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CONTENTS OF NUMBER 23

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SOME INVESTIGATIONS ON THE SCHOOL STRUCTURE OF SPERM WHALE*

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ABSTRACT

Social structure of the sperm whale is studied by means of catch of all individuals which form the same school, whale marking and whale sighting.

The sperm whale is matriarchal in social organization. Types of schools are classified into nursery school, harem school, juvenile school, bachelor school, bull school and lone bull. The fundamental is nursery school which is a maternal family and is composed of mature females, suckling and immature males and females. Puberal males lose their association with the nursery school, and make a loose bachelor school. Harem is only temporary, and it is formed joining a winned bull into nursery school in the breeding season.

Social tightness of nursery school is very close, and family lives within the same school for long years.

Number of mature females served by a bull in harem is estimated to be 14 on an average.

INTRODUCTION

As one of the biological parametres on the stock assessment of the sperm whale (*Physeter catodon*), there is the number of mature females served by a bull in the reproduction. The sperm whale is gregarious and polygamous, and it is considered that the males which join into the reproductive activity are only a part of all adult males. However, it has not been confirmed yet how many bulls are needed for reproduction. Without solution of this problem, it is difficult to get the sustainable yield which is needed for stock management of the sperm whale. The study of social behavior must be introduced for this problem.

Sperm whales migrate in the wide space of seas during the period of their whole life span, and their habitat is cubic and wide, so that observing the structure of schools in the waters is very difficult by means of the present technics, although there are relatively many reports on the social behavior of the sperm whale as reviewed by Caldwell, Caldwell and Rice (1966).

For the purpose to approach the solution of the problem of school structure, I used some results of biological investigations, such as catching all whales which form a school, whale sighting and whale marking. And I want to offer a hypothesis on the formation of sperm whale schools, and to introduce a preliminary calculation of the ratio of the number of males needed to that of mature females for reproduction.

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MATERIALS AND METHODS

The Whales Research Institute was permitted by the Japanese Government to take each and every individuals forming three schools of the sperm whales for the scientific purposes in the coastal waters of Japan and in the pelagic oceans of the Southern Hemisphere. The outline of the schools investigated is shown in Table 1.

TABLE 1. THREE SCHOOLS OF SPERM WHALES CAUGHT FOR THE SCIENTIFIC PURPOSE

Items	School A	School B	School C
Time found	1015 29 Sept., '65	1505 9 Nov., '66	0600 10 Nov., '66
Position found	40°35′N, 144°34′E	40°34′S, 73°28′E	40°41′S, 71°56′E
Form of school	A rank, 50 m spread	Fan shaped, 30 m² spread	Long oval, long axis: 120 m
Composition observed at the time of finding	35–39′ : 5, 30–34′ : 11, 25–29′ : 5, Calves : 5, Total 26	35–39′ : 5, 30–34′ : 25, 25–29′ : 11, Calves : 2, Total 40	30–34′ : 34, 25–29′ : 12, Calves : 2, Total 48
Leader	Not recognized	Not recognized	Not recognized
Moving direction	NE	W	S–SW
Escaping direction	NE/N	W–WSW	Separated into two groups, one (14 whales) E→N, another SSW–S
Relation to other schools	A school of 5–6 of 35–36′ long sperm whales, 3 miles apart from the School A moving NE	Not recognized clearly but some sperm whale like spouts were observed	Not found
Relation to other whale species	Not found	Unknown	A sei whale 3 miles apart from School C, eastward
Weather	bc	m	c
Wind force and direction	W, 4–5	NW, 6	W, 5
Visibility	Good	5 miles	8 miles
Water and air temperature	15.4°C, 19.5°C	12.6°C, 14.1°C	12.8°C, 12.4°C
Shiome	No	No	No
Sea birds	Some	No	Few small birds
Fishes	Mackerels	No	No
No. of catcher boats engaged in catching	4	5	7
No. of whales caught	20*	12	39

* One whale lost

In each case of taking schools, crew of a catcher boat which found an objective school observed and noted some informations about it on the field sheets, chasing the school until all other boats got to gather at the position where the school was found. These catcher boats tried to take all whales of the school co-operatively.

Four catcher boats co-operated to take School A, and five and seven boats to take Schools B and C, respectively. Positions taken are shown in Appendix-Fig.1. Twenty whales were taken from School A, which was composed of 26 whales, 12 whales from School B of 40 whales and 39 whales from School C of 48 whales. Real conditions of school composition can be estimated from Schools A and C, but School B is too small for its composition to be estimated. However, the materials obtained from School B are also useful to get other biological knowledges. Biological data on each whales caught are shown in Appendix-Tables 1–3.

As the second method of studying school structure of the sperm whales, I used the records of the scouting boats which were engaged in the whale marking on some items of information about sperm whales forming a school. The recorded items are the position and time of sighting, sea conditions, whale species, number of whales which form a school and estimated size ranges of individuals of school.

TABLE 2. SCHOOL SIZE OF THE SPERM WHALES OBSERVED

	North Pacific				Antarctic	
			Pelagic ground			
Size (whales)	Bonin Is.	Off Japan	South 50°N	North 50°N	North of A.C.	South of A.C.
1	1	16	23	221	15	23
2	1	12	5	30	14	1
3	—	8	4	21	9	7
4– 5	2	22	13	26	10	—
6– 10	3	45	6	24	10	—
11– 20	5	54	11	7	6	—
21– 30	3	26	7	10	3	—
31– 50	3	30	—	2	2	—
51– 75	1	15	—	1	—	—
76–100	—	7	—	—	—	—
101–125	—	1	—	—	—	—
Total no.	19	236	69	342	69	31
Average	19.4	20.3	7.1	3.3	6.3	1.5

I also examined the continuance of school composition of sperm whales by means of checking the recaptured whales which had been marked in the same school at the same time of whale marking investigation.

NUMBER OF WHALES FORMING A SCHOOL

It is really very difficult to identify the range of a school in waters. When many whales scatter around, it is quite hard to recognize which whales form which schools. Long time of observation will be taken to identify the same school clearly, as be used for the social behavior of terestrial mammals. However, such an observation is almost impracticable technically and economically in the case of marine mammals. Whales are mobile and there have not been any proofs whether the territory of each school exists in the whale society in open seas. Therefore, two or more schools might be found closely to each other in some cases. On the other hand, there is a possibility that some whales move separately from a main school (Caldwell *et al.*, 1966). Sometimes a school separates into two or more sub-schools, when we chase the school. It is a problem how we should recognize a school in such cases. The individuals in the same school must move in the same manner, then in the former case, the separate ones will move with main school, and the separate groups in the latter case will gather each other soon.

Furthermore, counting of the number of whales forming a school is practically very difficult. Some members of a school may be diving at the time of counting. Unless a long time is spent for observation on the same school or for catching all individuals at the same chance, the real number is not obtained.

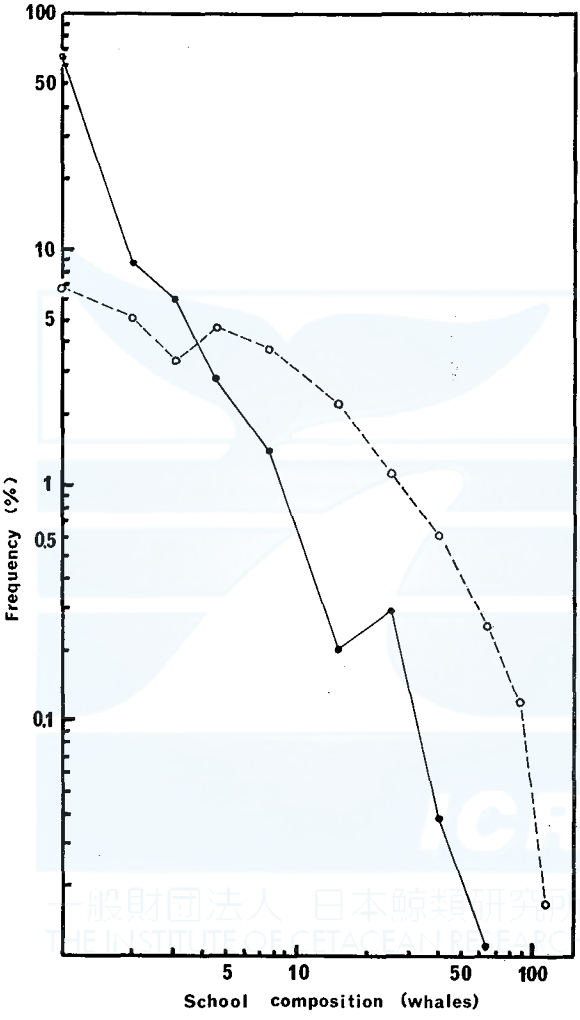


Fig. 1. Frequency distribution of school composition (number of whales in a school) in the sperm whale.
Open circle and broken line: Japanese coastal waters,
Closed circle and solid line: northern part of the North Pacific (north of 50°N).

In the case of whale sighting by scouting boats, the sound of engine will affect the behavior of whales abnormally, so that we have to take this problem into account at the time of observation of whale school by vessel. Whale sighting by means of aircraft as reported by Nishiwaki (1962), Gambell (1967, 1968), Bannister (1968) and Best (1969) will be good for this purpose, for it does not so much affect the behavior of whales. However, the method requires much money and is limited in its activity.

Table 2 shows the frequency of school occurrence by number of sperm whales in each school, based on the reports of scouting boats. Seasons of investigation were from May to September in the North Pacific, and from October to March in the Southern Hemisphere. They are during the period from mid-spring to early autumn in the both Hemispheres. The largest school was composed of 120 sperm whales. There were other large schools which were composed of over 50 whales, but most of them were noted to be composed of some smaller sub-schools. Therefore, it is conceivable that the large school is a combined group of several sub-schools. Concerning with the large sperm whale school, Caldwell *et al.* (1966) reviewed many records, and summarized as twelve to several hundreds in harem-type groups, with the largest record of "well over 1,000" by Boyer (1946). According to Gambell (1967), the highest number was 200 animals off the coast of South Africa.

Frequency of occurrence of single whale increases as the investigation area shifts to higher latitude. Table 2 also shows the average numbers of whales which form a school in each area. In the sea around the Bonin Is. and off Japan, it is about 20 whales, and in the pelagic whaling ground south of 50°N it is 7.1. In the waters north of 50°N it decreases to 3.3 (Fig. 1). In the waters north of the Antarctic Convergence, it is 6.3, but it becomes only 1.5 in south of the Convergence. Although there were no schools which were composed of more than four whales south of the Antarctic Convergence, there were some schools observed which were composed of more than 10 whales in the waters north of 50°N of the North Pacific. This phenomenon will be related to the fact that the oceanographic structure is more complicated in the North Pacific than in the Antarctic, and a warm water mass extends into the area north of 50°N (Ohsumi and Nasu, 1970).

SIZE DISTRIBUTION OF WHALES WHICH FORM A SCHOOL

It is practically rather difficult to measure with the eyes the body length of a whale which swims in the waters. And the estimated length sometimes differs very much from the real one. Ohsumi (1960) shows that this difference is $-7 \sim +4$ feet comparing the estimated body lengths of sperm whales with eyes at the time of marking with the real lengths of the same ones which were recaptured soon after the marking.

Table 3 shows a size distribution of lone sperm whales. The smallest was 32 feet long and the largest was 57 feet. The average lengths were 44.3 feet in the North Pacific and 44.6 feet in the Antarctic. The modes were both 44–45 feet. The estimated size distribution of lone sperm whales which were found in the waters north of 50°N closely fits that of the male sperm whales which were caught in both waters of the Bering Sea and surrounding the Aleutian Is. by the Japanese expeditions in 1957, as shown in Fig. 2. Since in this area almost of sperm whales seem

TABLE 3. ESTIMATED SIZE DISTRIBUTION OF SOLITARY SPERM WHALES SIGHTED

Estimated body length (feet)	North Pacific					Antarctic Convergence		
	Bonin Is.	Off Japan	50°N		Total	North	South	Total
			South	North				
32–33	—	1	—	—	1	—	—	—
34–35	—	1	1	1	3	—	—	—
36–37	—	2	—	3	5	1	—	1
38–39	—	—	1	10	11	1	1	2
40–41	—	2	—	33	35	1	2	3
42–43	—	4	3	28	35	2	2	4
44–45	—	1	3	41	45	7	4	11
46–47	—	—	3	21	24	—	4	4
48–49	1	—	1	12	14	—	2	2
50–51	—	1	3	15	19	1	2	3
52–53	—	—	—	7	7	1	—	1
54–55	—	—	1	3	4	—	—	—
56–57	—	—	—	1	1	—	—	—
Total	1	12	16	175	204	14	17	31
Average (ft)	48.5	40.5	45.5	44.5	44.3	43.9	45.1	44.6

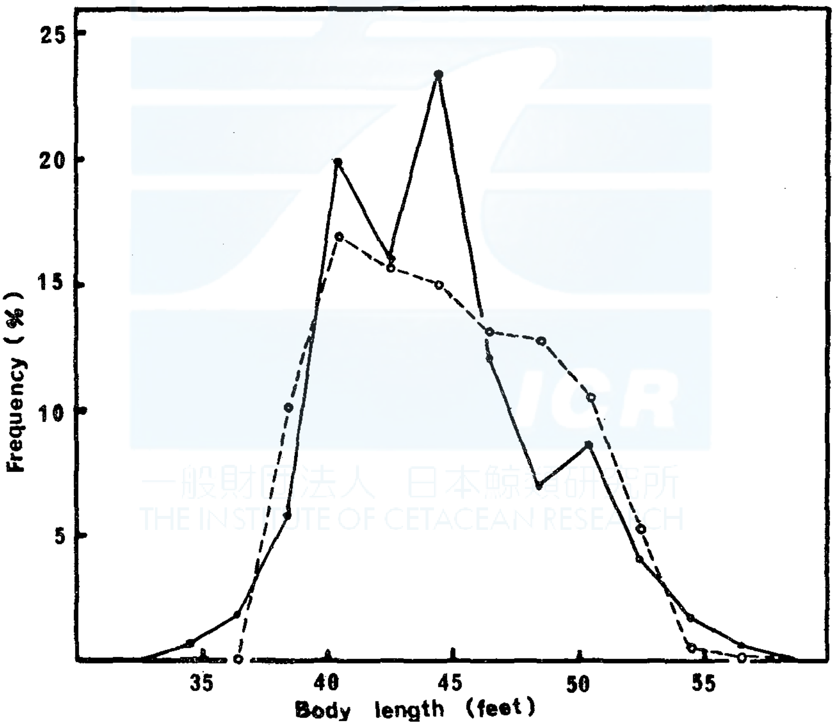


Fig. 2. Estimated size distribution of solitary sperm whales and size distribution of male sperm whales caught in the northern part of the North Pacific in 1957. Closed circle and solid line: solitary whales, Open circle and broken line: males caught.

to be male and lone, the great part of the whales caught were regarded as lone whales. Furthermore, this means that lone sperm whales are mostly males.

Male sperm whales attain to their sexual maturity at 31 feet in body length (Clarke, 1956). According to Best (1969), 50% of testes of males at 39–46 feet of body length are mature, and those of most males at 45–46 feet become fully mature. Lone sperm whales appear from 32 feet in body length at which male whales begin to be sexually mature, increase in number from the stage of 40 feet, and attain to the maximum at the time when most male's testes are fully mature. In other words, it will be regarded that lone sperm whales are males with fully matured testes.

TABLE 4. ESTIMATED SIZE DISTRIBUTION OF PAIRED SPERM WHALES SIGHTED

Body length (feet)	North Pacific				Antarctic Convergence		
	Off Japan	North 50°N	South 50°N	Total	North	South	Total
20–21	1	—	—	1	—	—	—
30–31	2	—	—	2	—	—	—
32–33	—	—	—	—	—	—	—
34–35	6	—	1	7	—	—	—
36–37	—	2	4	6	2	—	2
38–39	1	—	8	9	6	—	6
40–41	1	—	10	11	6	2	8
42–43	3	—	10	13	8	—	8
44–45	—	—	6	6	6	—	6
46–47	—	3	1	4	2	—	2
48–49	—	3	4	7	—	—	—
50–51	—	—	2	2	—	—	—
52–53	3	—	—	3	—	—	—
54–55	1	—	—	1	—	—	—
Total	18	8	46	72	30	2	32
Average (ft)	39.3	44.8	41.9	41.6	41.6	40.5	51.5

Size distribution of paired whales is shown in Table 4. Range of estimated body length is within 20–55 feet, and the averages are 41.6 and 41.5 feet for the North Pacific and the Southern Hemisphere, respectively. These are lower than those of the lone whales. There is a tendency that similar sized whales make paired schools in most cases, and paired whales are all over 30 feet long. It is considered that sexually mature males are apt to make a paired group, but they are younger than the lone whales on an average.

The schools which are composed of more than three whales are classified into the following groups by head: 3, 4–5, 6–10, 11–20, 21–30, 31–50, 51–75, 76–100, and 101–125. And the range of estimated body length is shown by each group of school in Fig. 3 A-H. The schools which are distributed in higher latitude have a tendency to be composed of large sized whales.

