Barkley, 1940; Einarson, 1945; Ponomareva 1959) and it also is known that the high concentration layer of diatom exists less than 50 meters in depth (Moberg, 1928; Phifer, 1934 a, 1934 b; Kokubo and Tamura, 1934). Consequently, the baleen whaling grounds seems to be closely related to the maximum layer of vertical stability.

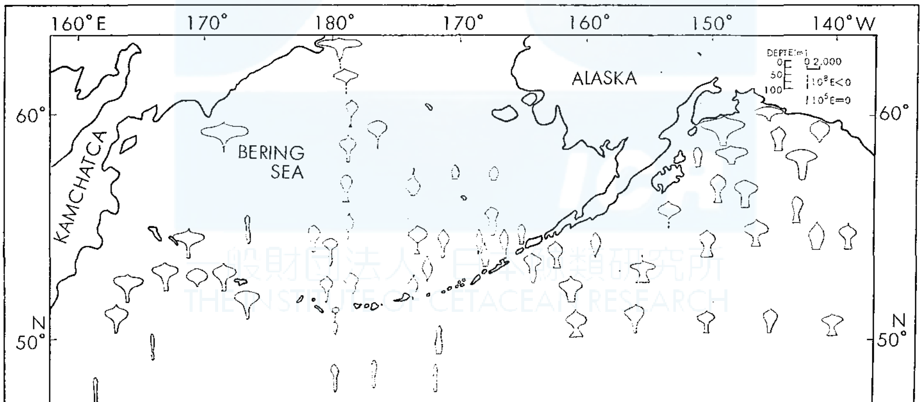
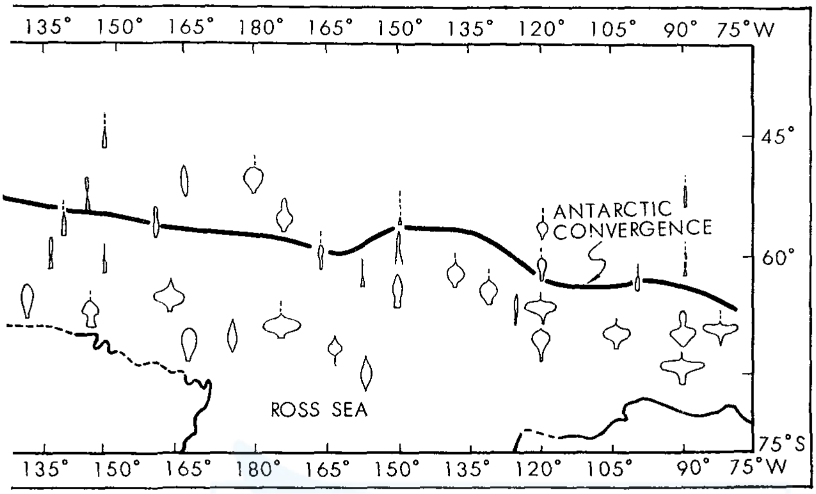


Fig. 52. Vertical stability in the Subarctic Pacific Ocean.

As already discussed in previous chapter it is clear that the favourable whaling grounds correspond to each special three-dimensional oceanographic structure. Especially favourable whaling ground are formed in the zone of dynamic eddy along



in the Antarctic Ocean.

the oceanic fronts between the water masses. Topographically-developed back-eddy systems also are good whaling grounds as shown in the vicinity of South Georgia (Hardy and Gunther 1935) and the Cape Olyutorsokii in the Bering Sea. The good whaling grounds also were found in the area of upwelling caused by the submarine topography and gyre.

The oceanographic character of the baleen whaling grounds can be summarized as follows;

1) Oceanic front type	
Off Sanriku and Hokkaido	Polar Front between the Oyashio and Kuroshio waters.
Subarctic Pacific	
East area off Navarin	Oceanic front between the melted-ice waters of the Siberia Continent and the Bering warm waters.
Southern area of Aleutian Is.	Oceanic front between the westward Alaskan stream and eastward West Wind Drift.
Antarctic	Oceanic front between the southward warm water mass and northward melted-ice water mass in the vicinity of pack-ice. Antarctic Convergence Subtropical Convergence
2) Eddy type	
a) Dynamic eddy	Eddy develops along the oceanic fronts, and found in the Antarctic, Subarctic Pacific, and off Sanriku-Hokkaido.

b) Topographic eddy	
Subarctic Pacific	
West of Cape Olyutorskii	Back eddy which was formed at the west of Cape by the southward current along the Siberia continent.
Antarctic	
South Georgia	Back eddy which was formed at the east of island by the West Wind Drift.
3) Upwelling type	
a) Dynamic upwelling	
Subarctic	
East area of Kamchatka Peninsula	Upwelling by the anticlockwise gyre.
Gulf of Alaska	Upwelling by the anticlockwise gyre.
b) Topographic upwelling	
Subarctic	
St. Mathew I.	Upwelling along the edge of continental shelf.
Unalaska I.	” ” ”
Antarctic	
South Georgia I.	Upwelling in the vicinity of the Island.

SUMMARY

In this paper the formation mechanism of whaling grounds and the movement of ballen whales were discussed from the view point of fishery oceanography.

1) The concentrated sei whales off Sanriku coast in last of April came along the waters of 12.2–13.0°C which corresponds to the southern area in the Polar Frontal Zone.

2) Favourable whaling seasons of sei whale in the east sea regions of Japan are in May to June off Sanriku area and are in September to October off Hokkaido, respectively. It may be considered that the moving mechanism of whaling grounds from off Sanriku to Hokkaido were influencd by the conspicuous tongue shaped Kuroshio waters which project towards the north.

3) In the east sea regions of Japan there are two whaling condition types. Good catch off Sanriku—It is general type, the prosperous whaling season are in June off Sanriku, and the catch of sei whale off Sanriku is better than Hokkaido. The oceanographic conditions were characterized by that the Kuroshio waters flowing towards the north close to the Sanriku coast.
Good catch off Hokkaido—The prosperous whaling seasons generally are in July, and the catch of sei whale off Hokkaido is better than Sanriku. The oceanographic character in these years is that the northward Kuroshio waters are located more easterly than good catch year off Sanriku.

4) The main whaling grounds in the Subarctic Pacific Ocean were divided into six areas by the geographic distribution of Islands and continents etc. i) East

area off Kamchatka Peninsula—it may be considered that the whaling grounds in this region were formed by the dynamic upwelling which was developed by the anticyclonic eddy.

ii) Off Cape Navarin and Olyutorskii—The whaling grounds off Cape Navarin were located near the mixing zone between the water mass of low temperature and salinity along the Siberian Continent and the Bering Sea water mass of relative high temperatured and salinity. The formation of whaling ground off Olyutorskii was the result of the topographic back eddy which was located at the west of Cape Olytorskii.

iii) St. Mathew Island area—It may be considered that the whaling grounds were at the oceanic front which was formed by the topographic upwelling and the water mass covering the continental shelf to the Alaska.

iv) North area off Unalaska Island—It seems that the whaling grounds was formed by the topographic upwelling and the mixing area.

v) Southern area of Aleutian Islands—Many fin whales in this area were captured mostly of in the upwelling area from the relative deep layer, being especially plentiful near the boundary zone which exists between the sinking and upwelling area.

vi) Gulf of Alaska—It may be assumed that the dynamic upwelling by the anticyclonic eddy and the Alaskan stream were the important factors in the formation of the whaling grounds.

5) The results of oceanographic analysis in some Antarctic whaling grounds were summarized up as follows. The favourable whaling grounds were located in the oceanic front between the southward warm water and northward cold water, melted-ice water. To the south of Antarctic Convergence, the favourable whaling grounds corresponded to the upwelling zone of Warm Deep Water.

6) The whaling operation in the sea-region of 47–51°S, 24°E–36°E have been carried on since 1961/62. The stomach contents of whales caught in this area were found to contain *Euphausia superba*, *Euphausia vallentini*, and *Parathemisto gaudichaudi*.

Morever, the relation among the species of food, predator (whales) and surface temperature was as follows:

Species of food		Surface temperature
E. superba	Fin whale, Sei whale	<4.5°C
E. vallentini	Pigmy blue whale, Fin whale Sei whale	>4.50°C
P. gaudichaudi	Sei whale	>5.0°C

7) The whaling operations in the Antarctic in later years have been carried on further north than earlier. A possible explanation may be 1) Change of oceanographic environment 2) Decreasing of whale population. According to the results in this paper, as already stated by Ichihara (1962) it supposed that the shift of fin whaling grounds were influenced by the relation of demand and supply between the amount of foods and whales ensuing the diatom of whale population.

8) The baleen whales in the feeding area have a tendency to move along the oceanic front and the current which develops in local regions.

9) The favourable whaling grounds seems to be closely related with the maximum layer of vertical stability.

10) The oceanographic character in the baleen whaling grounds can be summarized as follow:

2) Eddy type
  a) Dynamic eddy develops along the oceanic eddy
  b) Topographic eddy
3) Upwelling type
  a) Dynamic upwelling develops in the anticyclonic (northern hemisphere) or cyclonic (southern hemisphere) gyre
  b) Topographic upwelling

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EXTERNAL MEASUREMENTS AND WEIGHT OF A SOUTHERN ELEPHANT SEAL

TADAYOSHI ICHIHARA AND MASAHARU NISHIWAKI*

Permission was given by the government of The Falkland Island Dependencies to take for scientific purposes a specimen of the southern elephant seal, *Mirounga. leonina*. A six year old male elephant seal was shot at Little Jason in South Georgia on 5 November, 1964. The animal was frozen within an hour after killing and was brought to Japan by refrigerator ship. This animal was flensed on 28 January, 1965. Because the body was frozen without first opening the body cavity some of the internal organs deteriorated to the extent that they were not suitable for histological study. The external measurements of the body (Fig. 1, 2, Table 1) and the weights of body parts (Table 2) are presented in this paper.