Fig. 4 shows the change of frequency ratios of occurrence of the schools which are composed of whales over 40 feet long together with the changes of school size. The larger the school size becomes, the smaller the ratio of the school which compose

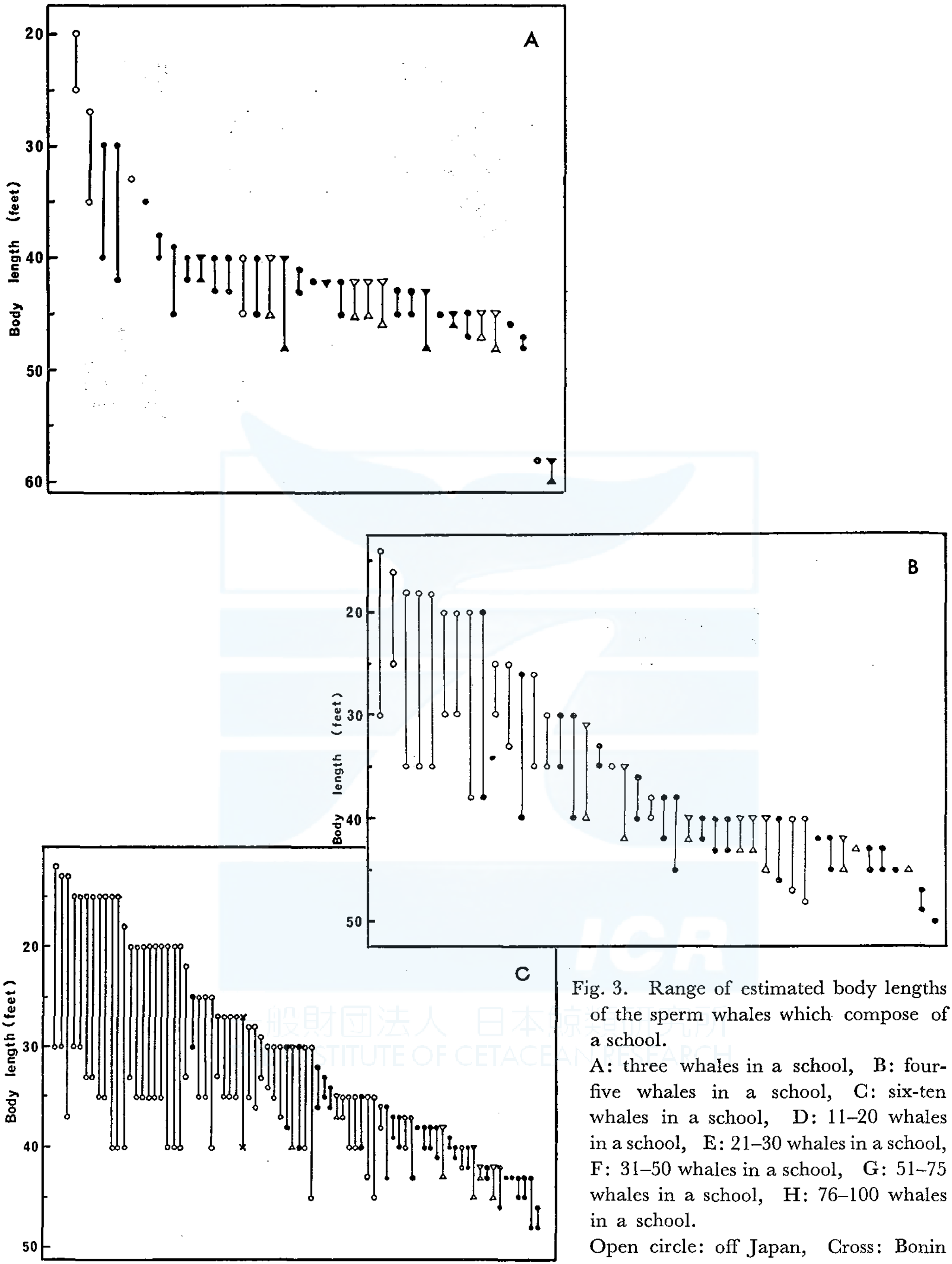
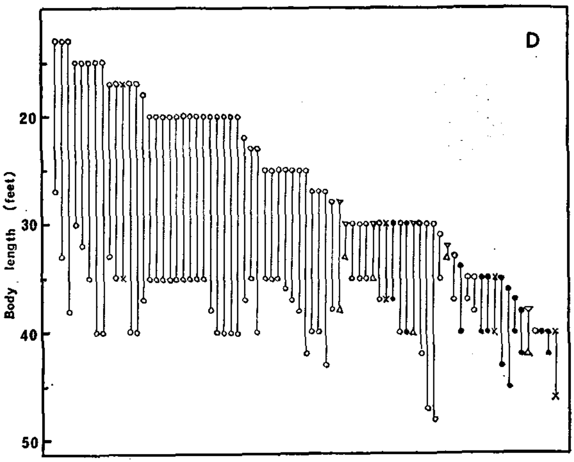
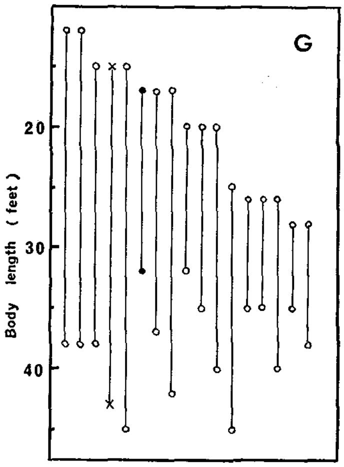
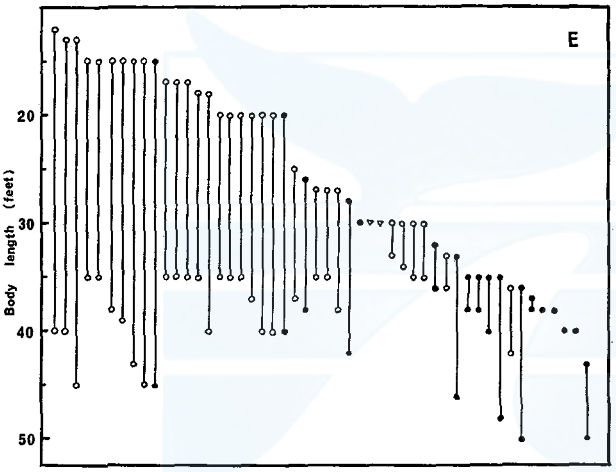
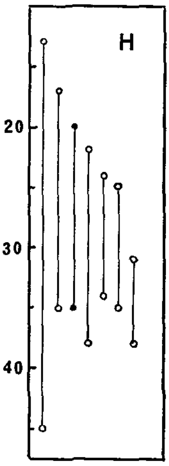


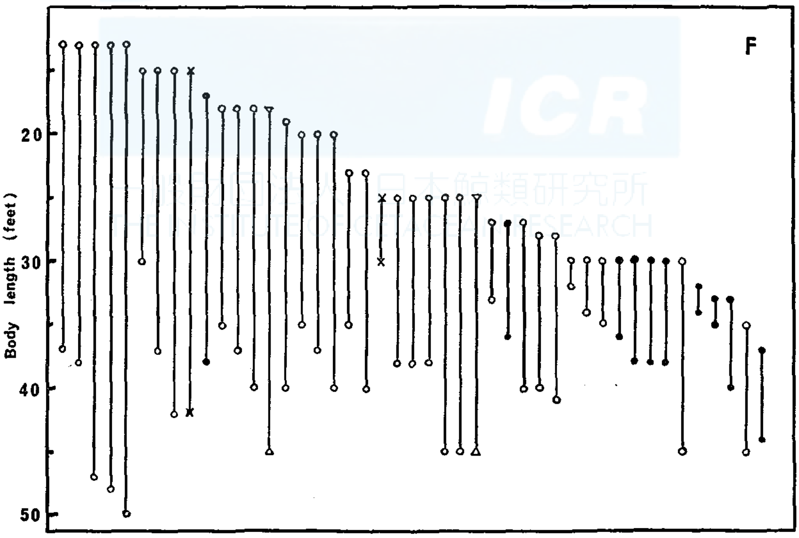
Fig. 3. Range of estimated body lengths of the sperm whales which compose of a school.
A: three whales in a school, B: four-five whales in a school, C: six-ten whales in a school, D: 11–20 whales in a school, E: 21–30 whales in a school, F: 31–50 whales in a school, G: 51–75 whales in a school, H: 76–100 whales in a school.
Open circle: off Japan, Cross: Bonin Is., Closed circle: northern part of the North Pacific, Open triangle: north of the Antarctic Convergence, Closed triangle: south of the Antarctic Convergence.


D
Body length (feet)
20
30
40
50


G
Body length (feet)
20
30
40


E
Body length (feet)
20
30
40
50


H
20
30
40


F
Body length (feet)
20
30
40
50

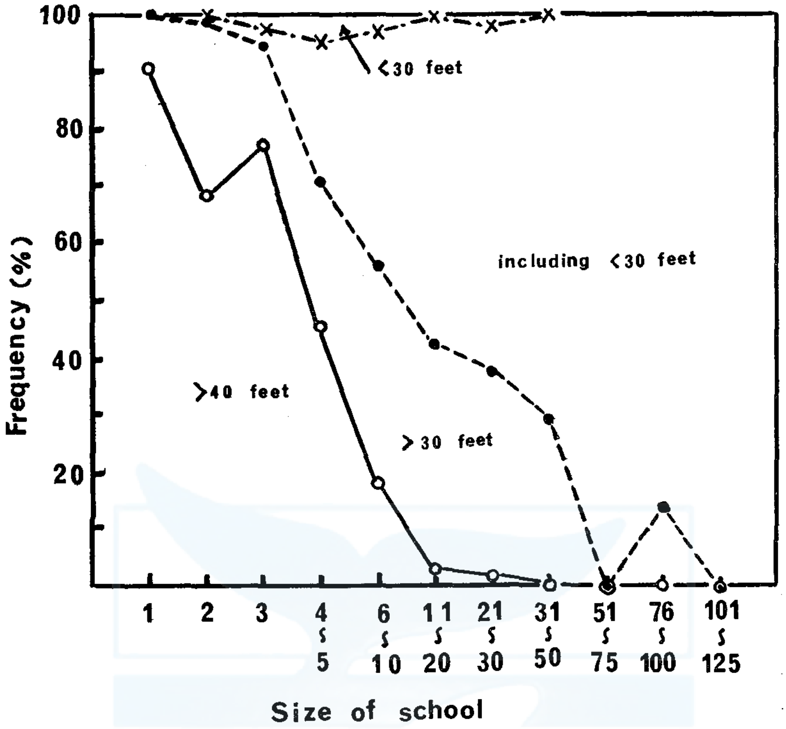


Fig. 4. Change in ratio of frequency occurrence of sperm whale schools classified by range of body length according with the size of school.
+40 feet: Schools composed with individuals over 40 feet in body length, +30 feet: Schools composed with individuals over 30 feet in body length, Including +30 feet: Schools composed with individuals including less than 30 feet in body length, +30 feet: Schools composed with individuals less than 20 feet in body length.

TABLE 5. FREQUENCY OCCURRENCE OF SCHOOL SIZE BY THE GROUPS SEPARATED WITH RANGE OF BODY LENGTH

School Size (whales)	Range of body length in feet				
	>40	>30	Including <30	<30	Total
1	222	13	—	—	235
2	30	21	1	—	52
3	27	5	1	1	35
4–5	20	11	11	2	44
6–10	14	30	30	4	78
11–20	4	28	41	2	75
21–30	3	19	28	—	50
31–50	—	13	21	1	45
51–75	—	—	17	—	17
76–100	—	1	6	—	7
101–125	—	—	1	—	1
Total	320	107	157	10	594
Average	2.2	16.8	27.1	8.2	

with the whales over 40 feet becomes, and the ratio is about 80% with regard to the schools of 3 whales, but it becomes under 20% in the schools of 6–10 whales or over. This means that most schools of 3 whales and less are composed of mature males, and mature males seldom make larger schools of over 6–10 whales. The average whale number of the schools composed with over 40 feet long whales is 2.2. Fig. 4 also shows that the number ratio of the schools which are composed of whales over 30 feet long is the highest with regard to those of 6–10 whales. The average whale number of the schools is 16.8. The number ratio of the schools which are composed of the whales including under 30 feet long whales increases with the increase of school size. The mode of occurrence frequency of this kind of school lies at their size of 11–20 whales, and the average whale number of the schools is 27.1. The schools which include whales of under 30 feet long are considered to be nursery ones as described in the following chapter. If it is true, the average size of nursery schools will be about 27 whales.

There is another kind of school which is composed of only the whales under 30 feet long. The size of the schools is 3–50, having a mode at their size of 6–10 whales. The schools are regarded as juvenile ones.

CONTINUANCE OF SOCIAL SCHOOL COMPOSITION

The behavior of formation and separation of a school is a biologically interesting problem. However, it is very difficult to study on this problem about marine animals. Because, it is still almost impossible to observe the same school in the waters for long time.

Whale marking will be one of the ways to approach this subject. Table 6 shows the results of recaptured sperm whales which were marked in the same school at the same time. School No. 3 had been composed of 50 whales, of which 15 whales were marked. Two females of them were recaptured from the same school 10 days after the time of the marking. Two females of School No. 5 were recaptured from the same school 6 days after. There have been no whales which had been marked in a school and were recaptured from separated schools in the same season.

There were some examples of whales which had been marked in a school and were recaptured one year and over after from the same school. Two females of each of School Nos. 4 and 7 were recaptured from the same schools after 10 years elapsed from the time of marking. Two females were also recaptured from the same school 5 years after. According to the reports of recoverey, two females were recaptured by the same catcher boat on the same day after 8 years elapsed. Although the positions of these two recaptured whales are little apart from each other, they are regarded as belonging to the same school at the time of recapture.

Above examples are all considered showing the fact that sperm whales move and migrate belonging to the same school for long years. If sperm whales easily form a school and separate from the school, such results would not be obtained, for sperm whale stocks are very large (Ohsumi *et al.*, 1971) and the chance that the several whales which had been marked in the same school meet again and belong-

TABLE 6. RESULTS OF SPERM WHALE MARKING WHICH SHOWS CONTINUANCE OF THE SCHOOL COMPOSITION

		At the time of marking				At the time of recapture			
Sample No.	Mark No.	Date	Position	Body length (ft)	School No./ Marked No.	Date	Position	Body length (ft)	Sex
3	1889	3/VIII/51	39-46N, 145-19E	30	50/15	26/VIII/51	41-56N, 146-59E	37	F
	1898			33				36.4	F
4	2871	12/IX/52	43-44N, 148-44E	—	—	24/X/62	41-22N, 144-52E	35	F
	2878			—			41-24N, 144-51E	35	F
5	2881, 85, 89	12/IX/52	44-00N, 149-40E	30	40/15	18/IX/52	40-05N, 146-56E	36	F
	2882, 83			28-34			40-06N, 146-52E	36	F
	3051			34		23/IX/60	42-55N, 148-05E	36	F
7	2983	12/IX/52	43-44N, 148-44E	30	60/12	24/X/62	41-17N, 144-53E	35	F
	2984			30				38	F
12	6429	5/VIII/55	39-09N, 148-52E	33	60/11	12/IX/60	42-01N, 146-41E	36	F
	6434			32				37	F
14	6650	7/VIII/55	41-12N, 148-30E	32	100/10	22/IV/56	42-17N, 147-46E	35	F
	6669			32			41-28N, 148-00E	35	M
15	7304	18/VIII/55	45-55N, 152-56E	36	30/12	20/VIII/63	36-21N, 144-24E	36	F
	7326			35			36-22N, 144-35E	37	F
	7811			38		-/VII/57	Shinshil Is. (USSR)	—	—
16	6660	7/VIII/55	41-19N, 148-52E	32	40/7	14/VI/63	41-51N, 146-43E	40	M
	7342			35			42-07N, 146-03E	38	F
	7348			—		20/VI/63	42-06N, 146-15E	45	M

TABLE 7. A RECORD ON RECAPTURE OF SPERM WHALES WHICH WERE MARKED IN A SAME SCHOOL (SCHOOL NO. 6, 50 WHALES WERE MARKED OF 120 WHALES IN A SCHOOL AT 43°43′N, 148°36′E ON 12 SEPTEMBER, 1952).

		Body length (feet)			
Mark No.	Sex	At marking	At recapture	Data recaptured	Position recaptured
2896	M	37	36	4/V/56	42°09′N, 147°43′E
2906	M	38	37	6/XI/59	41°59′N, 145°41′E
2917	M	28	41	25/VI/53	39°49.5′N, 143°42′E
2931	M	35	35	2/VIII/58	42°06′N, 145°38′E
2934	F	27	36	24/X/62	41°17′N, 144°53′E
2936	M	25	41	20/VI/63	52°52′N, 170°40′E
2947	F	34	35	11/IX/55	41°22′N, 148°38′E
2954	F	37	35	17/IX/57	41°45′N, 146°06′E
2960	—	40	—	27/VIII/54	(42°08′N, 147°11′E)

ing to another same school is almost negligible. From this viewpoint, it will be probable that sperm whale schools have a tight family union for long time. It is notable that the above six examples are all related to females. Sperm whales are polygamous, and the fundamental type of schools is a nursery one which is composed of mature females and calves as described below.

There is another example that a male and a female which had been marked in the same school were recaptured at almost the same position (School No. 14) on the same day of next year. These two whales are regarded as moving about in the same school for at least 8 months. In the case, the male was reported to be 35 feet long at the time of recapture and may be at the age of puberty. The relationship between whales Nos. 6660 and 7342 of School No. 16 is an example almost similar to that in School No. 14. These two examples will witness that some males at the age of puberty remain in breeding school.

On the separation of bachelor from nursery school, there is a case of School No. 6 of which 50 whales were marked (Table 7), and it was apparently nursery school from the size distribution. Of the marked whales 9 individuals has been recaptured, and one bachelor (No. 2936) was recaptured in the northern part of the North Pacific, although others were all recaptured in the coastal waters of Japan. This means that the male separates from the nursery school after attainment of puberty.

CATCH OF ALL WHALES WHICH FORM A SCHOOL

We have the results of the three cases of investigations for catching all members of a school under special licence of the Japanese Government. School A was caught in the waters off Hokkaido in late September, 1965. Schools B and C were caught in the southern part of the Indian Ocean in early November, 1966. These positions are the waters where nursery schools are commonly distributed.

The results of observations on the schools at the time of finding are noted as shown in Table 1. So-called " harem master " was not found in any of these three schools, although calves and immature whales were found. Therefore, all of these schools are considered to be nursery ones. Catching of these schools was done by the co-operation of several catcher boats, and the number of whales caught are 20 (one of which sank and lost) and the catch rate was 76.8%, 12 (30.0%) and 39 (81.3%) for Schools A, B and C, respectively. Excluding the result from School B which was difficult to be caught because of bad weather condition, the whales caught from Schools A and C will represent a certain type of composition of nursery school of sperm whales.

1. Sex ratio: The sex ratios of males were 15.8%, 16.7%, 28.2% and 22.9% for Schools A, B, C and their average. Then, it is clear that females are the subject of the nursery school.

2. Sexual maturity: All males were calves, sexually immature or puberal, and the estimated body length of the whole whales including escaped ones were all under 39 feet. Therefore, it is considered that there were no socially mature males, which could join the nursery schools for reproductive action (Table 8).

Rate of calves and immature females were 31.2%, 20.0%, 14.3% and 20.4% for Schools A, B, C and their average. Calves and immature whales are composed of 12 males and 11 females, so that the sex ratio of both sexes is almost the same in such developmental stage in the nursery school. This will mean that males and females remain in the school at least until attainment of sexual maturity in the

TABLE 8. SIZE DISTRIBUTION OF SPERM WHALES CAUGHT

Body length (feet)	School A					School B					School C								
	Male	Female			Total	Male	Female			Total	Male			Female				Total	Grand Total
	I	I	SM	PM		P	I	SM	PM		C	I	P	I	P	SM	PM		
18	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	2	2
23	—	—	—	—	—	—	—	—	—	—	—	4	—	—	—	—	—	4	4
26	—	—	—	—	—	—	2	—	—	2	—	1	1	—	—	—	—	2	4
27	—	—	—	—	—	—	—	—	—	—	—	1	1	1	—	—	—	3	3
28	1	1	—	—	2	—	—	—	—	—	—	—	—	1	—	—	—	1	4
29	1	1	1	—	3	—	—	—	—	—	—	—	—	—	—	4	—	4	7
30	—	2	—	—	2	1	—	1	—	2	—	1	—	1	—	2	—	6	10
31	1	1	1	—	3	1	—	1	1	3	—	—	—	—	—	5	1	6	12
32	—	—	2	—	2	—	—	2	2	4	—	—	—	1	—	2	3	6	12
33	—	—	1	—	1	—	—	1	—	1	—	—	—	—	1	2	2	5	7
34	—	—	4	1	5	—	—	—	—	—	—	—	—	—	—	1	—	1	6
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1
36	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Total	3	5	9	2	19	2	2	5	3	12	2	7	2	4	1	16	7	39	70
Average	29.3	29.6	32.6	35.0	31.5	30.5	26.0	31.6	31.7	30.5	18.0	25.0	26.5	29.3	33.0	30.9	32.6	30.7	30.9

Remarks: I: Immature, P: Puberal, C: Calf, SM: Sexually mature, PM: Physically mature.