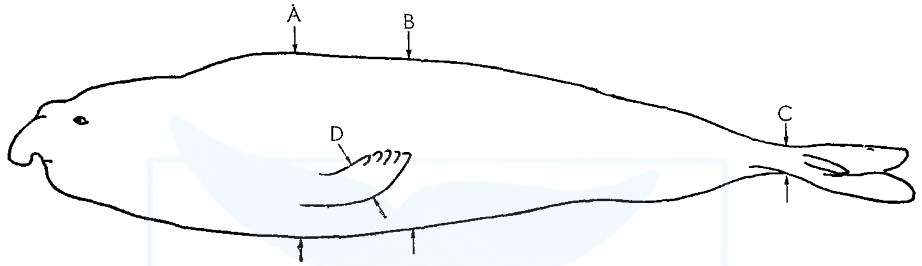

Fig. 1. Outline of a southern elephant seal, 6 years old male from South Georgia. A, B, C and D indicate the measured positions of girths.

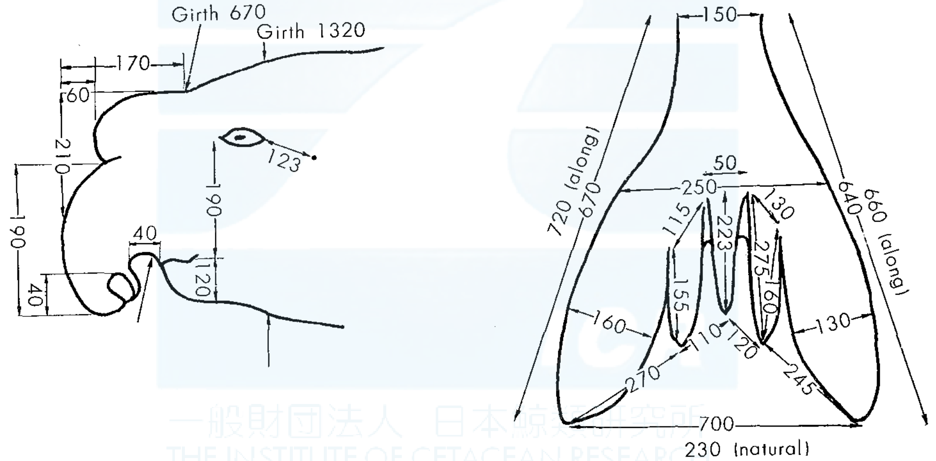

Fig. 2. External measurements in detail for the head region and the left hind limb.

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TABLE 1. EXTERNAL MEASUREMENTS IN MM, LENGTHS PARALLEL TO BODY AXIS

		%
Total length (straight, from tip of nose to tip of tail)	3450	100.0
Total length (along dorsal side)	3730	
From tip of nose to shoulder (straight)	1200	34.8
,, ,, (along abdomen)	1330	
From tip of tail to anus	180	5.2
From tip of tail to penis opening (straight)	570	16.5
,, ,, (along abdomen)	630	
From penis opening to umbilicus	265	7.7
From tip of tail to tip of hind-limb	530	15.4
From tip of nose to eye	220	6.4
From eye to ear	105	3.0
Fore-limb, maximum width	220	6.4
Fore-limb, tip to anterior end of lower border	650	18.8
Fore-limb, length along curve of lower border	700	
Fore-limb, axilla to tip	460	13.3
Girth at shoulder (A)	2470	71.6
Girth at tip of fore-limb (B)	2500	72.8
Girth at anus (C)	750	21.7
Girth at middle of fore-limb (D)	480	42.9
Numbers of hair (one side of head)	34	
Thickness of blubber	60	

TABLE 2. WEIGHT OF BODY IN KG (EXCLUDE BLOOD)

				%
Skin		103.0		11.4
Blubber		192.8		21.3
Bone		125.6		13.8
Muscle		406.6		44.8
Internal organs		78.9		8.7
Liver		15.9		
Small intestine		13.7	5522 mm in length	
Large intestine		1.3	1470 mm in length	
Stomach		6.5		
Heart		5.2		
Lung	7.4 (L) 8.9 (R)	16.3		
Spleen		6.7		
Kidney	1.3 (L) 1.2 (R)	2.5		
Testis	0.4 (L) 0.4 (R)	0.8		
Penis		2.2		
Tongue		4.7		
Others		3.1		
Total weight		906.9		100.0

STUDIES ON THE OILS CONTAINED IN BLUBBER OF A SOUTHERN ELEPHANT SEAL

HIDEO TSUYUKI* AND SHINGO ITOH*

INTRODUCTION

The Southern elephant seal, *Mirounga leonina*, is found off the Antarctic Ocean and thinking approximate species, the Northern elephant seal, *Mirounga angustirostiris*, is mostly distributed over the coast of California and Mexico. They are the largest of all the marine carnivores and belong to the seal family. They grow up body length 5.5–6.7 metres and body weight about 3 tons.

As to the study on the seal family oil, we find the following reports ; Saghalien seal oil (Tsujimoto, 1916), Antarctic seal oil (Ueno & Iwai, 1939), common seal oil (Bauer & Neth, 1942), common seal, *Phoca vitulina*, oil (Williams & Makhrov, 1935), commercial Newfoundland seal oil (Burke & Jasperson, 1944), blubber and liver oil of Grey Atlantic seal, *Halichoerus grypus* and common seal (Hilditch and Pathak, 1947, 1949), milk oils of Grey Atlantic and common seals (Meave, 1952), blubber oils of Leopard seal, *Hydrurga leptonyx* and Crabeater seal, *Lobodon carcinophagus* (Winter & Nunn, 1950, 1953).

Reviewing the works ever reported on the elephant seal oil, Tsuyuki studied on the properties of the oils contained in various blubbers of the Northern elephant seal caught at the coast of Mexico (1957) and its component fatty acids (1958), and Winter and Nunn studied on the fatty acid composition of the blubber oils from a wide range of specimens of the Southern elephant seal caught at Macquarie and Herald Island in the Antarctic (1950, 1953).

The writers wish to express here their thanks to President of The Whales Research Institute, Dr. Hideo Omura and Dr. Tadayoshi Ichihara who are kind enough to present us the Southern elephant seal oils.

MATERIALS AND METHODS

Sample used

The Southern elephant seal, *Mirounga leonina*, caught off the South Georgia Island on the 15th of November, 1964 was used in this experiment. It was immediatly frozen within an hour after the catch. The frozen body was brought to Japan on the 28th of January, 1965. The details of the Southern elephant seal used in this experiment are shown in Table 1 and Fig. 1. Oils were extracted by boiling with water from various blubbers which are shown in Fig. 1 and Table 2. The properties of various blubber oils were examined by ordinary methods (Table 3).

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* Laboratory of Food Engineering, College of Agriculture & Veterinary Medicine, Nihon University. (49,3-Chome, Setagaya-Ku, Tokyo)

TABLE 1. DETAILS OF SOUTHERN ELEPHANT SEAL
(Cited from ICHIHARA & NISHIWAKI, 1966)

Sex	Age	Body weight (except blood)	Body length	Girth at the tip of flipper	Girth at the shoulder	Girth at anus
Male	6	906.9 Kg	2.73 m	2.50 m	2.47 m	0.75 m

TABLE 2. BLUBBERS AND OILS

Sample	Kinds of blubber	Thickness of blubber (cm.)	Oil content in blubber (%)	Appearance (at 30°C)
A	Dorsal blubber of abdominal cavity	4–6	67.2	Yellowish orange liquid
B	Blubber of frontal (part between eyes)	2–3	53.8	Yellowish orange liquid
C	Dorsal blubber of thoracic cavity	4–6	57.1	Yellowish orange liquid
D	Dorsal blubber of abdominal cavity	5.5–6	76.9	Yellowish orange liquid
E	Ventral blubber of thoracic cavity	5–6	52.1	Yellowish orange liquid
F	Ventral blubber of neck	3–4	69.5	Yellowish orange liquid
G	Ventral blubber of thoracic cavity	4–5	62.9	Yellowish orange liquid
H	Ventral blubber of abdominal cavity	3–4	57.7	Yellowish orange liquid
I	Ventral blubber of pelvis	2–3	71.8	Yellowish orange liquid
J	Ventral blubber of hindmost part	2	56.9	Yellowish orange liquid
K	Blubber of tongue	1	66.3	Yellowish orange liquid

TABLE 3. PROPERTIES OF BLUBBER OILS

Sample	$N_D^{30^\circ}$	Acid value	Sapon. value	Iodine value	Unsapon. matter (%)
A	1.4691	1.67	191.4	127.3	0.23
B	1.4689	1.32	197.5	127.6	0.26
C	1.4690	1.73	189.5	117.6	1.10
D	1.4699	1.55	190.7	130.7	0.58
E	1.4691	1.29	193.1	118.2	0.69
F	1.4684	1.59	195.8	121.5	0.55
G	1.4690	1.49	196.2	126.5	0.24
H	1.4690	1.47	196.1	120.5	0.19
I	1.4689	1.42	191.6	132.2	0.23
J	1.4692	1.28	190.3	132.4	0.26
K	1.4691	1.21	192.7	129.7	0.23

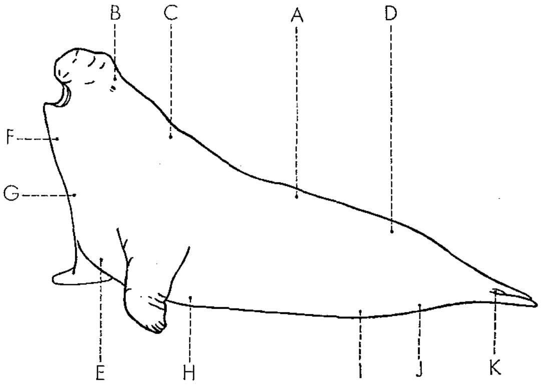

Fig. 1. Various blubbers of Southern elephant seel

Preparation of the methyl esters of the fatty acids

The various blubber oils were saponified by refluxing them with excess 2N alcoholic potash for 2 hours on a steam bath. The alcohol was evaporated, the soap residue dissolved in water and excess dilute sulphuric acid added to liberate the fatty acids. These were washed with successive portions of water to remove mineral acid. The fatty acids were dissolved in ether and this solution was dried by adding anhydrous sodium sulphate. The ether was evaporated under reduced pressure. The properties of conjugated fatty acids are shown in Table 4.