TABLE 9. AGE DISTRIBUTION OF SPERM WHALES CAUGHT

Age (yrs.)	School A					School B					School C								
	Male	Female			Total	Male	Female			Total	Male			Female				Total	Grand Total
	I	I	SM	PM		P	I	SM	PM		C	I	P	I	P	SM	PM		
0– 3	—	—	—	—	—	—	—	—	—	—	2	2	—	—	—	—	—	4	4
4– 7	1	1	—	—	2	—	2	—	—	2	—	3	1	2	—	—	—	6	10
8–11	2	4	2	—	8	2	—	—	—	2	—	2	1	—	—	1	—	4	14
12–15	—	—	3	—	3	—	—	3	—	3	—	—	—	2	1	6	—	9	15
16–19	—	—	2	—	2	—	—	—	—	—	—	—	—	—	—	4	—	4	6
20–23	—	—	1	—	1	—	—	2	—	2	—	—	—	—	—	1	—	1	4
24–27	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	1
28–31	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32–35	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	1	1	2	3
36–39	—	—	—	1	1	—	—	—	1	1	—	—	—	—	—	1	—	1	3
40–43	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	1	1	2
Unknown	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	2	5	7	8
Total	3	5	9	2	19	2	2	5	3	12	2	7	2	4	1	16	7	39	70
Average	6.7	9.0	16.6	38.5	15.4	10.0	5.0	16.4	32.0	17.3	0.0	5.3	8.0	10.5	12.0	18.5	37.0	12.6	14.3

same ratio.

3. *Physical maturity:* Only females were physically mature, and the ratio of physically mature females to sexually mature females are 28.5% in the combined three Schools. The range of body length in physically mature females was 31–36 feet, and the average length of them was 32.8 feet.

4. *Size distribution*: As shown in Table 8, the maximum body length of males

caught was 31 feet, and that of females was 36 feet. The ranges of body lengths were 28–36 feet, 26–33 feet and 18–35 feet for Schools A, B and C, respectively. Two 18 feet long whales contained milk in their stomachs, so that these whales were clearly sucklings. The average body lengths of the whole whales were 31.5 feet, 30.5 feet, 30.7 feet and 30.9 feet for Schools A, B, C and their average.

5. *Age distribution:* The maximum age of males was 10 years and that of females was over 45 years, by means of tooth reading (Table 9). Old whales were not easily identified of their ages because of the wear of a tooth at tip. Two sucklings were both 0 year. The average ages of whales caught were estimated to be 15.4, 17.3, 12.6 and 14.3 years for Schools A, B, C and their average, respectively.

TABLE 10. DEVELOPMENTAL AND REPRODUCTIVE COMPOSITION IN THREE SPERM WHALE SCHOOLS

	School A			School B			School C		
	Males	Females	*	Males	Females	*	Males	Females	*
Calves	—	—	5	—	—	2	2	—	—
Immature	3	5	1	—	2	26	7	4	9
Puberal	—	1	—	2	—		2	1	
Pregnant		5a)	1c)		2			3	
Lactating		5			1			14b)	
Resting		—			5			6b)	
Total	3	16	7	2	10	28	11	28	9

Remarks: *: Number of whales which were not caught, a): One of which was simultaneously lactating, b): One of which was simultaneously ovulating, c): Lost after catch.

6. *Sexual conditions:* The mature females of School A were composed of one puberal, five pregnant (one of which was simultaniously lactating), and five lactating ones, so that there were no resting females. The number of lactating females, six, almost corresponds with the number of calves, five, which were not caught (Table 10). School B had two pregnant, one lactating and five resting females, but I wonder whether these values represent the actual composition of this school or not, for the catch rate was too low. There were one puberal, three pregnant, 14 lactating and six resting females in School C. It will be a questionable point of School C that calves were only two, although we found 14 lactating females. The ratio of each sexual conditions is similar to the figures in November in the Southern Hemisphere as reported by Best (1968).

FORMATION OF SPERM WHALE SCHOOL

I want to offer my hypothesis on the formation of sperm whale school on the basis of the informations mentioned above, previous biological knowledges on sperm whales and ecological knowledges on the formation of school of other kinds of mammals.

I consider that the fundamental form of sperm whale school is " nursery school ". This type of school is composed of mature females and calves which are nursed by mature females. Immature males and females are also nursed by mature females until the time of sexual maturity. The average size of school is estimated to be 27.1 whales, and the half of them will be mature females. A nursery school is supposed to move as a tightly united school as a family for long time. In conclusion, the behavioral foundation of sperm whales will be regarded as a maternal family group.

TABLE 11. REAL AND CALCULATED STRUCTURES OF THE SPERM WHALE SCHOOLS A AND C COMBINED.

	Real		Calculated	
Suckling calves	7 (19)		15 (16)	
Immature	20		28–37	
Puberal	4		2–3	
Pregnant	8	33	8	32
Lactating	19		16	
Resting	6		8	

We have not got a real information yet on the question whether all of immature whales remain in their nursery school after weaning or some of them leave the school. I tried to approach this subject using the data obtained from Schools A and C. The number of whales caught or estimated by developmental stage are shown in Table 11. Mature females excluding those at puberty are 33 in total of Schools A and C. The reproduction cycle of sperm whales was reported to be four years (Ohsumi, 1965; Best, 1968), so that the number of calves which are born from this school will be about eight (33/4) per year. Gestation period of the sperm whale is about 15–16 months, but in September in the North Pacific (when School A was caught; Ohsumi, 1965) and in November in the Southern Hemisphere (when School C was caught; Best, 1968), there will be no foetuses which were fertilized in both the year and the previous year, therefore, the calculated pregnant whales must be eight. This is the same as the actual figure. We have no confirmed value on the natural mortality rate of the sperm whale during calf and immature stages, but if the survival rate during these stages is set up as 0.9–0.85 (which is higher than that in adult stage when the natural mortality coefficient is 0.06–0.07; Ohsumi, 1966; Best, 1970), the number of survival calves and immature whales at each age would be calculated. As lactation period is 24–25 months (Ohsumi, 1965; Best, 1968), the number of sucklings are calculated to be 15. This figure is smaller than the actual lactating females, but more than the actual sucklings. Furthermore, it is almost the same as the number of calculated lactating females, 16. I think the number of calves sighted is fewer than the real number of calves in the school, for counting or recording calves in the waters may be difficult and incomplete, although there remains a doubt that the estimated survival rate may be higher than the true one. However, we would not need to care much about the doubt, because there were 19 lactating females which had functional mammary glands and therefore which were supposed to nurse calves, as Best (1968) studied.

Age at sexual maturity of the sperm whale is considered to be nine years (Ohsumi, 1965), so that the calculated number of immature whales is 28–37 in total excluding sucklings, if survival rate at immature stage is 0.90–0.85. The actual figure of immature whales was 20. If this figure reflects the real phase of schools, a part of immature whales must leave the nursery school after weaning. There are some whale sighting materials as shown in the previous section that smaller whales under 30 feet long make a small school (8.2 whales form this type of school in average). This kind of school may afford proof of the present examination, and will be called as " juvenile school ".

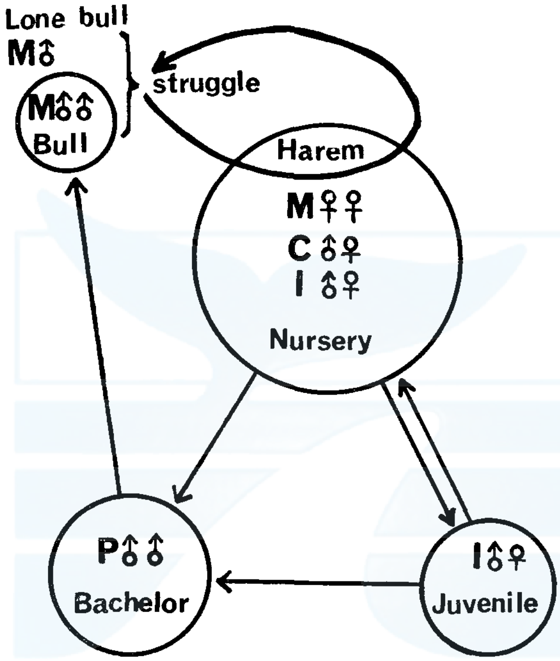


Fig. 5. Types and their relationship of social organization in the sperm whale.
M: mature, I: immature, C: suckling, P: puberal.

After attainment to puberty, all males gradually leave the nursery school. Sexual segregation of male sperm whales was studied by Ohsumi (1966), and there were no males older than 10 years of age in the investigated three Schools, although some males at puberty were found. Males at puberty or bachelors which have left nursery school are considered to form a " bachelor school ". Size of this kind of school is uncertain, but a part of schools which were composed of whales over 30 feet in body length in Table 5 may be regarded as bachelor schools.

Socially mature males or bulls form a small " bull school " or live alone. Most of bulls are considered to live solitary.

Bulls struggle with each other for joinning a nursery school in the breeding season, and winning bull and the nursery school make so-called a " harem ". Tooth scars which are found on the head and back of large males may be the result of struggle at that time.

I think a harem is a temporary formation only in the breeding season, and the harem bull leaves the nursery school by the end of breeding season. School A was caught in September, and the main breeding season ends by that months in the North Pacific (the main season is in April; Ohsumi, 1965). Therefore, it is conceivable that there would be no bull in School A. In Schools B and C bulls were also not found. The main breeding season begines in late November in the Southern Hemisphere (Best, 1968), and the schools were investigated in early November, so that grouping for reproductive activity may not be made on these schools.

NUMBER OF MATURE FEMALES SERVED BY BULL

The main purpose of the present report is to obtain the rate of number of males needed for reproduction of sperm whales. However, result was not directly obtained with the present materials.

The average size of a nursery school was estimated to be 27.1 whales, and the half of the whales which form a nursery school is mature females. If it is reasonable, the mature females of an average nursery school would be 14. If one bull is enough join the typical nursery school in the breeding season as a harem master, the ratio of the number of sexually mature females to a bull will be 14: 1 in average. The age at social maturity has not certainly obtained yet, but it is estimated to be about 25 years (Ohsumi, 1966; Best, 1970). If the natural mortality coefficient of adult stage is 0.06 for the males as same as females, the ratio of stock sizes at initial population level of mature females and socially mature males is calculated into 1: 0.34. Then, the rate of needed bull stock size for reproduction per socially mature male stock size is also calculated into 1: 4.8.

DISCUSSION

In the present report I classified the sperm whale school into the following types:

(1) Nursery school
(2) Harem school
(3) Juvenile school
(4) Bachelor school
(5) Bull school
(6) Lone bull

Bennett (1940)'s grouping of sperm whale schools is basically valid still today as reviewed by Caldwell *et al.* (1966). And Rice (in Caldwell *et al.*, 1966)'s detailed discription of the sperm whale schools is similar with the present report. The fundamental school is a nursery one, and harem school is considered to be formed only in the mating season.

There are many types of social organizations among mammals. The social organization in the sperm whale is resemble to that in the red deer herd. According to Etkin (1964), the red deer herd is matriarchal in organization, and the young all associate with their mother for the first three years. Sexually mature males lose their association with the herd, whereas the females remain with the maternal herd. The mature males live in loosely organized herds separated from the females. In the rut season the male herds break up and the individuals scatter widely. They invade the female territories, round up the hinds, and keep them in harems. Leaderships are exercised by the older females. In contrast to the females herd, no hierarchy or leadership is evident in the male herds.

In the case of nursery school of the sperm whale, older females are considered to have leadership of the school, but it must be need to observe the behavior of the same school for long time for the solution of this existense of leadership in the sperm whale school.

It is interesting but unknown how the bulls join into the nursery school and form " harem ". In the case of the red deer, males display aggressively to other males which try to approach and as necessary, fight to exclude other males from their harem areas (Etkin, 1964). On this connection, it will be one of the proof of fighting among sperm whale bulls that the sperm whale bulls have much scars which are caused with teeth on the head and back, although females and young males have not such scars. If these scars are caused with the fighting among bulls before forming harem, the tooth scars on the male will be one of the features of social maturity of the males.

Social maturity of the sperm whale males is difficult to be estimated. Ohsumi (1966) estimated by means of sexual segregation of the sperm whale that the age of 25 years or body length of 45 feet was suggested to be the age at full maturity when males commenced breeding activity. According to Best (1970), the males reach full sexual maturity at a body length of 44–45 feet and an age of 25–27 years by means of hitological examination of tesetes, and he (1969) also consideres that harem master status is achieved at this stage.

There are some doubts on the assumption that the solitary old males join into the nursery schools and serve for the mature females in breeding. Caldwell *et al.* (1966) note that some whalers believe that solitary males are more or less " out cast ", and most of breeding are done by the younger adult males. Therefore, it is important to investigate the harem master directly. On this connection, Best (1969) shows the size distributions of mature males accompanying female sperm whales. This result does not support the above assumption.

Best (1969) discusses on a very interesting problem from analogy with the Southern elephant seal that the disproportional exploitation of large males will result that the number of bulls per schools would increase so that the smaller animals each controlled fewer females than the larger breeding bulls. It is considerable that the number of females served by a bull in the case of the sperm whale will change with the exploitation of the adult males. Then, we must investigate thouroughly on this important problem, for it is one of the biological parametres on the stock assessment of the sperm whale.

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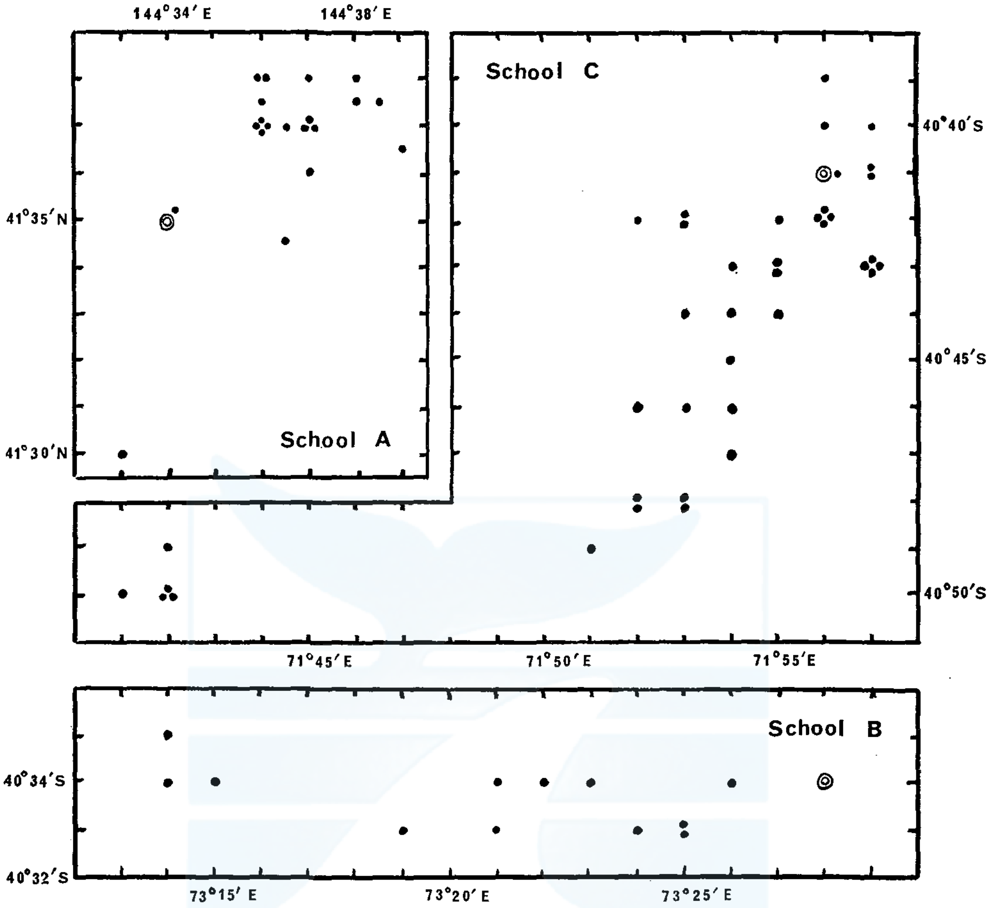

Appendix-fig. 1. Positions found and caught of the sperm whales in the special investigations of school catch.
Double circle: position found, Closed circle: position caught.

APPENDIX TABLE 1. BIOLOGICAL DATA ON THE

Samp. No.	Sex	Body length (m)	Age (years)	Mammary gland		Breadth of uterine cornu (cm)		Foetus		Gonad[b]		V.[c]
				Thickness (cm)	Condition[a]	Left	Right	Sex	Length (cm)	Left	Right	
A 1	F	10.3	34	19.0	L	24	29	None		0-6,	0-2	n
A 2	F	8.6	10	7.0	I	9	9	None		0-0,	0-0	N
A 3	F	9.9	13	9.0	R	38	51	M	108	0-0,	1-2	n
A 4	F	8.8	7	8.5	I	12	12	None		0-0,	0-0	N
A 5	M	8.5	3							0.55,	lost	N
A 6	F	10.3	18	20.0	L	18	18	None		0-3,	0-2	N
A 7	F	9.3	11	10.0	I	9	10	None		0-0,	0-0	N
A 8	F	9.8	18	21.0	L	15	17	None		0-2,	0-2	n
A 9	F	9.7	13	15.0	L	23	23	None		0-1,	0-1	n
A10	M	9.3	8							0.45,	lost	N
A11	F	10.3	22	17.0	L	18	16	None		0-3,	0-3	n
A12	F	10.4	36	8.5	R	21	17	F	51	1-3,	0-4	a
A13	F	10.4	18	14.0	L	30	34	F	80	0-1,	1-1	n
A14	M	8.6	4							0.30,	0.25	N
A15	F	9.1	8	6.0	I	9	9	None		0-0,	0-0	N
A16	F	8.9	10	6.0	I	13	12	None		0-0,	0-1	N
A17	F	9.1	10	7.0	I	12	11	None		0-0,	0-0	N
A18	F	9.3	8	7.0	I	36	18	F	76	1-0,	0-0	N
A19	F	11.1	41	11.0	L	57	45	M	106	1-6,	0-5	A

Remarks: a) L: Lactating, R: Resting, I: Immature.
b) Number of corpora lutea and corpora albicantia in ovary for females and weight of testis (kg) for males.
c) Ossification of column of dorsal vertebrae: N: Clearly not ankylosed, n: Not ankylosed.

SPERM WHALES CAUGHT FROM SCHOOL A

Thickness of blubber (cm)	contents			Body colour	Eruption[d] of teeth		Number of teeth			Time caught	Remarks
	Species	Quantity	Freshness		Lower	Upper	Lower		Upper		
							Left	Right			
8.0		0		—	+	—	22	22	L13	12:10	
9.0	Sq	r	f	—	—	—	27	28	L15	13:05	
10.5		0		—	+	—	20	20	R12	12:20	
8.0	Sq	r	f	B	—	—	25	25	R10+	12:50	
7.0	Sq	r	f	A	—	—	25	26	R14	15:30	
11.5	Sq	r	f	B	+	+	22	22	R13	12:20	Mother
10.0	Sq	r	f	B	—	—	27	27	R11+	12:55	
10.5	Sq	r	f	B	+	—	22	24	R15	12:00	
10.0		0		C	+	—	26	26	L16	12:20	Mother
8.5		0		C	—	—	21	21	L10+	13:10	Large scar on top of head
10.0	Sq	r	ff	A	+	—	Broken		L12	10:35	Mother
9.5		0		C	+	+	Broken		R13+	12:00	
10.0		0		B	+	—	23	23	L13+	12:30	
8.0		0		C	—	—	24	25	R13	14:35	
9.0	Sq	r	f	D	—	—	23	23	R15	14:25	
9.0	Sq	r	f	CD	±	—	22	22	R14+	13:10	
8.5		0		D	±	—	23	22	R14	12:45	
7.5	Sq	r	f	A	—	—	22	22	L11	12:25	
10.0		0		C	+	+	21	21	R14	12:10	

a : Ankylosed, A : Fully ankylosed.

d) + : Erupted, — : Not erupted, ± : Erupting.

e) All whales had nematoda in stomach, and all whales had no external parasites.