TABLE 4. PROPERTIES OF MIXED FATTY ACIDS

Sample	Appearance (at 30°C)	$N_D^{30°}$	Iodine value	Neutralization value
A	Reddish orange liquid	1.4599	129.6	193.2
B	Yellowish orange liquid	1.4590	129.5	199.0
C	Yellowish orange liquid	1.4518	127.0	195.8
D	Yellowish orange liquid	1.4598	133.5	191.0
E	Reddish orange liquid	1.4600	124.8	194.1
F	Reddish orange liquid	1.4598	128.2	198.1
G	Orange liquid	1.4595	131.5	198.5
H	Reddish orange liquid	1.4597	128.6	199.2
I	Yellowish orange liquid	1.4582	137.3	193.3
J	Yellowish orange liquid	1.4589	136.7	192.7
K	Yellowish orange liquid	1.4561	131.7	194.1

The fatty acid residue was refluxed for 10 hours on the steam bath with four to five times its weight of a 2% solution of sulphuric acid in methanol under N_2 gas.

After removal of the bulk of the methanol, the residue was dissolved in ether and washed first with water to remove mineral acid, then with 5% sodium carbonate solution to remove unesterified fatty acid, and finally with water to remove carbonate.

The ether solution of the methyl esters was dried over anhydrous sodium sulphate and the solvent evaporated under reduced pressure. The methyl esters were colorless liquid and slightly ester-smell.

Gas chromatographic examination of the fatty acids methyl ester

Gas chromatographic apparatus used in this study was a Shimadzu Model GC-1B. A three metres stainless steel column of 4 mm. internal diameter was packed with 60/80 mesh succinate polyester. Helium was used as the carrier gas at flow rate of 50 ml./min. at 2.5 kg./cm^2. and chart speed 0.5 cm./min.. A sample size of 7 μl gave a good general chromatogram of all the fatty acids. The identity of the peak was established by reference to relatively pure standard samples of methyl ester of the various fatty acids and other peaks on the chromatograms were presumed by reference to retention time of each peak and carbon numbers.

RESULTS AND DISCUSSION

Gas chromatogram operated with above mentioned condition obtained the peak more than 20 as shown in Fig. 2. After the fatty acid methyl ester was hydrogenated by a catalyzer of platinum black, stirring with a magnetic-stirrer as 10% solution of methanol for 24 hours at room temperature, gas chromatography was operated about it (shown in Fig. 3), and the following results were obtained.

TABLE 5. FATTY ACID COMPOSITION OF BLUBBER OILS OF SOUTHERN ELEPHANT SEAL

Peak No.	Fatty acid	Sample oils A	B	C	D	E	F	G	H	I	J	K
1	12 : 0	0.49%	0.64%	1.52%	0.46%	0.56%	0.46%	0.51%	0.41%	0.57%	1.16%	0.69%
2	13 : 0	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
3	14 : 0	5.07	4.80	4.93	5.06	4.70	4.32	5.00	5.16	4.46	4.17	5.41
4	14 : 1	0.81	1.08	1.07	1.02	1.18	1.33	1.52	1.23	1.59	1.16	1.34
5	15 : 0	0.16	0.70	0.15	0.63	0.68	0.81	1.00	0.76	1.02	0.47	0.89
6	14 2	0.08	0.25	trace	0.40	0.25	0.11	0.13	trace	0.10	trace	trace
7	16 : 0	11.60	10.85	12.63	12.16	11.77	10.51	11.60	12.24	10.43	10.22	11.63
8	16 : 1	11.11	12.00	11.68	11.83	11.94	11.37	11.03	11.19	11.56	12.68	11.42
9	{17 : 0 16 : 2	0.94	0.89	1.07	0.85	0.79	0.93	1.12	0.88	1.59	0.47	1.84
10	16 : 3	1.71	1.46	1.52	1.54	1.69	1.79	1.82	1.64	1.87	1.47	1.89
11	18 : 0	2.91	1.40	1.75	2.39	1.30	1.80	1.43	1.64	1.42	1.32	3.18
12	18 : 1	38.30	41.47	40.46	38.92	39.76	39.66	37.10	41.13	37.50	36.27	35.40
13	18 : 2	2.10	2.29	2.05	1.90	2.48	2.67	2.50	2.17	2.53	2.64	2.49
14	19 : 0	0.10	0.25	trace	trace	trace	0.21	0.11	0.10	0.12	trace	0.37
15	18 : 3	trace	0.70	trace	1.14	1.30	1.10	1.84	0.65	1.99	1.80	1.04
16	20 : 0	0.35	0.24	0.26	0.15	0.31	0.40	0.22	0.26	0.14	0.34	0.31
17	20 : 1	12.20	11.77	10.65	11.07	11.43	11.35	11.23	10.75	10.86	12.35	11.19
18	20 : 2	1.26	1.00	1.07	1.10	1.21	1.11	1.01	1.11	1.06	1.21	1.13
19	22 : 0	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
20	22 : 1	6.60	4.04	4.55	4.56	5.17	5.05	6.72	5.39	5.87	6.77	4.78
21	22 : 5	2.00	2.17	2.54	2.56	1.43	2.38	2.11	1.36	2.71	2.86	2.64
22	22 : 6	2.21	2.00	2.10	2.26	2.05	2.64	2.00	1.93	2.61	2.74	2.36
Totals		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

It was comfirmed that the component fatty acid of the blubber oil of Southern elephant seal was the saturated fatty acids as follows ; C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17}, C_{18}, C_{19}, C_{20}, C_{22} and other peaks were estimated by the relation of straight line in the numbers of double-bond of carbon and the logalism of retention time as the unsaturated acids of following ; C_{14} monoenoic, C_{14} dienoic, C_{16} monoenoic, C_{16} dienoic,

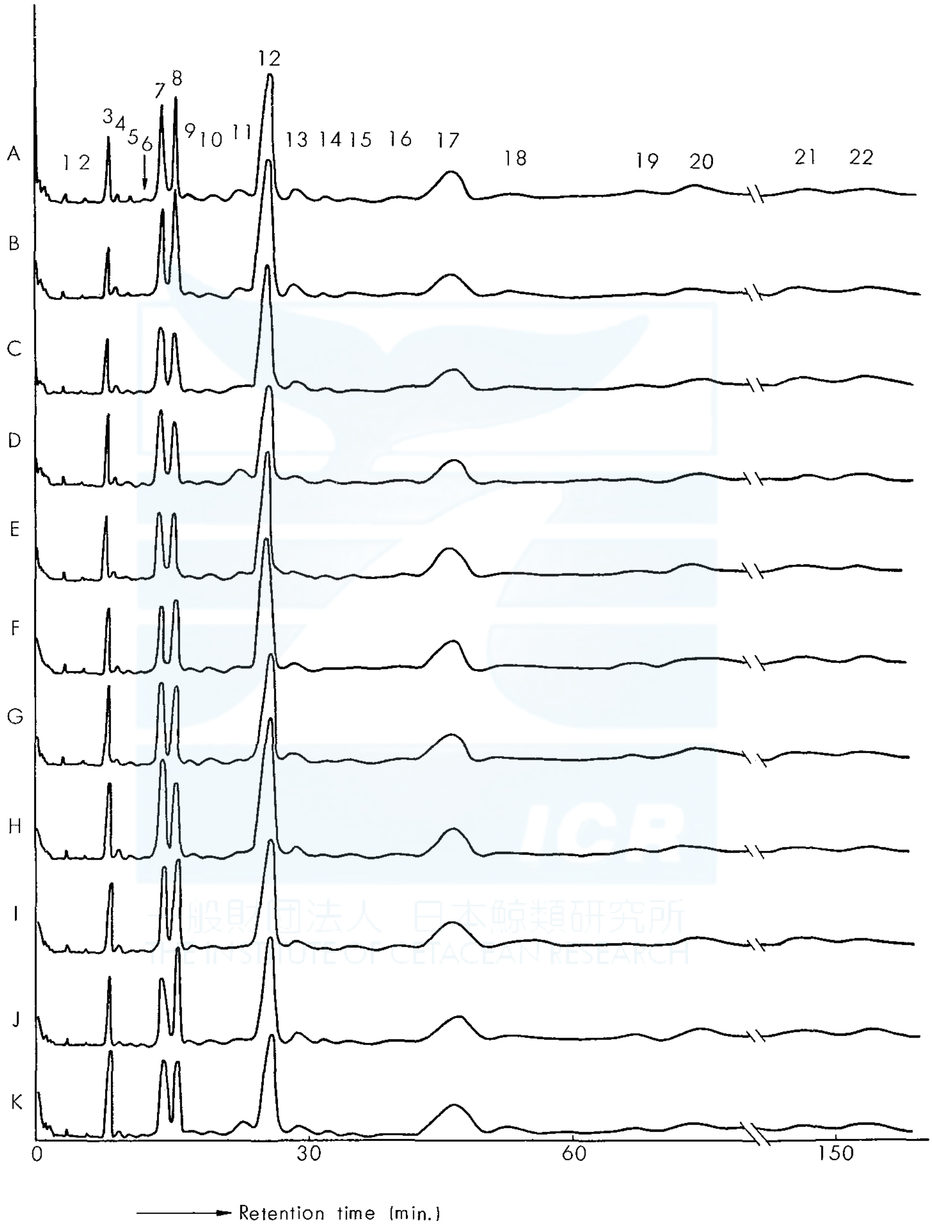

Fig. 2. Gas chromatogram of fatty acid metyl esters of blubber oils

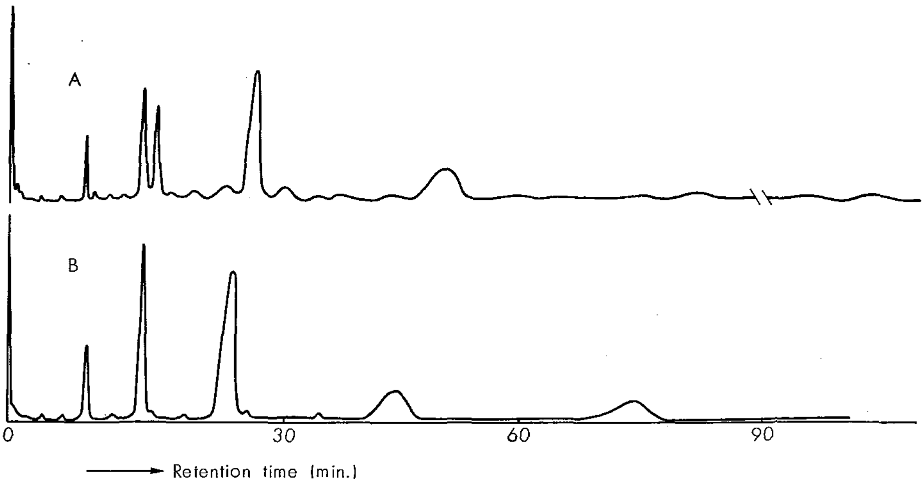

Fig. 3. Gas chromatogram of fatty acid methyl ester of blubber oil before and after hydrogenation A. before hydrogenation B. after hydrogenation

C_{16} trienoic, C_{18} monoenoic, C_{18} dienoic, C_{18} trienoic, C_{20} monoenoic, C_{20} dienoic, C_{22} monoenoic, C_{22} pentaenoic, C_{22} hexaenoic.

According to the weight method of each peak area, the percentages of total fatty acids were shown in Table 5.

The acid values of blubber oils extracted from various parts of Southern elephant seal were low as shown in Table 2, therefore it proved that the free fatty acids were less in blubber oils.

On the other hand, both acid value and unsaponification material content are comparatively low, therefore these facts seem to show that the blubber oils consist of nearly glycerides.

As shown in Fig. 2, the component fatty acids of oils obtained from various blubbers are nearly similiar.