APPENDIX TABLE 2. BIOLOGICAL DATA ON THE SPERM WHALES CAUGHT FROM SCHOOL B

Sample No.	Sex	Body length (m)	Age (years)	Mammary gland	Foetus		Gonad	Thickness of blubber (cm)	Stomach contents		Ossification of vertebrae	Time caught	Remarks
					Sex	Length (cm)			Species	Quantity			
B 1	F	9.9	21	R		None	0–4, 0–1	8.5	Sq	rrr		17:40	
B 2	F	7.8	6	I		None	0–0, 0–0	8.0	Sq	rr	n	18:40	
B 3	F	9.8	26	R	F	303	1–3, 0–3	10.5	Sq	rr	A	17:00	
B 4	F	9.7	12	R		None	0–2, 0–1	9.0	Sq	rr	N	18:35	
B 5	F	9.7	20+	R		None	0–6, 0–4	10.0	Sq	r	A	17:25	
B 6	F	8.0	4	I		None	0–0, 0–0	8.0	Sq	r	N	17:30	
B 7	F	10.1	23	R		None	0–8, 0–0	8.5	Sq	r	N	17:05	
B 8	M	9.6	10				0.8, 0.8	10.5	Sq	r	n	18:10	
B 9	F	9.5	35+(1–3)	L		None	0–5, 0–4	8.5	Sq	r	A	16:35	
B 10	M	9.2	10				0.8, 0.8	9.0		0	n	19:05	
B 11	F	9.5	12	R	F	300	1–3, 0–1	7.0	Sq	rr	N	18:30	
B 12	F	9.2	14	R		None	0–1, 0–1+	8.5		0	N	17:15	

Remarks: Symbols are the same as Appendix Table 1.

APPENDIX TABLE 3. BIOLOGICAL DATA ON THE SPERM WHALES CAUTHT FROM SCHOOL C

Sample No.	Sex	Body length (m)	Age (years)	Mammary gland	Foetus		Gonad	Thickness of blubber (cm)	Stomach contents		Ossification of vertebrae	Time caught	Remarks
					Sex	Length (cm)			Species	Quantity			
C 1	F	9.5	17	R	M	339	0–5, 1–0	6.0	Sq	r	N	09:25	*Cyamus* on belly
C 2	F	9.1	15	R		None	0–3, 0–2	4.5	Sq	rrr	N	08:10	
C 3	F	8.9	16	L		None	0–2, 0–1	6.0		0	N	08:30	
C 4	F	10.1	23+	R		None	0–8, 0–3	7.5	Sq	r	A	09:55	
C 5	F	9.3	11	R		None	0–3, 0–2	7.0		0	N	09:40	
C 6	F	9.9	36	R		Unknown	1–2, 0–4	7.5	Sq	r	n	10:15	
C 7	F	8.5	6	R		None	0–0, 0–0	7.0	Sq	r	N	10:00	
C 8	F	9.8	33	L		Unknown	1–2, 0–6	7.5	Sq	r	a	09:40	*Cyamus* on dorsal head

C 9	F	8.9	12	I	F	285	1–0, 0–0	8.0		0	N	11 : 20	
C10	M	5.4	0				0.1, 0.1	5.5	Milk		N	12 : 50	
C11	M	8.0	4+(2–4)				0.3, 0.3	6.5		0	N	11 : 15	
C12	M	7.0	3				0.2, 0.3	7.0		0	N	12 : 10	
C13	M	7.0	4				0.3, 0.3	7.5	Sq	r	N	12 : 25	
C14	M	7.1	5				0.3, 0.3	7.0		0	n	12 : 10	
C15	M	9.0	9				0.3, 0.2	8.0	Sq	r	n	12 : 10	
C16	F	9.3	13	L	None		0–1, 0–0	8.5		0	N	11 : 00	
C17	F	8.9	14	L	None		0–2, 0–2	8.0		0	N	09 : 05	
C18	F	9.7	20	L	None		0–2, 0–1	8.0		0	N	08 : 15	
C19	F	10.4	17	L	None		0–4, 0–0	8.5		0	N	08 : 25	
C20	F	8.2	5	I	None		0–0, 0–0	7.5	Sq	r	n	09 : 05	
C21	F	10.2	38+	L	None		0–3, 0–2	8.0	Sq	r	A	09 : 35	*Conchoderma* on tip of lower jaw
C22	F	9.4	13+	L	None		0–5, 0–4	7.5	Sq	r	a	09 : 40	
C23	M	8.1	9				0.3, 0.4	7.5	Sq	rr	n	12 : 10	
C24	F	9.1	13	L	None		0–3, 0–1	7.5	Sq	r	n	10 : 20	
C25	F	9.6	18	L	None		0–4, 0–1	7.5		0	N	10 : 35	
C26	F	10.0	28+	L	None		0–4, 0–2	8.0		0	n	08 : 30	
C27	M	5.5	0	I			0.2, 0.2	5.0	Milk		N	09 : 15	
C28	F	10.8	20+	L	None		0–4, 0–3	9.5		0	A	10 : 45	
C29	F	10.2	12	I	None		0–1, 0–0	10.0	Sq	r	n	08 : 20	
C30	M	7.0	3				0.3, 0.3	6.0		0	N	11 : 40	
C31	F	10.1	32	L	None		0–3, 0–1	10.0	Sq	r	n	08 : 35	
C32	M	8.0	9				0.4, 0.7	7.5	Sq	rr	N	08 : 30	*Conchoderma* on lower tooth
C33	F	9.4	17+	L	None		0–2, 0–2	8.0	Sq	r	n	08 : 05	
C34	M	8.3	7				0.8, 0.6	8.0	Sq	r	N	08 : 45	
C35	F	8.8	14	R	F	313	1–1, 0–1	7.0		0	n	14 : 10	
C36	F	9.8	14	I	None		0–0, 0–0	7.5	Sq	r	N	14 : 30	
C37	F	9.0	13	I	None		0–0, lost	9.0	Sq	r	n	14 : 20	
C38	F	9.8	19+	R	None		Lost	7.5	Sq	r	A	14 : 05	
C39	F	9.8	45+	R	None		0–4, 0–2	8.0	Sq	rr	A	14 : 20	

Remarks: Symbols are the same as Appendix Table 1.


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INFLUENCE OF CHASING TIME TO STOMACH CONTENTS OF BALEEN AND SPERM WHALES

AKITO KAWAMURA

ABSTRACT

The duration of chasing time by catcher boats which might influence on the fulness of stomach contents of whales was examined on fin, sei, and sperm whales caught in the northern North Pacific during the summer of 1969. Of 895 whales observed only 28 whales (3.6%) vomited out their stomach contents while chasing, and sperm whale vomited most frequently (16.8%) whereas sei and fin whales were 1.1% and 0.78% respectively. The diet of the whales concerned was consisted of boarfish, squid, copepods and euphausiids. It was often observed that the whales likely to vomit out more larger sized foodstuff such as boarfish than smaller one. The amount of stomach contents vomited was negligibly few, and has no significant influences on the amount of stomach contents which have been obtained from carcasses. Most whales (81%) were caught within 40 minutes of chasing, and the number of whales which would vomit out their stomach contents does not always increase in proportion to the prolongation in the duration of chasing time. It was estimated also that the fully repleted stomach of the baleen whales would be almost emptied by digestion within 15 hours or so.

INTRODUCTION

The quantity and its fulness of the stomach contents of baleen whales have long been observed, and a considerable amounts of those knowledges were accumulated in the pelagic and coastal whaling operations (e.g. Collett, 1911–12; Klumov, 1961; Nemoto, 1957, 1966, 1970: Brown, 1968; Gambell, 1968; Kawamura, 1970a). These observations can be considered as one of the very important items in the biological observations of whales to offer basic data for realizing a feeding behavior of whales along with the swarm forming mechanisms of prey organisms such as an estimation of swarm density (Kawamura, 1970b; Omori *et al.*, 1971). In addition, they will give a fundamental material for a nutritional budget between predator and prey animals as Marr (1962) tried to evaluate an approximate estimation of quantitative relationships between *Euphausia superba*, one of a principal food sources of the Antarctic baleen whales, and the feeding of baleen whales.

In the post-war years, on the other hand, the proportional increase of vacant stomachs among the whales caught was reported as Mackintosh (1965) denoted (e.g. Nishiwaki and Oye, 1951; Peters, 1955). Nemoto (1957) pointed out that the actual fulness of first stomach of the North Pacific fin whale in percentage figures has been reduced distinctly in accordance with the prolongation of chasing time of catcher boats, and later, he suggested a possible causative reason on this

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subject (Nemoto, 1959), *i.e.* an awful improvements of fishing effort especially in the greately increased power of modern whalers enabled them to chase the whale more actively rather than stalk so as to the whales can not swim so powerfuly anymore. Hence a possible causative factors which may induce the decrease in the fulness of stomach contents on the whole would be due to a vomit of foodstuff during those long and restless chasing by the whalers though it seems partly due to digestion. The decrease in the quantity of stomach contents in relation to chasing time can be considered to be caused by both vomit and digestion, although there still remains some physiological problems whether such a muscle fatigue is responsible for the vomiting behavior of whales.

In this point of view, the present observations were chiefly focussed on the above mentioned subject to know how much and often the whales actually vomit out their stomach contents by chasing in the recent whaling operations. If the actual amount of stomach contents vomited was negligibly small, it would be needless to take these loss of food into considerations when we measure the whole amount of stomach contents of carcasses. I made a brief analysis on the materials to give some criterion concerning to those " vomit " problems.

MATERIALS

The material used in the present study was compiled by the personnel who belonged to six whale catchers which participated in the North Pacific whaling operations during the summer of 1969. Sending a form to whaling companies, I asked them to fill the following observation items, *i.e.* date, position at which whale caught, time (L.T.) of first sight, beginning time of chasing, time of harpooned, occurrence of vomit, amount and kind of food organisms vomited, chasing speed, and whale species concerned. Season, localities and whale species were not designated beforehand because any of these were not thought likely to give inherent effects on the results.

The whale catchers participated in the observations in the whaling ground were six in all as described below, and I will extend my great appreciations to the whaling companies and all personnel on boad.

Taiyo Gyogyo K.K.	Toshi Maru No. 17 and Toshi Maru No. 18
Nihon Suisan K.K.	Konan Maru No. 25 and Konan Maru No. 26
Kyokuyo Hogei K.K.*	Kyo Maru No. 12 and Kyo Maru No. 15

RESULTS

An outline of observations

The general features of the investigation are summarized in Table 1. In the season of 1969 three Japanese whaling fleets operated in the mid-latitudes of the northern North Pacific, approximately between 40°N and 50°N. It was 0420 hour

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* Present name: K. K. Kyokuyo.

TABLE 1. NUMBER OF WHALES OBSERVED BY SIX CATCHER BOATS WHICH PARTICIPATED IN THE NORTH PACIFIC WHALING OPERATIONS IN 1969.

Fleets		Kyokuyo Maru No. 3		Tonan Maru		Nisshin Maru		
Cather boats participated		Kyo Maru No. 12	Kyo Maru No. 15	Konan Maru No. 25	Konan Maru No. 26	Toshi Maru No. 17	Toshi Maru No. 18	
Duration of operation (day/month)		18/V–25/VI	6/V–18/VIII	19/V–24/VII	24/V–8/VII	16/V–4/VIII	17/V–4/VIII	Total
Sei whale	Vomited	—	—	—	—	1	5	6
	None	22	74	55	102	—	174	427
	Unknown	—	—	15	13	175	6	209
Fin whale	Vomited	—	—	—	—	—	1	1
	None	4	16	25	16	—	24	85
	Unknown	—	—	8	7	28	—	43
Sperm whale	Vomited	—	20	—	—	—	1	21
	None	—	81	—	—	—	23	104

Note: Sperm whale was not observed except Kyo Maru No. 15 and Toshi Maru No. 18.

that the whale was sighted at the most earliest in the morning, and 2105 hour for the latest time of catch. The observations were performed throughout the whole whaling seasons, May to August, and the material can be considered to represent a general results of whaling of this season. The total numbers of fin, sei, and sperm whales concerned to this study were 129, 742, and 125 whales respectively. They were chased at various ship speed but usually it was 17–18 knots in the first of chasing then slowed down to 8–12 knots when the whales were harpooned. The whaling sonar was often used while under chasing. As it is noticed in the results of two Konan Maru and Toshi Maru No. 17, there were considerable number of *unknown* whales. This fact suggests that there was some difficulties in practical observations of whale's vomit from heavily heaving ships. The actual number of whales which leaked out their stomach contents to some extent while under chasing was only 28 whales (or 3.6%) among 895 whales through three whale species concerned. Kyo Maru No. 15, however, observed one fifth (20.0%) of vomited sperm whales. The sperm whale on the whole seems more likely to vomit out the stomach contents (16.8% on an average) than fin (0.78%), or sei (1.1%) whales. It was suggested from those facts that the whales unlikely to vomit their foodstuff so frequently by chasing of whale catchers as to have been thought previously.

Kind of food organisms

Table 2 shows the degree of fulness of the first stomach by the kind of food organisms along with the time of whale caught, which concerns to only whales vomited during chasing. Of 28 whales vomited only 3 whales were caught in the early morning when the degree of fulness of the first stomach is relatively high in general (Nemoto, 1957, 1959; Kawamura, 1970a). It is suggested on the whole that both baleen and sperm whales likely to vomit out their stomach contents much easier when their stomachs are not so fully repleted. However, as it is noticed in the table, the acutual fulness of stomachs in percentage figures as being found later

TABLE 2. TIME OF WHALES CAUGHT AND THE DEGREE OF THE FULNESS OF STOMACH BY THE KIND OF FOOD ORGANISMS

Sei whale						Fin whale		Sperm whale	
Boarfish		Copepoda		Euphausiids		Squid		Squid	
Time of whale caught	Stomach fulness	Time of whale caught	Stomach fulness	Time of whale caught	Stomach fulness	Time of whale caught	Stomach fulness	Time of whale caught	No. of whale observed
1420	rrr	1210	R	0807	r	1110	rr	0610	3
1445	rr							0855	3
1605	rr							1010	2
1820	R							1120	1
								1250	4
								1300	1
								1440	4
								1600	1
								1630	2

Note: Fulness of stomach in percentage figures
R: 75–100 %, rrr: 50–75 %, rr: 25–50 %, r: less than 25 %

by flensing carcasses varied from " r " (less than 25%) to " R " (completely full). There observed no clear trends that well repleted whales do not vomit out the stomach contents much easier but rather moderately repleted whales. It seems difficult to draw any conclusive tendency from these observations, but it can be said that there are no clear relationships between vomiting behavior and the degree of the fulness of whales stomach.

The kind of food organisms found in sei and fin whales was consisted of boarfish (*Pseudopentaceros richardsoni*), *Calanus cristatus*, *Calanus plumchrus*, *Euphausia pacifica*, *Thysanoessa inermis*, and squids. Among these food organisms boarfish and squids are quite large in body size as the diet of baleen whales usually found. As the size of boarfish which was found in the whales stomach was varied 22–32 cm in folk length, its population seems to be consisted of sexualy immature individuals which form a dense swarms in the very surface water during the night (Sengoku, 1970). The sei whale vomited boarfish most frequently than much smaller organisms, *i.e.* copepods or euphausiids. However, the very few instances of vomiting those copepods and euphausiids might be the results partly due to some difficulties to detect the vomit which is accompanied by so small organisms at the rough high sea only by visual observations.

Relationship between chasing time and vomit

Table 3 shows the frequency distribution of the number whales of in relation to the duration of chasing time in 10 minutes intervals. The duration of chasing was represented by the time between beginning of chasing and whale harpooned. There were no sperm whale being reported as *unknown* possibly because the observations for sperm whales on this matter would be much easier than the baleen whales due to larger size of main foodstuff in sperm whales. In the frequency distribution of each whale species by the duration of chasing, 10 percent or more of whales were caught

TABLE 3. OCCURRENCE OF WHALES CONCERNING TO VOMITING BEHAVIOR IN RELATION TO THE DURATION OF CHASING BY CATCHR BOATS.

Duration of chasing (min.)	Sei whale			Fin whale			Sperm whale	
	Vomited	None	Unknown	Vomited	None	Unknown	Vomited	None
9>	3	68	60	—	10	4	5	20
10	1	103	63	1	9	12	4	30
20	1	74	33	—	14	6	6	23
30	—	53	19	—	13	10	1	10
40	—	33	14	—	9	2	1	7
50	—	26	9	—	9	2	1	3
60	—	20	5	—	6	1	1	3
70	—	14	2	—	3	1	—	—
80	—	9	—	—	—	1	—	2
90	—	4	—	—	3	2	1	3
100	—	6	2	—	—	—	1	1
110	1	3	—	—	1	1	—	—
110<	—	15	3	—	6	—	—	2
Total	6	428	210	—	83	42	21	104

within 20 minutes to 30 minutes. These percentage figures decreased steadily in proportion to the prolongation of chasing time. There were only 2.9 percent of whales which were caught after two hours or more of chasing. Sei and sperm whales as they are shown in the table, it is clear that the whales do not always likely to vomit their stomach contents by the longer chasing time, but they vomit rather more frequently by very short duration of chasing time within 20 minutes. This tendency seems to run parallel with the variation in the numbers of whole whale catch (see also Fig. 3).

TABLE 4. AMOUNT OF STOMACH CONTENTS VOMITED.

Whale species	Kind of food	Amount of food vomited
Sei whale	Boarfish	3–15 individuals
Fin whale	Squid	ca. 10 individuals
Sperm whale	Squid	ca. 1 individual

The actual amount of stomach contents which was vomited out into the sea by the whale under chase was negligibly small (Table 4). Even the most heavily vomited cases, the amount was about 15 individuals of boarfish in a sei whale, and 10 squids in a fin whale. From those amount of food organisms vomited, it may be considered that the whales usually do not vomit out any amount of their stomach contents so as to make under-estimate the whole amount of stomach contents which is measured on carcasses later when they are flensed on the deck. Consequently, the duration of chasing time does not seem so responsible for vomiting be havior as to result a significant decrease in the degree of the fulness of first stomach.