According to the results, the component fatty acid is unsaturated C_{18} monoenoic (35.40–41.73%), the next prominent is unsaturated C_{16} monoenoic (10.83–12.68%). Other component fatty acids are as follows ; saturated C_{16} (10.22–12.63%), unsaturated C_{20} monoenoic (10.03–12.35%), unsaturated C_{22} monoenoic (4.04–6.77%), saturated C_{14} (4.17–5.16%), unsaturated C_{18} dienoic (1.90–2.67%), unsaturated C_{22} hexaenoic (1.51–2.74%), unsaturated C_{22} pentaenoic (1.36–2.86%), saturated C_{18} (1.29–3.18%), unsaturated C_{16} trienoic (1.20–1.89%), unsaturated C_{14} monoenoic (0.81–1.59%), unsaturated C_{20} dienoic (0.98–1.26%), unsaturated C_{18} trienoic (0.65–1.24%), unsaturated C_{16} dienoic+saturated C_{17} (0.47–1.21%), saturated C_{15} (0.15–1.02%), saturated C_{12} (0.41–1.00%), saturated C_{20} (0.14–0.42%), saturated C_{19} (0.10–0.37%), unsaturated C_{14} dienoic (0.08–0.40%), saturated C_{13} and C_{22} (respectively trace), as shown in Table 6.

After all, the total saturated fatty acids content is 16.95–24.99%, while the total unsaturated fatty acids content is 68.54–90.09%.

TABLE 6. EACH FATTY ACID CONTENT (%) IN VARIOUS BLUBBER OILS
(in order of large value)

Order	Fatty acid	Percentages	Average percentage
1	$C_{18:1}$	35.40–41.73	38.67
2	$C_{16:1}$	10.83–12.68	11.61
3	$C_{16:0}$	10.22–12.63	11.37
4	$C_{20:1}$	10.03–12.35	11.27
5	$C_{22:1}$	4.04– 6.77	5.19
6	$C_{14:0}$	4.17– 5.16	4.83
7	$C_{18:2}$	1.90– 2.67	2.36
8	$C_{22:6}$	1.51– 2.74	2.21
9	$C_{22:5}$	1.36– 2.86	2.05
10	$C_{18:0}$	1.29– 3.18	1.94
11	$C_{16:3}$	1.20– 1.89	1.67
12	$C_{14:1}$	0.81– 1.59	1.21
13	$C_{20:2}$	0.98– 1.26	1.11
14	$C_{18:3}$	0.65– 1.24	1.06
15	$C_{17:0}+C_{16:2}$	0.47– 1.21	1.03
16	$C_{15:0}$	0.15– 1.02	0.66
17	$C_{12:0}$	0.41– 1.00	0.43
18	$C_{20:0}$	0.14– 0.42	0.27
19	$C_{19:0}$	0.10– 0.37	0.17
20	$C_{14:2}$	0.08– 0.40	0.09
21	$C_{13:0}$	trace	—
22	$C_{22:0}$	trace	—