Possible cause induces a decrease in the fulness of stomach contents

It is well known fact that the more the whales stomach repleted well the more fresher stomach contents are expected (Nemoto, 1957). The baleen whales likely to

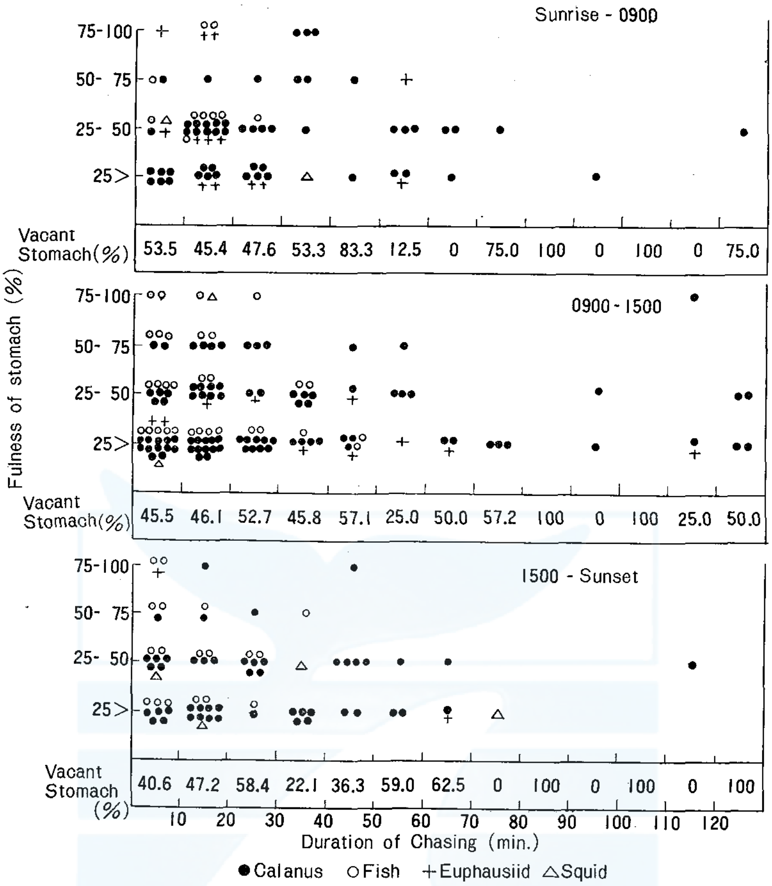

Fig. 1. Relationship between the duration of chasing and the fulness of stomach by the kind of food organisms in sei whale.

become so dull when they took much foods as to be caught easily by a slight chasing. According to Ingebrigtsen (1929), the North Atlantic sei whales with vacant stomach are so shy, and could not be harpooned easily from a reasonable shooting range.

Figs. 1 and 2 demonstrate the relationship between the duration of chasing time and the quantitative degree in the fulness of first stomach. The figures are shown separately in three different time bands which roughly correspond to the general features of daily change of feeding percentages in the North Pacific baleen whales (Nemoto, 1957). The number of sei and fin whales well repleted with food decreased along with the duration of chasing growing longer over 40 minutes regardless the kind of food organisms. The whales with fully repleted stomach were found up to 30 to 40 minutes of chasing time in the morning but they decreased gradually down to less than 10 minutes chasing in the evening. The whales with moderately repleted stomach, on the other hand, were found up to 70 to 80 minutes of chasing time in the morning, then it remarkably prolonged to more than 120 minutes of

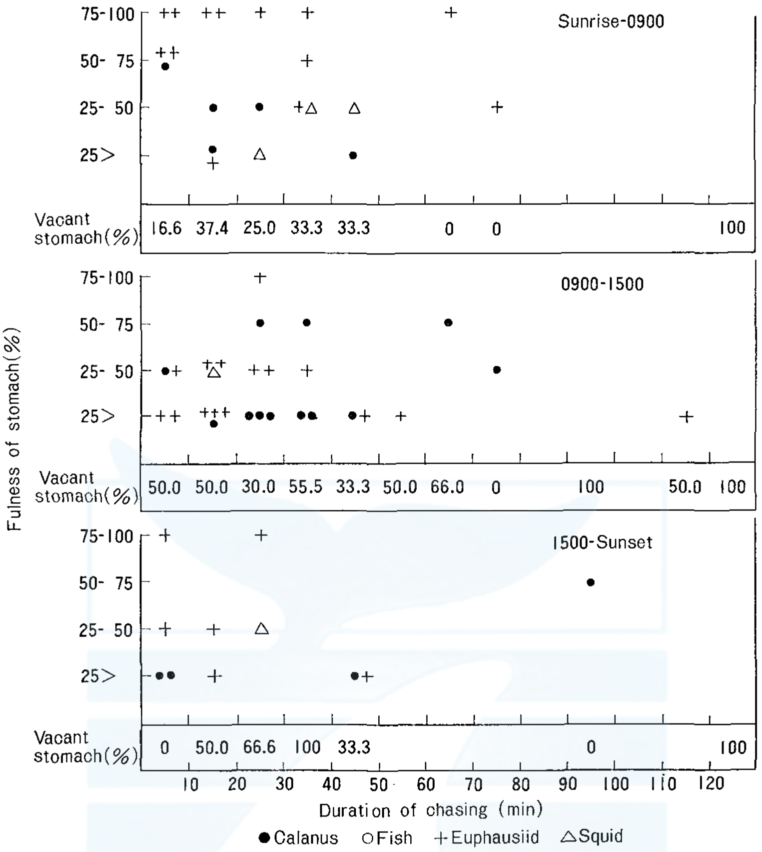

Fig. 2. Relationship between the duration of chasing and the fulness of stomach by the kind of food organisms in fin whale.

chasing during midday until it was shortened again in the evening. There observed to present two different kinds of variation patterns in relation to the daily change of the duration of chasing time and the degree of the fulness of stomach. One of possible explanations for those two different patterns would be found in the proceed of digestion, that is, most whales with moderately repleted stomach in midday might have had been fully repleted in the morning, and such whales would shift to those moderately repleted stomach by digestion toward midday (Fig. 3). The duration of chasing time which corresponds to the degree of the fulness of stomach seems to be shortened from morning toward evening. There observed more or less inversed relationship between the duration of chasing time and the degree of the fulness of first stomach through three different time bands, *i.e.* the more the stomach fully repleted, the more shorter time of chasing is expected. This fact makes us confirm the former observations (Ingebrigtsen, 1929; Nemoto, 1957). So often occurrence of well repleted whales in the morning along with relatively longer duration of chasing time and its hourly change lead to a consideration that

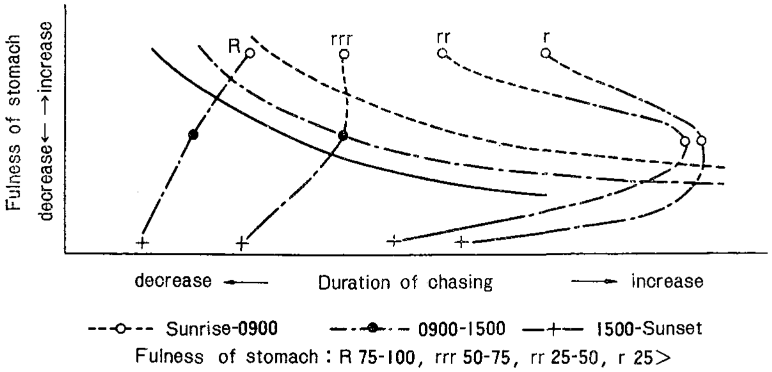

Fig. 3. Schematic curves showing regressive tendency of the fulness of stomach contents along with the duration of chasing in three different time bands. Curves with circles and cross by four different degrees of the fulness of stomach show a shift of those degrees toward lesser direction with the lapse of time from sunrise to sunset.

the most whales take a bulk of foodstuff once a day in the morning.

The copepod and euphausiid foods were found in the whales which were caught after more or less longer duration of chasing than those fed on squid or boarfish. This may be the result partly due to vomit, *i.e.* the large sized food organisms likely to be vomited much easier than the smaller one.

It is also supposed from the figures that an approximate time required for the digestion of foods may be estimated. The whales which carry a well repleted stomach were found most frequently in the morning, and consequently they were found being widely scattered up to the duration of 30 to 40 minutes chasing before 0900 hour. However, these whales were greatly decreased in the late afternoon, and they were only found in 10 to 20 minutes chasing after 1500 hour. This must be a result of decrease in the absolute number of whales which are well repleted with food. If it is assumed that the whales with fully repleted stomach could be expected to be caught by the same difficulties throughout the day, the time being required to catch them would give an index for estimating the speed of digestion. The number of whales with fully repleted stomach reduce down to about 70 percent in the first half of day and then to 50 percent in the afternoon; the relative abundance of whale with fully repleted stomach is considered to have decreased down to about half in a day time. In another words, 25 to 30 percent of their stomach contents would be digested within 5 hours or thereabouts, and these whales should be shifted to the stomach conditions of " r " to " rrr " of degrees. The fully repleted stomach with foods would be emptied in this way by the proceed of digestion in the following 14–15 hours.

DISCUSSION

The aim of this study was to know whether the duration of chasing time by catcher boats has any influences on the decrease in the fulness of first stomach of whales in relation to vomiting behavior induced by the chasing as has been suggested previously (Nemoto, 1957, 1959). The sei, fin, and sperm whales were vomited their stomach contents more or les by the restless chasing of catcher boats. The number of those vomited whales to total catch, and their amount of stomach contents were negligibly few. Relatively larger sized food organisms such as boarfish are considered to be vomited more easier than the foods consisted of copepods or euphausiids. Vomiting of stomach contents was not always occurred along with the longer duration of chasing. Most whales vomited were moderately repleted with foods rather than those fully repleted. So it is supposed that there are no obvious and causal relation between vomiting behavior and degree of the stomach fulness. Accordingly, it is supposed that the decrease in the degree of the fulness of stomach contents which have been found in recent whaling operations does not seem to be explained fully only by those vomiting behavior of whales which might be induced by some improvements in fishing ability of modern whalers. The amounts of stomach contents which has been measured (Nemoto, 1959; Klumov, 1961; Kawamura, 1970a) can be considered reasonable as they are, and there seems little possibility to give a significant under-estimation on to those measurements.

There are one possibility left behind that whales may vomit the stomach contents in the subsurface waters during long restless chasing by catcher boats, since it must be fairly difficult to detect any vomited foodstuff from the boats. The behavior of vomiting a bulk of foodstuff in the subsurface waters, however, presumably causes heavy muscular activity for those whales, and they would not vomit any foodstuff in the subsurface waters since the whales under diving likely to minimize the oxygen consumption as little as possible (Scholander, 1940; Slijper, 1962).

It was observed that the whales concerned were caught or at least in visible during 0420–2105 hours throughout the operations, and accordingly 16–17 hours are the upper most extreme of the duration elapsed as far as Figs. 1 and 2 concerned. From the regressive trends in the number of whales fully repleted with foods as time goes by, it was estimated that 25–30 percent of stomach contents seems to be digested in 5 hours or so, and the fully repleted stomach would be almost emptied in the following 15 hours or thereabouts. It is known in the blue white dolphin (*Stenella caeruleoalba*) and Gill's bottle nosed dolphin (*Tursiops gilli*) which were kept alive in aquarium that their stomachs likely to be emptied within 10 hours or more (Tobayama, personal communication). He also observed that a small instrument swallowed by mistake was excreted after 17 hours. The digesting speed proposed above for baleen whales as found in this study does not seem unreasonable estimations by taking account of the fact that high feeding rates in percentage figures are usually found twice a day with intervals of 10 to 15 hours.

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CONSIDERATION OF DISTRIBUTION AND MIGRATION OF TOOTHED WHALES OFF THE PACIFIC COAST OF JAPAN BASED UPON AERIAL SIGHTING RECORD

TOSHIO KASUYA*

ABSTRACT

The seasonal and annual fluctuation of the sperm whale, Baird's beaked whale, killer whale, the globicephalids, and the dolphins and porpoises in the past 11 years are discussed. The sperm whale is abudant in the northern areas, in summer and autumn seasons. Its density fluctuates with a period of 4 years. The Baird's beaked whale is found only in the northern areas in the season from spring to autumn. The killer whales is relatively abundant in the northern areas.

The globicephalids and the delphinids from the warmer waters migrate into the northern areas in summer season.

INTRODUCTION

In this report the distribution, seasonal movement and annual fluctuation of several toothed whales off the Pacific coast of Japan was discussed basing on the sighting records from airplane. About the larger cetacea caught by commercial whaling, much informations on the distribution and abundance are available from the whaling result, however it is necessary to compare them with the data free from the bias caused by whaling operation or whaling regulation. About the most of the delphinid species the identification of the species was not acomplished, and, in this report, only the seasonal fluctuation of the density or seasonal movement is studied. But this can afford rough information on the seasonal fluctuation of the population of the delphinid species, and can be a first step of the population study of them as one of the members of the marine ecosystem.

MATERIALS AND METHOD OF ANALYSIS

The materials used in this study are the aerial sighting record made in the 11 years from April 1959 to March 1970. It was conducted by The Suisan Koku Co., Ltd. (Fisheries Aviation Co., Ltd.), which has been mostly operating the survey of fishing ground or other oceanographic observation in the adjacent waters of Japan. The aerial sighting of the cetacea was conducted, during the flight for these oceanographic survey, as one of the routine works by Messrs. S. Takashima, Y. Ogawa or S. Tano. The types of used aircrafts were Cessna 175 from 1959 to 1965, and

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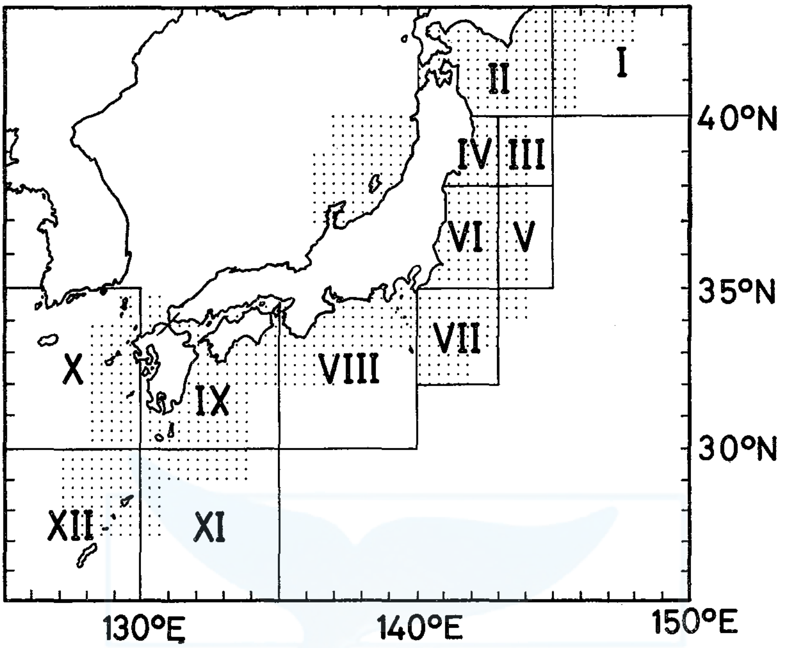

Fig. 1. Section of areas used in this report. Dotted area indicates the approximate range covered by the flight.

TABLE 1. SIGHTING EFFORT SHOWN BY NAUTICAL MILES OF THE DISTANCE FLOWN, FROM APRIL 1959 TO MARCH 1970.

	Month												
Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
I	0	0	0	106	55	0	0	0	1,802	350	0	0	2,313
II	0	0	0	0	756	63	212	2,928	13,984	7,085	552	0	25,580
III	50	0	0	0	455	629	830	913	1,287	1,365	1,315	85	6,929
IV	471	350	19	217	1,513	2,705	3,970	3,686	5,013	6,933	8,533	1,199	34,609
V	55	0	0	36	160	202	71	115	155	123	74	132	1,123
VI	2,585	1,265	1,019	1,165	6,254	6,076	4,344	2,894	3,671	5,123	11,766	6,474	52,636
VII	1,623	572	601	662	1,558	0	326	808	399	486	1,523	1,169	9,727
VIII	1,269	802	1,146	721	1,633	0	488	2,560	371	2,543	2,179	1,186	14,898
IX	845	924	2,061	0	3,197	0	0	1,305	0	0	1,441	1,415	11,188
X	1,237	916	56	0	3,499	0	372	39	0	0	0	0	6,209
XI	808	585	985	0	0	0	0	145	0	0	384	130	3,037
XII	269	669	1,483	0	140	0	48	951	0	0	0	0	3,560
Total	9,302	6,083	7,370	2,907	19,220	9,675	10,661	16,344	26,682	24,008	27,767	11,790	171,809

Cessna 182 from 1965 to 1970. The cruising speed was 100 knot and the height was 500 m, but in case of precise observation it was lowered to 50 m. The flight was operated only on the day with good visibility and the wind less than 7 m/sec. The flown area covered the waters within 90 to 130 miles from the coast (Fig. 1). It is told that efficient observation was made within the range of 15 nautical miles on each sides of the airplane.

In this report, the Japanese coastal waters is divided into 12 areas, and the seasonal and annual fluctuation of the densitly of the whales or schools are discussed in each areas. The density index of the whales are expressed by the number of the whales sighted per 1,000 miles flown, and that of schools by the number of schools encountered per 1,000 miles flown. The speceies of the cetacea are classified, after the flight records, into following 5 categories or sperm whale, Baird's beaked whale, killer whale, Globicephalids whales, and dophins and porpoises.

SPERM WHALE

Distribution

In the Pacific coast of Japan 759 sperm whales, *Physeter catodon*, in 188 schools were sighted during the 11 years. The number of the schools sighted in each 1° squares is shown in Fig. 2. As seen in this figure, the schools sighted distribute from off Ryukyu Islands in the southern waters to the coastal waters of Hokkaido I. in the north. But most of the schools were found at the waters east of 140°E, and the sightings in the south west waters are only 9 occasions which occurred in the coastal area of Ryukyu Islands.

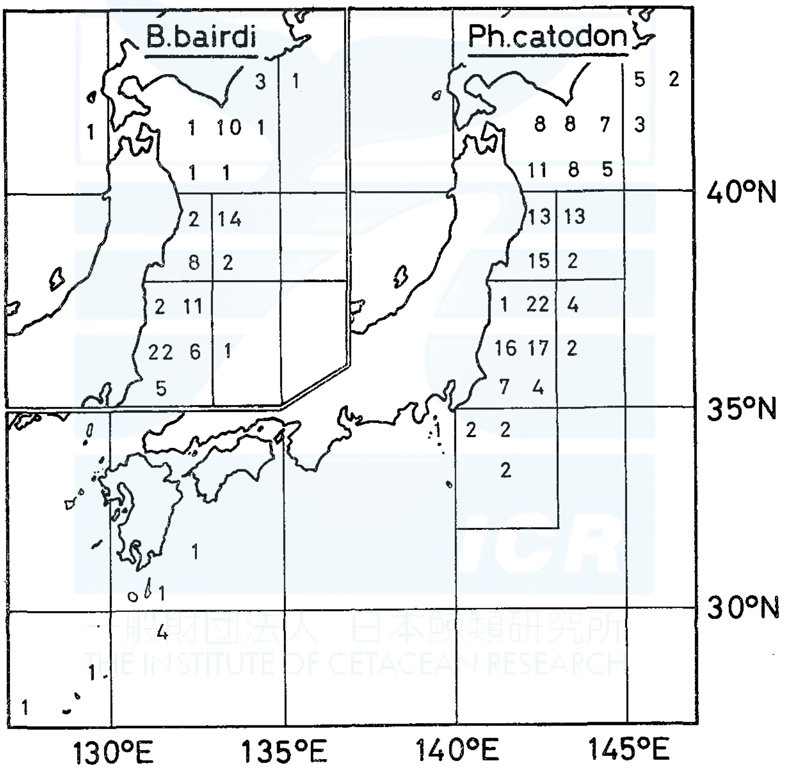

Fig. 2. Number of schools of the Baird's beaked whale and the sperm whale sighted in the 11 years. The number is shown in each 1° squares.

TABLE 2. NUMBER OF SCHOOLS SIGHTED IN RELATION TO THE DISTANCE FROM THE COAST, AREAS I-VI.

1 degree squares	*Ph. catodon*		*B. bairdi*		*O. orca*		Globicephalids		Delphinids	
	no.	%	no.	%	no.	%	no.	%	no.	%
Coastal	27	15.3	18	19.8	4	15.4	87	21.6	263	41.5
Intermediate	117	65.6	64	70.3	17	65.4	260	64.5	327	51.7
Off shore	34	19.1	9	9.9	5	19.2	56	13.9	43	6.8
Total	173	100.0	91	100.0	26	100.0	403	100.0	633	100.0

In the waters off the west coast of Kyushu I. (area X), inspite of sighting effort, there was no sighting. It will indicate that only few sperm whale migrates into this shallow waters.

Table 2 shows the number of schools sighted in relation to the distance from the coast in the areas I-VI. In this table " coastal square " indicates the one degree squares which contain the coast in it, the " intermediate " does those which are bordered by the former square, and the " off shore " does those which don't border on the first or those which do only at the corner. As seen in this table, the number of schools sighted in coastal squares is only 15.7% of the total, and that in off shore squares is 19.3%. This ratio is nearly same with that of killer whale, indicating that the sperm whale distributes in off shore waters compared with the Baird's beaked whale, the Globicephalids, and the dolphins and porpoises. Same phenomenon is seen also in Fig. 3, the density of this species is rather low in the coastal areas IV, VI and VII, and higher in the off shore areas of I, II, III and V.

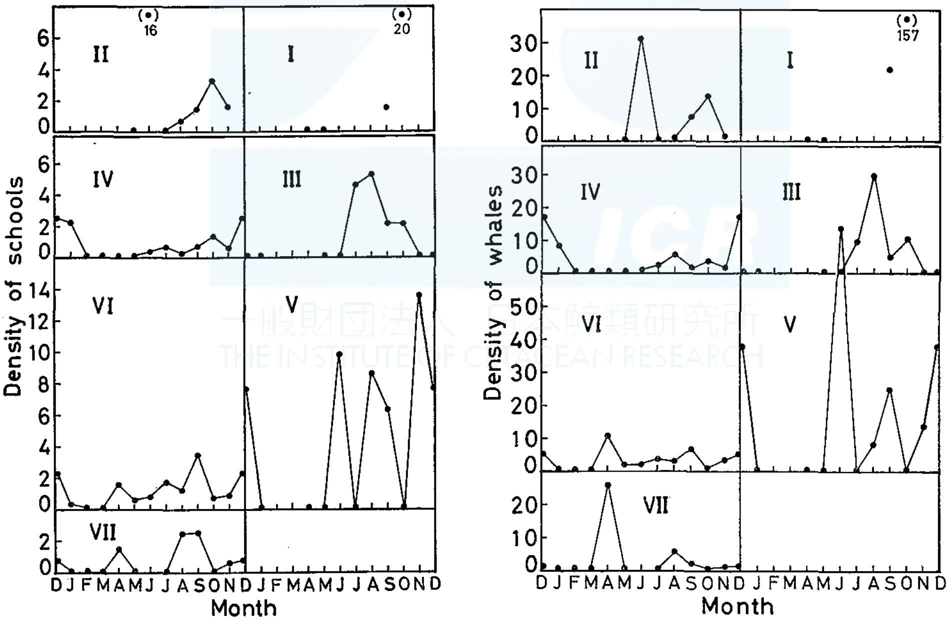

Fig. 3. Monthly fluctuation of the density of the sperm whale (right) and of the schools (left) in areas I–VII.

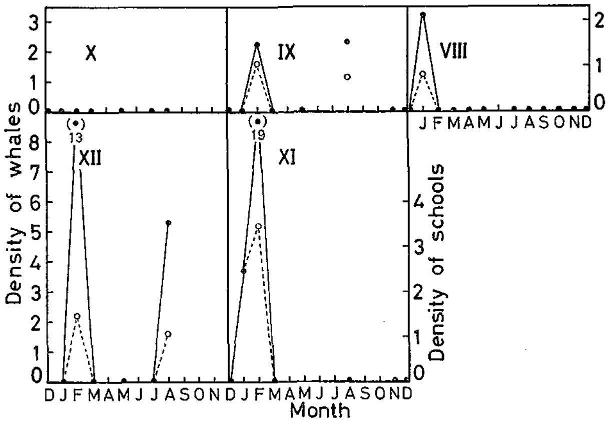

Fig. 4. Monthly fluctuation of the density of the sperm whale (closed circle and solid line) and of the schools (open circle and dotted line) in areas VIII–XII.

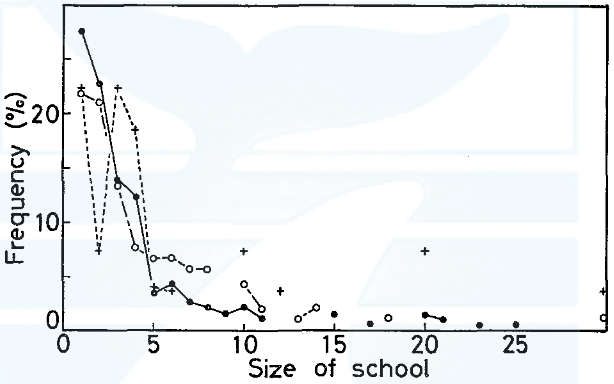

Fig. 5. Frequency distribution of the number of individuals in a school (school size). Closed circle and solid line indicate the sperm whale, open circle and dotted chain the Baird's beaked whale, and cross mark and dotted line the killer whale.

TABLE 3. MONTHLY FLUCTUATION OF THE DENSITY OF SPERM WHALE

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Areas I–II												
no. of schools	—	—	—	0	0	1	0	2	23	30	1	—
no. of whales	—	—	—	0	0	2	0	2	144	156	1	—
density of schools	—	—	—	0	0	(15.9)	0	0.68	1.46	4.03	1.81	—
density of whales	—	—	—	0	0	(31.7)	0	0.68	9.12	21.0	1.81	—
Areas III–VI												
no. of schools	2	0	0	2	4	8	15	11	21	17	17	19
no. of whales	5	0	0	13	15	34	37	60	54	47	65	60
density of schools	0.63	0	0	1.41	0.48	0.83	1.63	1.45	2.07	1.23	0.78	2.41
density of whales	1.58	0	0	9.17	1.79	3.54	4.02	7.89	5.33	3.47	3.00	7.61
Areas VII–XII												
no. of schools	3	4	0	1	0	—	0	4	1	0	1	1
no. of whales	7	22	0	17	0	—	0	13	1	0	2	2
density of schools	1.14	0.90	0	0.64	0	—	0	0.69	1.30	0	0.18	0.26
density of whales	0.49	4.92	0	0.84	0	—	0	2.24	1.30	0	0.35	0.51

Seasonal movement

In the areas VII to XII, though the sighting record is scarce and the seasonal fluctuation of the density is not clear, it can be said that both densities of schools and whales are slightly higher in winter season and lower in summer (Fig. 4 and Table 3). But the winter density is not so high and nearly same with that of the corresponding season in the north eastern warters.

The seasonal fluctuation of the density of this species in the areas I-VI is shown in Fig. 3 and Table 3. In these areas the density is highest in summer season and lowest probably in February and March. The pattern of the seasonal fluctuation of the density is similar with the monthly catch shown by Omura (1950). The high density in June in area II is due to only one sighting, and the sighting data in area V is also very scarce, so they will not correctly indicate the real seasonal fluctuation. If these points are took into consideration, it is possible to say that in areas I and II the density fluctuation has only one peak in October. On the other hand, in areas III–VI, it has two peakes in August and December. The former may correspond to the north bound whales going up to areas I and II, and the latter may do the south bound whales probably comming from areas I and II or more north. The second peak seems to continue till January. The whales sighted in areas IV and VI in April to June may containe the male whales on the way to the north.

School size

The frequency distribution of the school size, or the number of individuals in a school, of the sperm whale is shown in Fig. 4, which is based on 188 schools sighted in areas I-XII. The number of individuals in a school is usually lower estimate of the real number, because some member may be diving. The largest number of the whales in a school is 25, and the mininum is 1. There is a discrepancy of the frequency between the schools with 5 or more members and those with 4 or less. Most of the schools, 77.2% of total number of the schools, are smaller schools and composed of 4 or less individuals, and the number of whales composing these schools is 41.7% of the total number of the whales sighted. The larger schools may be mostly so-called harem schools. As seen in Table 4 the percentage of the small schools, with 4 or less individuals, decreases from July to October and again increases from November to December.

Fig. 6 shows the monthly fluctuation of the mean school size in the areas I-VI. It indicates that the mean school size is high in August and September, and decreases after the summer. This is related with the increase of the percentage of small schools which will be the non-harem schools arriving from the north.

The mean school size in areas VII-XII is 4.3, and no significant difference between the northern areas was found.

Annual fluctuation

Fig. 7 shows the annual fluctuation of the density of this species migrating in areas I to VI. This annual density was calculated combining the above six areas

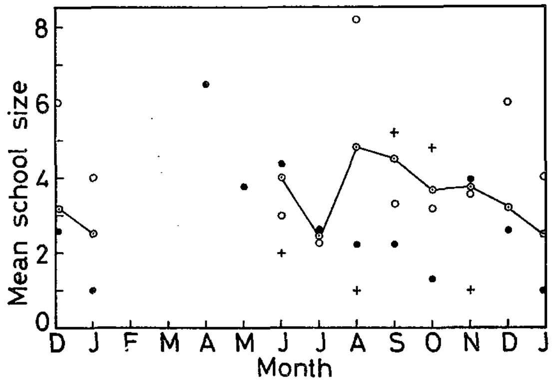

Fig. 6. Monthly fluctuation of the mean school size of the sperm whale. Double circle and solid line indicate the mean school size calculated combining the areas I–VI, cross mark areas I and II, open circle areas III and IV, closed circle areas V and VI.

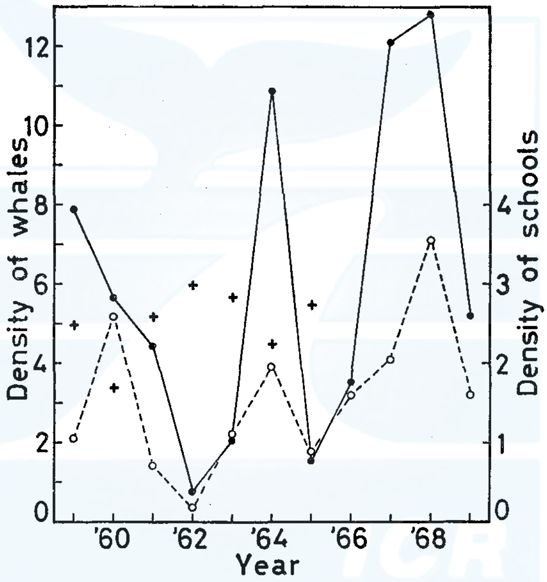

Fig. 7. Annual fluctuation of the density of the sperm whale (closed circle and solid line) and of the school (open circle and dotted line). Areas I–VI and seasons June to October are combined. For the cross mark read the left scale and see the text.

TABLE 4. MONTHLY FLUCTUATION OF THE RATIO OF SMALL SCHOOLS OF SPERM WHALE. "SMALL SCHOOL" INDICATES THE SCHOOL WITH 4 OR LESS INDIVIDUALS.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Area I–VI												
no. of total school	2	0	0	2	4	9	15	13	44	47	18	19
% of small school	100	—	—	50.0	75.0	77.8	93.3	84.6	77.3	63.8	83.4	84.3
Area VII–XII												
no. of total school	3	4	0	1	0	0	0	4	1	0	1	1
% of small school	100	50.0	—	0	—	—	—	75.0	100	—	100	100

and the season from June to October which is considered to be the flourishing migratory season. The annual density fluctuates with the interval of 4 years. Though Omura (1950, Fig 70) did not mention, same periodical fluctuation is seen in the catch of prewar period, but in this case the cycle is 4 or 3 years.

I consider that this fluctuation is resulted by the condensation of the whale in the coastal waters, due to some oceanographic condition. The cross marks in Fig. 7 indicate the distance, measured along 145°E meridian and shown by degree of latitude, between the isothermal lines of 24°C and 18°C surface water temperature in September (Japan Meteorological Agency, 1962–1970). They show the reverse correlation with the annual fluctuation, but further study will be necessary to have a conclusion on this relation.

Another stable trend of the increase of the annual density is observed in Fig. 7, but no explanation was obtained in the present data.

BAIRD'S BEAKED WHALE

Distribution

The distribution of this species, *Berardius bairdi*, off the Pacific coast of Japan is already studied by Omura (1955), and Nishiwaki and Oguro (1971). According to these reports the position of the catch in the Pacific coast is mostly restricted in the east of 139°E or east of the Sagami bay in the north east part of the area VIII, and southern most catch is approximately at 34°N.

In the present data, 414 whales in 91 schools were sighted in areas I-VI, and

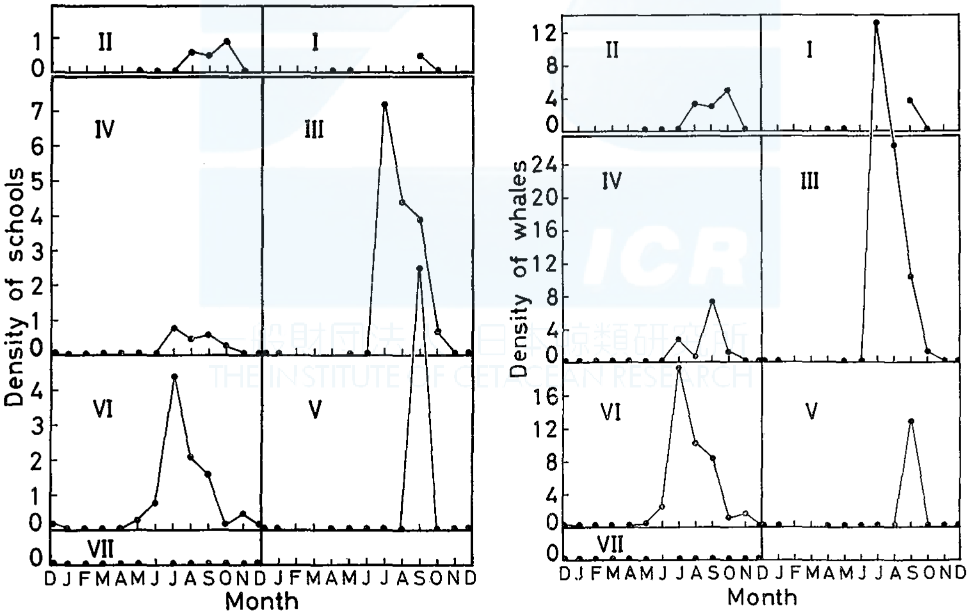

Fig. 8. Monthly fluctuation of the density of the Baird's beaked whale (right) and its schools (left) in areas I–VII.

TABLE 5. RELATIVE ABUNDANCE OF EACH SPECIES OF WHALES. ABUNDANCE IS SHOWN BY THE RATIO TO THE SPERM WHALE.

	I–II		III–VI		VII–XII	
Areas	no. schools	no. whales	no. schools	no. whales	no. schools	no. whales
Sperm whale (no.)	57	305	116	390	15	64
Baird's beaked w.	0.32	0.31	0.63	0.82	0	0
Killer whale	0.053	0.059	0.20	0.35	0.067	0.16
Globicephalids	1.2	3.2	2.9	17	2.1	9.9
Dolphins & porpoises	2.7	110	4.1	250	8.2	280

none in area VII and in the Sagami Bay. This will be due to the few flight in the warmer season in this warters.

As seen in Table 2, the percentage of schools sighted in the coastal squares is higher than that of the sperm and the killer whale. This will indicate that this species comes closer to the coast.

The number of whales sighted is about 30% of that of sperm whale in areas I-II, and 80% in areas III-VI (Table 5).

Seasonal movement

In the summer season the density of this species is higher in areas III and VI, and rather low in the northern three areas I, II and IV.

The monthly fluctuation of the density of this species shows vague bimodal distribution in areas II, III, IV and VI. The first mode arrives at area VI in May, at areas III and IV in July, and at area II in August. The second mode is not so clear as the first, but observed in September and October. The first peak is considered to show the north bound whales, some part of which will go further north beyond the area I, and the second the south bound. Probably the south bound migration will be started at a same season in all the areas, so the second peak will not be conspicuous.

Though some individuals are still found in November and December in the area VI, no individual is found in Janualy to April in all the coastal waters of Japan. In these months they seem to leave the coast of Japan.

School size

The frequency distribution of school size is shown in Fig. 5. The largest school observed was composed of 30 individuals and the smallest with one.

TABLE 6. SOME CHARACTERISTIC FIGURES OF THE SCHOOL SIZE IN AREAS I–XII

Species	Sperm whale	Baird's beaked w.	Killer whale	Globicephalids
Range of school size	1–25	1–30	1–30	1–500
School size at mode	1	1	1–3	1, 5
Mean school size	4.0	4.5	6.0	19.1
School size at the mode of no. of whales	2–4, 20	2–3, 8∼10	4, (?)	16–25

TABLE 7. MONTHLY FLUCTUATION OF THE RATIO OF SMALL SCHOOLS WITH 3 OR LESS INDIVIDUALS IN BAIRD'S BEAKED WHALE

Month	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Areas I–II								
no. of schools	0	0	0	2	8	7	0	—
% of small schools	—	—	—	50.0	50.0	42.8	—	—
Area III–VI								
no. of schools	2	5	28	12	15	4	6	1
% of small schools	100	80.0	50.0	66.7	53.3	50.0	66.7	100

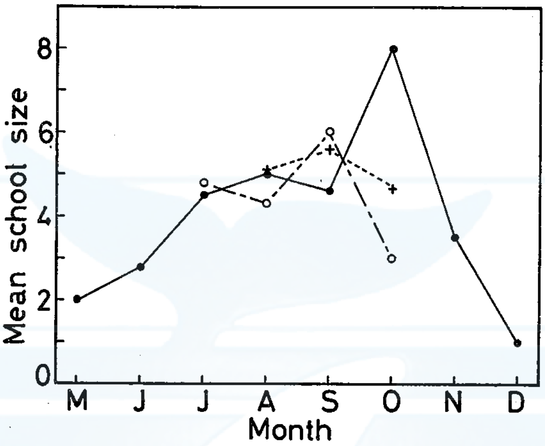

Fig. 9. Monthly fluctuation of the mean school size of the Baird's beaked whale. Cross mark and dotted line indicate the value calcurated combining areas I and II, open circle and dotted chain areas III and IV, and closed circle and solid line areas V and VI.

When the number of the individuals constituting each school size is considered, its distribution have two modes, one at the school size with two individuals and the other at that with 8 or 10 individuals.

As in the case of sperm whale the frequency distribution can be devided into two parts, or the part of the smaller schools and that of the larger. The former schools are composed of 3 or less individuals, and hold 56.0% of the total number of schools and do 22.7% of the total number of the individuals. These informations on the school are shown in Table 6, which shows that the Baird's beaked whale in the adjacent waters of Japan forms relatively larger schools than the sperm whale.

The monthly fluctuation of the percentage of the smaller schools is shown in Table 7, which shows no significant fluctuation. Fig. 9 shows the monthly fluctuation of the mean schools size of this species. It shows slight increase of the mean school size in summer season, but no significant difference between the areas.