TABLE 7. A COMPARISON OF THE FATTY ACID COMPOSITION OF THE SOUTHERN ELEPHANT SEAL AND THE NORTHERN ELEPHANT SEAL OIL

	Fatty acid	Southern elephant seal	Northern elephant seal
Saturated acid	C_{12}	0.41– 1.00%	—%
	C_{13}	trace	—
	C_{14}	4.17– 5.16	3.52
	C_{15}	0.15– 1.02	—
	C_{16}	10.22–12.63	12.82
	C_{17}	0.47– 1.21	—
	C_{18}	1.29– 3.18	3.61
	C_{19}	0.10– 0.37	—
	C_{20}	0.14– 0.42	0.41
	C_{22}	trace	0.01
Total saturated acid		16.95–24.99%	20.37%
Unsaturated acid	C_{14}	0.89– 1.99 (−2, −4H)	0.96 (−2.0H*)
	C_{16}	12.50–16.41 (−2, −4, −6H)	10.02 (−2.5H*)
	C_{18}	37.95–45.64 (−2, −4, −6H)	33.22 (−3.0H*)
	C_{20}	11.05–13.68 (−2, −4H)	24.50 (−4.4H*)
	C_{22}	6.15–12.37 (−10, −12H)	10.25 (−7.1H*)
	C_{24}	—	0.59 (−6.6H*)
Total unsaturated acid		68.54–90.09%	79.63%

* average unsaturation

Comparing with the component acids of Northern elephant seal, *Mirounga angustirostiris*, oil studied by Tsuyuki and Southern elephant seal, *Mirounga leonina*, oil in this experiment (Table 7), there is remarkable difference in C_{18} monoenoic acid content.

The total unsaturated C_{18} acid content (37.95–45.64%) of the Southern elephant seal oil is higher than that (33.22%) of the Northern elephant seal oil, on the contrary, the total unsaturated C_{20} acid content (11.05–13.68%) of the Southern elephant seal oil is lower than that (24.50%) of the Northern elephant seal oil. In other fatty acid contents, there is no remarkable difference between both seal oils.

In this study, the existance of the saturated acids with odd carbon atoms (13, 15, 17, 19) was comfirmed, but the unsaturated C_{24} acid was not comfirmed.

SUMMARY

1. The oils contained in various blubbers of the Southern elephant seal, *Mirounga leonina*, were studied.

The fatty acid composition of the Southern elephant seal oil was studied by gas chromatography on a polyester column.

The results obtained are as follows ;

Total saturated fatty acids 16.95–24.99% ;

lauric acid	0.41– 1.00%
tridecanoic acid	trace
myristic acid	4.17– 5.16%
pentadecanoic acid	0.15– 1.02%
palmitic acid	10.22–12.63%
heptadecanoic acid	0.47– 1.21%
stearic acid	1.29– 3.18%
nonadecanoic acid	0.10– 0.37%
arachidic acid	0.14– 0.42%
behenic acid	trace

Total unsaturated fatty acids 68.54–90.09%;

C_{14} monoenoic acid	0.81– 1.59%
C_{14} dienoic acid	0.08– 0.40%
C_{16} monoenoic acid	10.83–12.68%
C_{16} dienoic acid	0.47– 1.21%
C_{16} trienoic acid	1.20– 1.89%
C_{18} monoenoic acid	35.40–41.73%
C_{18} dienoic acid	1.90– 2.67%
C_{18} trienoic acid	0.65– 1.24%
C_{20} monoenoic acid	10.03–12.35%
C_{20} dienoic acid	0.98– 1.26%
C_{22} monoenoic acid	4.04– 6.77%

C_{22} pentaneoic acid	1.36– 2.86%
C_{22} hexaenoic acid	1.51– 2.74%

2. The component acids of blubber oil of the Southern elephant seal and the Northern elephant seal were nearly similar, except that there is remarkable difference in C_{18} monoenoic acid content.

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一般財団法人　日本鯨類研究所
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鯨類研究所
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編輯責任者　大村秀雄

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Author	*Present address*
Seiji Ohsumi	Tokai Regional Fisheries Research Laboratory, 5 Kachidoki, Chuo-ku, Tokyo.
Tadayoshi Ichihara	”
Keiji Nasu	”
Toshio Kasuya	Ocean Research Institute, University of Tokyo, Sakaechyo, Nakano-ku, Tokyo.

Whales Research Institute
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