Annual fluctuation

Fig. 10 shows the annual fluctuation of the density in the areas I-VI and in the

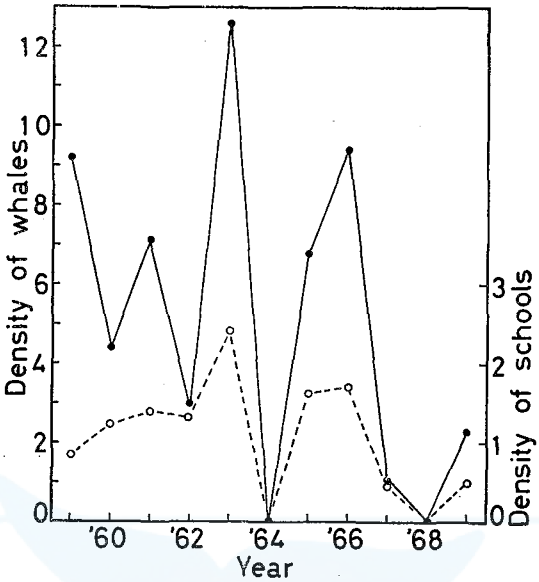

Fig. 10. Annual fluctuation of the density of the Baird's beaked whale (closed circle and solid line) and its schools (open circle and dotted line). Areas I to VI and seasons June to October are combined.

period from June to October, calculated same with the sperm whale. It is interesting to see that the annual fluctuation of the density of this species, especially when the density of whales is compared, shows the reverse correlation with that of the sperm whale. These fluctuation may be, at least in some part, related with some oceanographical conditions.

KILLER WHALE

During the 11 years, only 161 individuals in 27 schools were sighted in the Pacific coast of Japan. As shown in Fig. 17, this species, *Orcinus orca*, distributes in all the area of the Pacific coast of Japan, but most of the sightings were made in the areas I-VI in the months from April to November. Because the killer whale is smaller than the sperm whale or Baird's beaked whale, the ratio of the overlooked schools or individuals may be higher than that in the larger two species. But it seems to be

TABLE 8. MONTHLY FLUCTUATION OF THE DENSITY AND MEAN SCHOOL SIZE OF THE KILLER WHALE IN AREAS I-VI

Month	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
No. of schools	8	0	5	2	1	4	3	3	26
No. of whales	92	0	18	5	1	22	8	5	151
Density of schools	5.25	0	0.52	0.21	0.10	0.15	0.14	0.13	0.25
Density of whales	60.4	0	1.86	0.53	0.10	0.85	0.38	0.23	1.50
Mean school size	1.2	—	3.6	2.5	1.0	5.5	2.7	1.7	5.8

true that the density of this species is far smaller than that of them (Table 5).

The monthly fluctuation of the density of this species is shown in Table 8, but the data is too scarce to get some informations on its migration.

As shown in Fig. 5, Tables 6 and 8, the number of whales in a school ranges from 1 to 30. And the mean school size is 6.0 in areas I-XII, which is larger than the corresponding value of the sperm whale or Baird's beaked whale.

GLOBICEPHALID WHALES

Distribution

The toothed whales other than dolphins and porpoises and the three larger species dealt with in the former chapter are recorded as " smaller whales ". Considering the photographs and information from the crues of the airclaft, the " smaller whales " is thought to indicate mostly the *Globicephala*, *Pseudorca* and *Grampus*. And in this report it is dealt as the globicephalid whales. Though Mr. Takashima says that he has not seen *Ziphius* from the air, it is probable that some smaller ziphioid whales may have included in this category, but the number will be negligible.

As seen in Fig. 11 and Table 2, the globicephalids distributes rather off shore

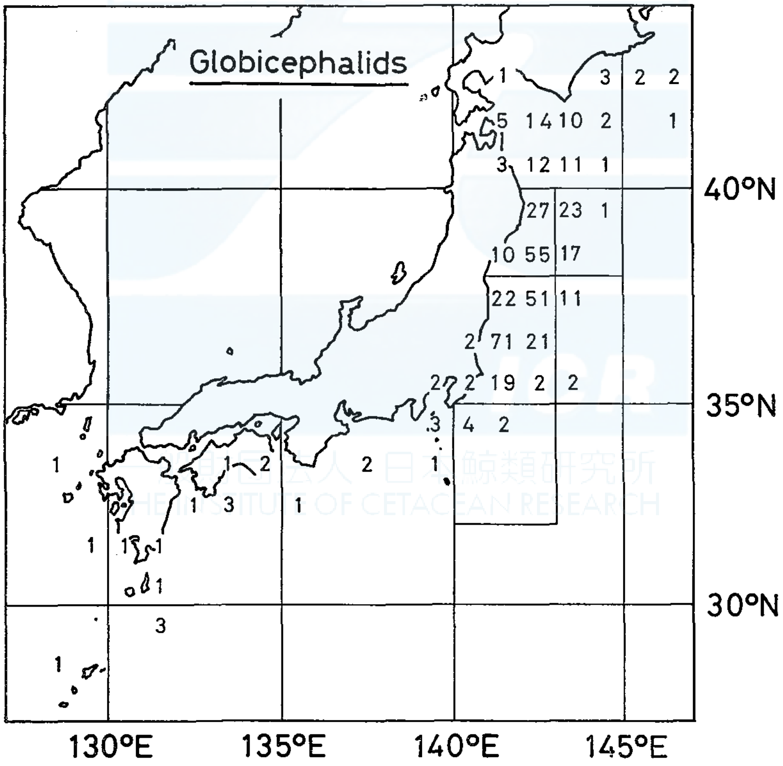

Fig. 11. Number of the globicephalid schools sighted in each 1° squares.

waters, and found in all the waters off the Pacific coast of Japan.

The relative abundance is so high that the number of whales sighted is about 3 to 17 times of that of sperm whales (Table 5).

Seasonal movement

The seasonal fluctuation of the density is shown in Figs. 12 and 13. In the south west waters, generally speaking, the density of the globicephalids is low, but slightly increases in autumn to spring. This is the reverse of the condition found in the north east waters. Same fluctuation is observed also in the Dolphins and porpoises.

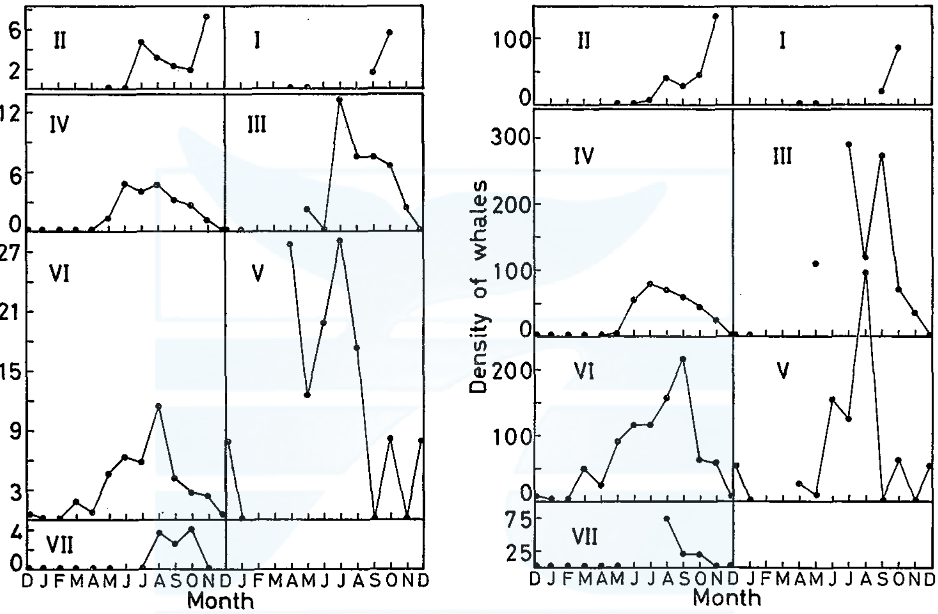

Fig. 12. Monthly fluctuation of the density of the globicephalid whales (right) and their schools (left) in areas I–VII.

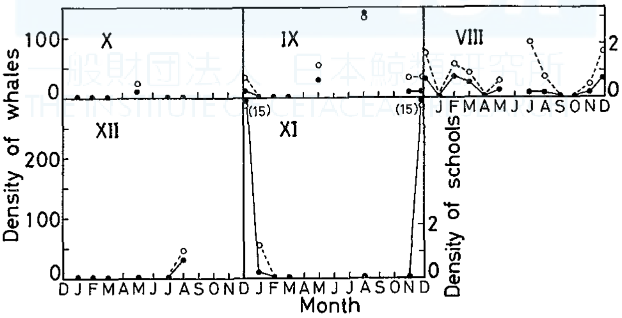

Fig. 13. Monthly fluctuation of the density of the globicephalid whales (closed circle and solid line) and their school (open circle and dotted line) in areas VIII–XII.

This will mean that the globicephalid whales migrate to the southern warters in the winter season. It is reported that, in the winter season, *Pseudorca*, *Grampus* and *Globicephala* migrate in the coastal waters adjacent to the north and west coast of Kyushu, area X, (Fisheries Agency of Japan, 1968, Table 16).

In the north east waters the density of the globicephalids is high in the off shore areas, or the areas III and V, and it is lower in the areas I and II. The density in the areas I-VI increases in summer season, but there is slight delay of the arrival in the northern areas. They arrive at area VI in March, area IV in May, and area II in July. The same tendency is observed also in the off shore areas I, III and V. In the areas III-VII the density decreases in Octorber and December, as the result the duration of high density is longer in the southern areas. This will show the expansion and retreat of range of the distribution.

However, in the areas I and II, the density shows bimodal fluctuation and there is a rapid increase of the density in October and November. It is supposed that this second mode may be composed of some species of the globicephalids, probably *Globicephala*, coming down from the northern warters, and spend the winter season in the northern areas without migrating to far south. According to the sighting records from the ship (Kasuya, unpublished), the range of distribution of *Globicephala sp.* extends from off the coast of Kyushu (areas IX and X) to the waters around 43°N, 177°E via the southern coast of Hokkaido. A part of this northern population might come to the areas I and II in the early winter.

School size

Fig. 14 shows the frequency distribution of the school size of all the globicephalids schools. The number of individuals in a school is a rough estimate, especially in case of large school. The school size ranges from 1 to 500. Its distribution is bimodal, with a mode at 1 and the other at 5. This is a quite unique character observed in the globicephalids schools. But this feature does not seem to be special case seen in the present aerial sighting records. Table 9 shows some characteristic

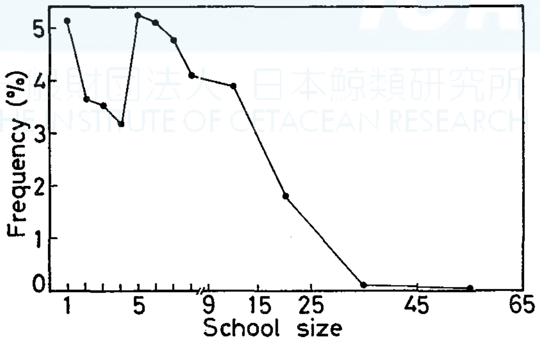

Fig. 14. Frequency distribution of the number of individuals in a schools (school size) of the globicephalid whales sighted in a reas I–XII. The horizontal scale is not in equal interval.

TABLE 9. SCHOOLS OF SOME GLOBICEPHALID WHALES OBSERVED ON THE SHIP

Species	*Globicephala* sp.	*Pseudorca*	*Grampus*
Range of school size	1-100	2-200	3-25
School size at mode	1, 10	—	—
Mean school size	19.6	55.0	11.3
No. of sample	30	6	6

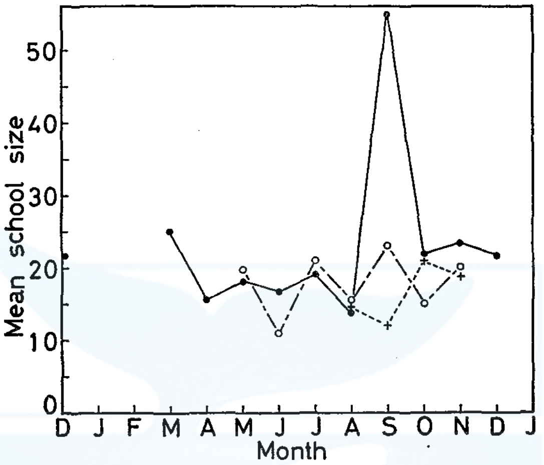

Fig. 15. Monthly fluctuation of the mean school size of the globicephalid whales. For marks see Fig. 9.

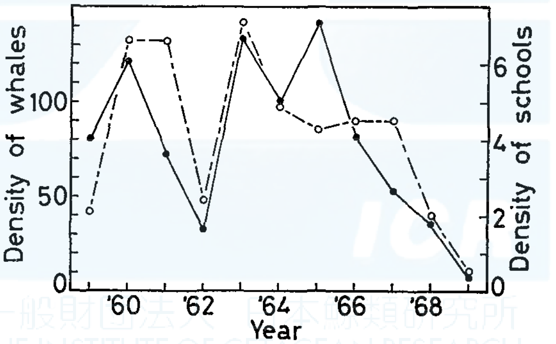

Fig. 16. Annual fluctuation of the density of globicephalid whales (closed circle and slid line) and their schools (open circle and dotted line). Areas I to VI, and seasons June to October are combined.

figures of school size of three globicephalid species in the north Pacific. These datum were cited from Nemoto *et al* (1966), Nishiwaki (1967), Kawamura and Kureha (1970) and Kasuya *et al* (unpublished) which are all obtained from the sighting on the research vessels. Several characters of the school, especially those of *Globicephala* sp. coincides with the bimodal distribution obtained from the aerial sightings (Table 6).

Fig. 15 shows the monthly fluctuation of the mean school size in areas I-VI. It shows slight increase in the Autumn, but no significant difference between the areas. The mean school size in areas VII-XII of all seasons is 20.5. So it can be concluded that there is no significant difference of the mean school size between the areas in the north and the south.

Annual fluctuation

Fig. 16 shows the annual fluctuation of the density of the globicephalid species in areas I-VI. It was calcurated by the same method used in the case of the sperm whale. The density does not show periodical fluctuation as in the case of the sperm and Baird's beaked whales.

DOLPHINS AND PORPOISES

Distribution

In case of the dolphins and porpoises, only the date, locality, size of the school were recorded, and no specification was recorded except few cases. The size of school was grouped into three categories of the " large ", " middle " and " small ". The large school is composed of estimatedly more than 300 individuals, the middle from 50 to 300, and the small less than 50 individuals.

The total number of the sighted large, middle and small schools are 121, 315 and 321 respectively. They are shown in Fig. 17 according to the locality and the school size.

As seen in Table 2, the ratio of the number of schools sighted in the coastal waters is about two times higher than the case of other species. This indicates that the dolphins and porpoises are rather coastal species.

Seasonal movement

In areas II, IV and VI monthly fluctuation of the density is bimodal with spring and autumn peaks. Among these three areas, the spring mode arrives earlier and finishes later in the southern area than the northern one. The autumn mode is conspicuous and arrives earlier in the area II, but appears late and inconspicuous in area VI.

In the area VI, the spring mode attains the peak in May or June, and is characterized by the high ratio of middle and small schools, however, autumn mode is peculiar in the decrease of them. The density of the large school is relatively stable all the year round. As the result, the percentage of the large school is highest in August.

In area IV, though the density in January to April is not available, the spring mode attaines the peak in June and July about one month later than area VI. In area II the spring mode is restricted only in June and July.

The autumn mode in area II begins in September, area IV in October, and area VI probably in November. The lowest density between the two peaks in area

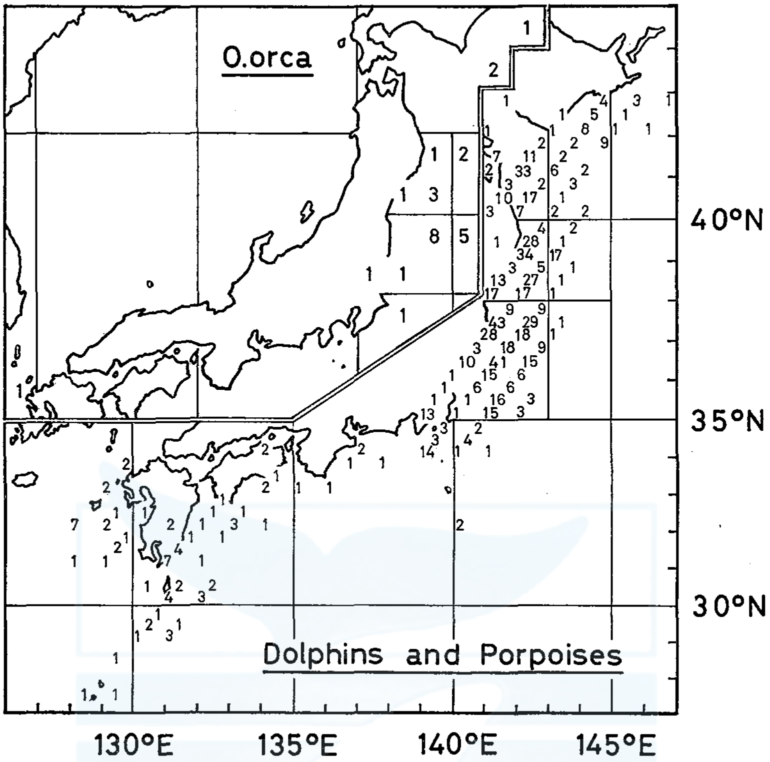

Fig. 17. Number of the schools of the killer whale, and that of dolphins and porpoises sighted in each 1° squares. For the dolphins and porpoises number of large school (upper right), middle school (middle), and small school (lower left) are shown separately.

II is observed in August, in area IV in September, and in area VI probably in October.

In area VII, present data suggests a peak in November and December, but the spring mode was not indicated because of the scarecity of the flight. In other southern areas, area VIII-XII, monthly fluctuation of the density has one mode in the months from January to March or April.

The above features of the density fluctuation suggest that the spring mode in areas II, IV and VI may be composed of the delphinid species from warmer waters. They, in the summer, will extend the range of distribution up to the area II. Then, in the August they start the retreat to the south, passing the area VII and north east part of area VIII in November and December, and may arrive in the west part of areas VIII and in area IX in January and February.

The distribution of the subtropical or tropical delphind species in area VI is indicated by the catch of *Stenella attenuata* at Onahama (36°56′N, 139°55′E) in summer season (S. Uchida, personal communication). The migration of this species is also seen in the fishing result at Sagami Bay (north east part of area VIII)

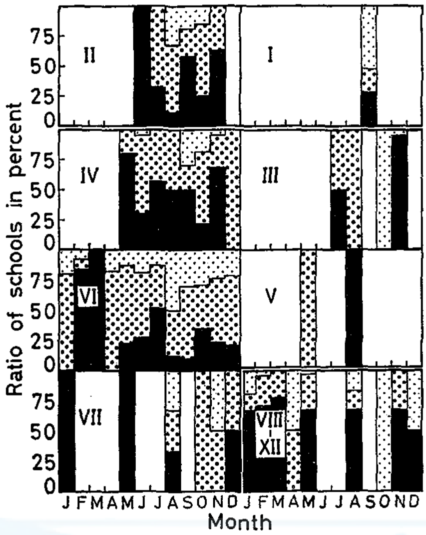

Fig. 18. Monthly fluctuation of the ratio of the number of schools of each sizes in the dolphins and porpoises. Black square indicates the density of the small school, square with larger spots the density of the middle school, and square with smaller spots the density of the large school.

TABLE 10. NUMBER OF *PHOCAENOIDES* SPP. BROUGHT TO KAMAISHI FISHING HARBOR**

Month	Jan.	Feb.	Mar.	Apr.	May
1969*	76	458	89	31	0
1970	85	239	351	109	1
Total	161	697	440	140	1

* calculated from the weight data in 1970. ** approx. 39°16′N 141°54′E.

TABLE 11. RATIO OF EACH SCHOOL SIZE OF THE DELPHINIDS IN ACCORDANCE WITH DISTANCE FROM THE COAST, AREAS I-VI

	Coastal		Intermediate		Off shore	
School size	no.	%	no.	%	no.	%
Large	38	14.4	57	17.4	10	23.2
Middle	122	46.5	143	43.8	20	46.5
Small	103	39.1	127	38.8	13	30.3
Total	263	100.0	327	100.0	43	100.0

in late October to early November before the arrival of *St. caeruleoalba* in November and December (Tobayama, 1969). These two species of *Stenella* had been caught at the Suruga Bay, in the north east part of area VIII and west of the Sagami Bay, in the season from May to July (Nishiwaki and Yagi, 1954; Nishiwaki 1965).

In the areas IX, and the west par of area VIII, *Tursiops* and *Stenella caeruleoalba* are known in all the year round. The concentration of *Legenorhynchus* is seen in winter season at the north east part of area X.

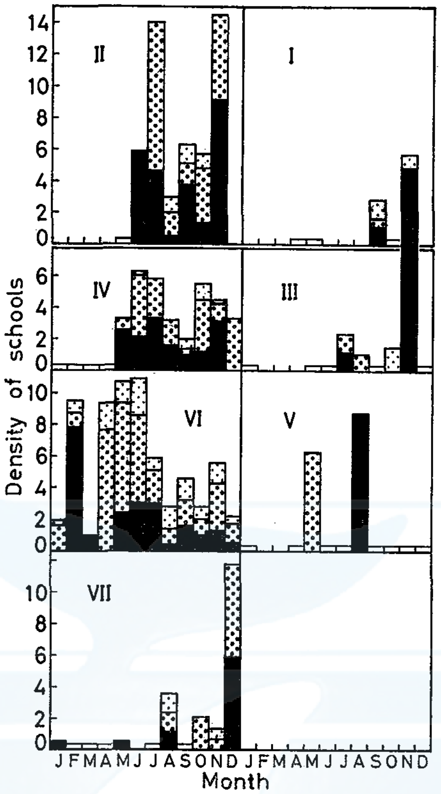

Fig. 19. Monthly fluctuation of the density of the schools of the dolphins and porpoises in areas I–VII. White small squares on the horizontal scale indicate no sighting in spite of the flight. Other marks are same with Fig. 18.

Phocaenoides and *Lissodelphis* are considered to be the species in the colder waters. In areas III, IV and VI, these species are sighted only in the season from September to June. The presence of *Phocaenoides* in winter and its decrease in April to May is also seen in the selling record in Kamaishi fish market (Table 10). In March and April *Lagenorhynchus*, which is considered to live in temperate warter's, migrates in area VI, in July *Tursiops* and *Lagenorhynchus* in area IV, and in September *Phocaenoides* appears again in this area. But some *Phocaenoides* seems to stay in the colder waters adjacent to Hokkaido coast north of 42°N. (Nemoto *et al* 1966; Nishiwaki 1967; Kasuya unpublished).

These informations also suggest the alternations of the delphinids fauna in areas II, IV and VI in June and September.

School size

Fig. 18 shows the monthly fluctuation of the ratio of the schools of three sizes. In areas VIII-XII, the ratio of large, middle and small schools, in the whole year, is 11.5, 23.0 and 65.5% respectively, and the percentage of the small school is slightly higher than that in the northern areas.

In the northern areas the school size changes by the distance from the coast and by the season. Table 11 shows the ratio of the sizes of the schools in accordance with the distance from the coast (for explanation see Table 2). The large school seems to frequent in the off shore waters and the small school in the coastal.

In areas II and IV, the large school is found only in the months from August to October. These large schools seems to be formed on the way to south bound migration by some species in the warmer or colder waters. But there may arise a question whether the low density of schools in this season is due to the annexation of several small or middle schools. To check this problem, the weighted density index is calculated for areas II, IV and VI (Table 12), summing the weighted density index of each school size. The weight of 1, 6 and 30 were used tentatively for small, middle and large schools, assuming the mean school sizes 25, 150 and 750 respectively. But there is still observed the same spring and autumn modes, this will suggests that these two modes are due to the real fluctuation of the number of individuals in that waters.

TABLE 12. WEIGHTED DENSITY INDEX OF THE SCHOOLS OF DOLPHINS AND PORPOISES

Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
II	—	—	—	—	0	5.9	*61.3*	41.2	*48.7*	*47.3*	41.6	—
IV	0	0	0	0	6.6	*42.8*	*18.4*	11.4	21.4	*51.4*	17.0	20.0
VI	21.0	36.4	1.0	*98.0*	*83.0*	*105.6*	36.1	*48.0*	*52.2*	30.3	*57.2*	21.7

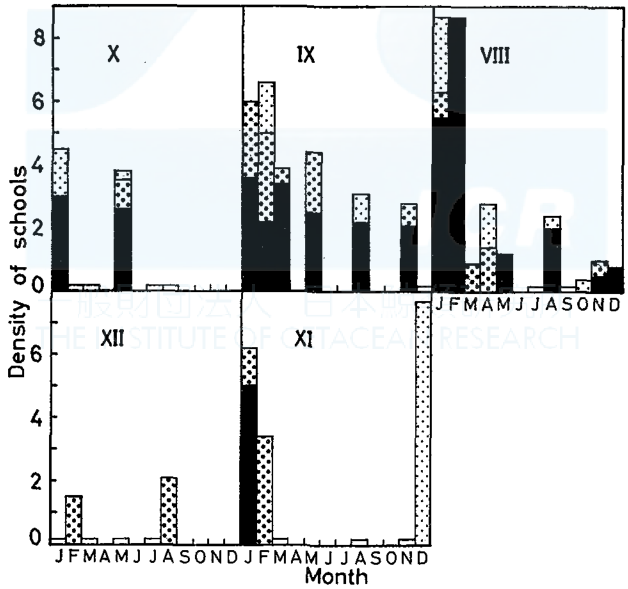

Fig. 20. Monthly fluctuation of the density of schools of the dolphins and porpoises in areas VIII–XII. Marks are same with Fig. 19.

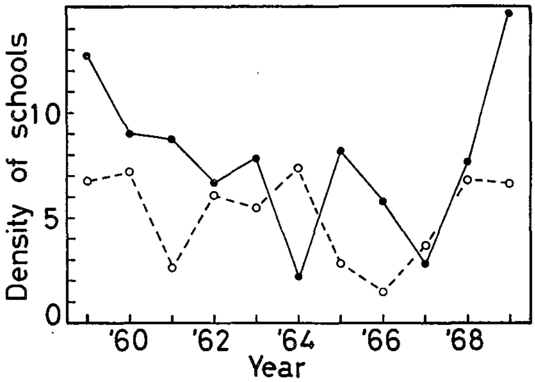

Fig. 21. Annual fluctuation of density of schools of the dolphins and porposises, areas from I to VI are combined. Closed circle and solid line indicate the season from April to July, and open circle and dotted line from September to December.

Using mean school sizes assumed in the above, the relative abundance of the number of individuals of dolphins and porpoises are calcurated in Table 9.

Annual fluctuation

Fig. 21 shows the annual fluctuation of density of the schools in areas I-VI. For the calculation of the density of the spring fauna, number of schools and the flight distance in the period from April to July are used, and for the autumn those from September to December. Though there will be remaining members of the autumn school in Janruay to March, it was ignored because of the absence of reliable density index.

The annual fluctuation of the autumn school is smaller and the density is more stable, however, that of spring school seems to show a long term fluctuation with the cycle of 10 years.

The correlation of the densities of both spring and autumn schools is not observed.

SUMMARY

1. The relative abundance of the species varies according to the season and locality. The ratio of the numbers of the sperm whale, the Baird's beaked whale, the killer whale, the globicephalids, and dolphins and porpoises sighted in the areas I-VI in past 11 years is 1: 0.60: 0.22: 11: 180 respectively, and that of number of schools is 1: 0.51: 0.15: 2.3: 3.6 respectively.
2. The affinity of the cetacea for the coast differes by species, and it decreases in the following order; the dolphins and porpoises, the globicephalids, the Baird's beaked whale, the killer whale, and the sperm whale.
3. Though the mean school size changes by species, locality and season, generally speaking, it increases in the order of the sperm whale, the Baird's beaked whale, the

killer whale, the globicephalids, and the dolphins and porpoises. The large mean school size of the latter species is resulted in both the increase of maximum size of the school and the decrease of the frequency of small sized schools.

4. The density of the sperm whale is higher in the northern areas than in the southwest areas. Most of the schools, probably with females, migrates up to off the coast of Hokkaido in summer and return to the south in autumn and winter. The density of this species in the northern areas fluctuates with the cycle of 4 years.
5. The Baird's beaked whale, off the Pacific coast of Japan, distributes mainly in the waters east of 139°E. It arrives, in the spring, off the Boso Peninsula, migrating in summer to the north beyond Hokkaido, and comes back to the south in winter. The wintering place will not be in the Japanese coastal waters. The annual fluctuation of the density shows the reverse correlation with that of the sperm whale.
6. The killer whale was sighted mostly in the northern waters.
7. The density of the globicephalids is higher in northern waters. In the summer, the range of high density extend to the north and retreats in winter. But it is suggested the existence of some population migrating, in autumn, from the north to the waters off the coast of Hokkaido and probably stay there in the winter.
8. From the density fluctuation of the dolphins and porpoises, it is suggested that species from the warmer waters seems to go up to the waters off the coast of Hokkaido in spring and summer season, on the other hand, those from the colder waters come down as far as area VI in autumn and winter season. The fluctuation of annual density indices of the both groups are independent and the former may show a fluctuation with the cycle of about 10 years.

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Greatest thanks are due to Mr. S. Takashima of Suisan Koku Co., Ltd. who kindly offered me the privilege to analyse the flight records and to reffer the aerial photographs of the cetacea. Thanks are also due to The Asahi Shinbun for offering the photograph of *Neophocaena* in Tokyo Bay.

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EXPLANATION OF PLATES

All the photographs, except Plate IV Fig. 3, are offered by courtesy of Suisan Koku Co., Ltd., Kojimachi, Tokyo, and the copyright belongs to it.

PLATE I

Fig. 1. A school of 21 sperm whales. 2 calves are seen by the mothers in the right sub-school. 41°35′N, 144°50′E, 28 Sept. 1967.

Fig. 2. A school of 5 sperm whales, probably all males. 40°40′N, 142°30′E, 24 Dec. 1960.

Fig. 3. A school of 10 *Pseudorca crassidens*. 33°40′N, 129°40′E, 27 Jan. 1968.

PLATE II

Fig. 1. A school of 12 Baird's beaked whales. 37°20′N, 142°40′E, 1 Aug. 1958.

Fig. 2. A school of 2 Baird's beaked whales. Off Cape Shioyazaki (37°00′N, 141°00′E), 16 May 1958.

Fig. 3. A small school of *Lagenorhynchus obliquidens*. 32°40′E, 128°20′E, 28 Jan. 1968.

PLATE III

Fig. 1. A school of *Globicephala macrorhyncha*. 37°20′N, 142°40′E, 14 June 1966.

Fig. 2. A school of *Globicephala macrorhyncha*. 42°00′N, 143°40′E, 12 Sept. 1961.

PLATE IV

Fig. 1. A large school of *Delphinus delphis*. 41°50′N, 141°50′E, 19 Sept. 1968.

Fig. 2. A school of 17 *Tursiops gilli*. 35°05′N, 139°20′E, 31 Aug. 1970.

Fig. 3. A school of 6 *Neophocaena phocaenoides*. 35°25′N, 139°50′E (by courtesy of Asahi Shinbun, Tokyo).

PLATE V

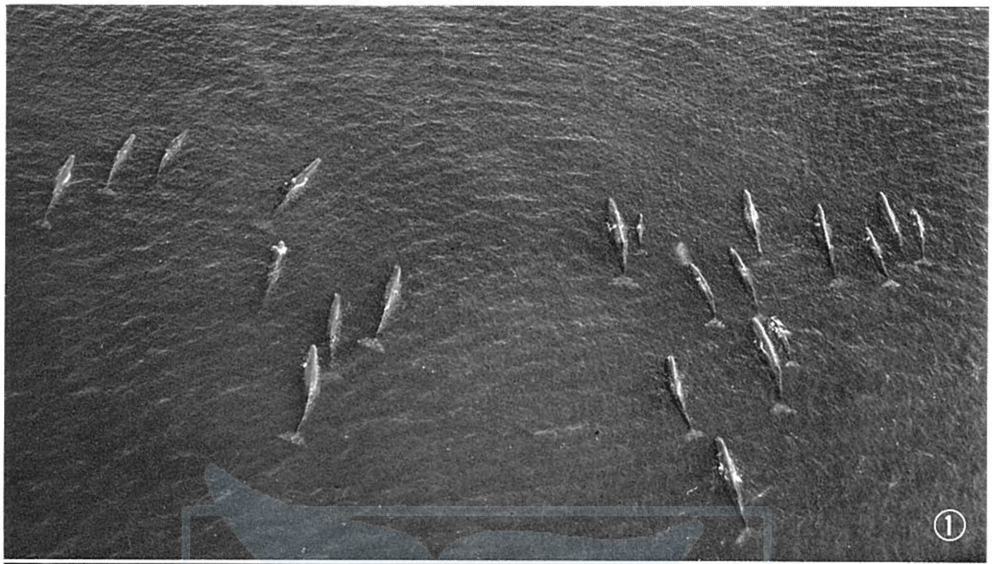
Fig. 1. A middle school of *Lissodelphis borealis*. 35°50′N, 141°20′E, 18 May 1958.

Fig. 2. A large school of *Lissodelphis borealis*. 36°20′N, 141°50′E, 6 Apr. 1960.

PLATE VI

Fig. 1. *Stenella caeruleoalba* attacking mackerel school. 35°14′N, 139°21′N, 6 Feb. 1970.

Fig. 2. A school of 7 *Grampus griseus*. 37°20′N, 142°05′E, 15 July 1963.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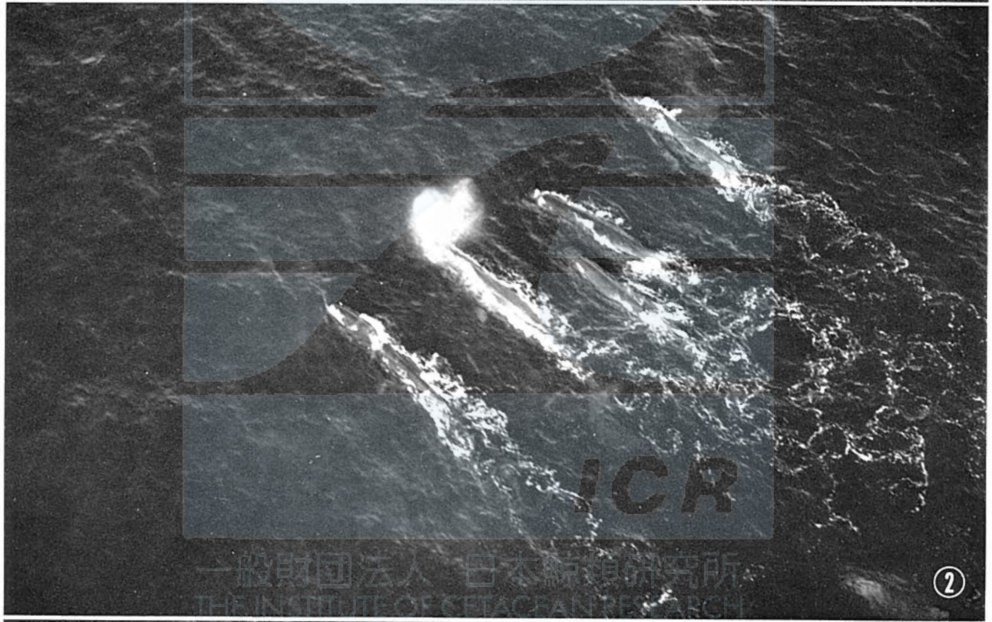
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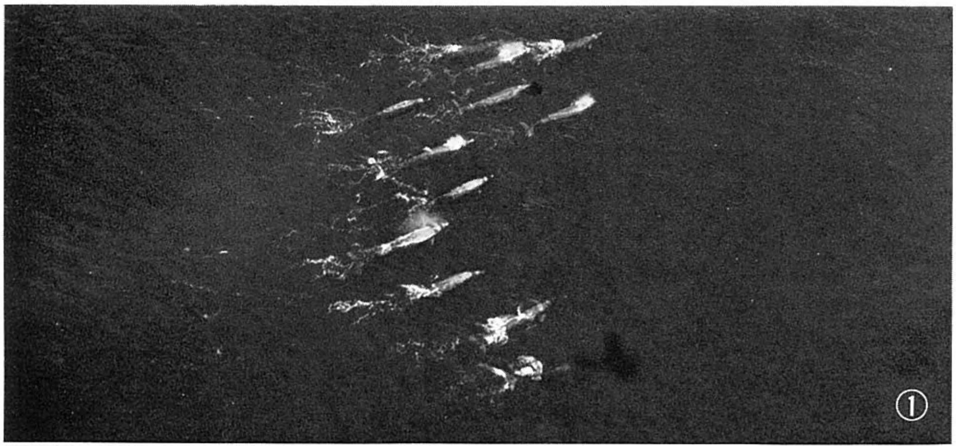
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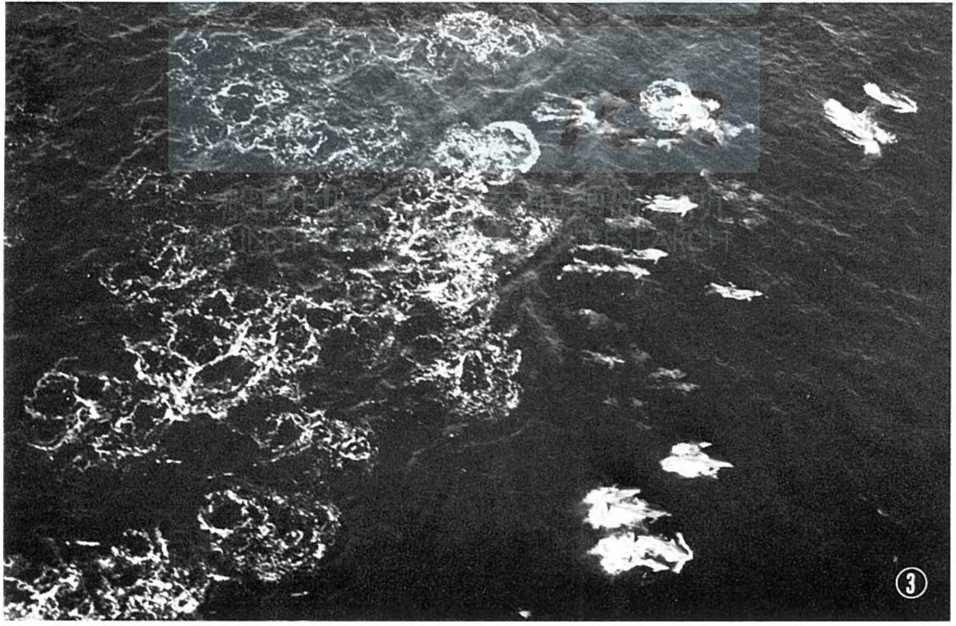
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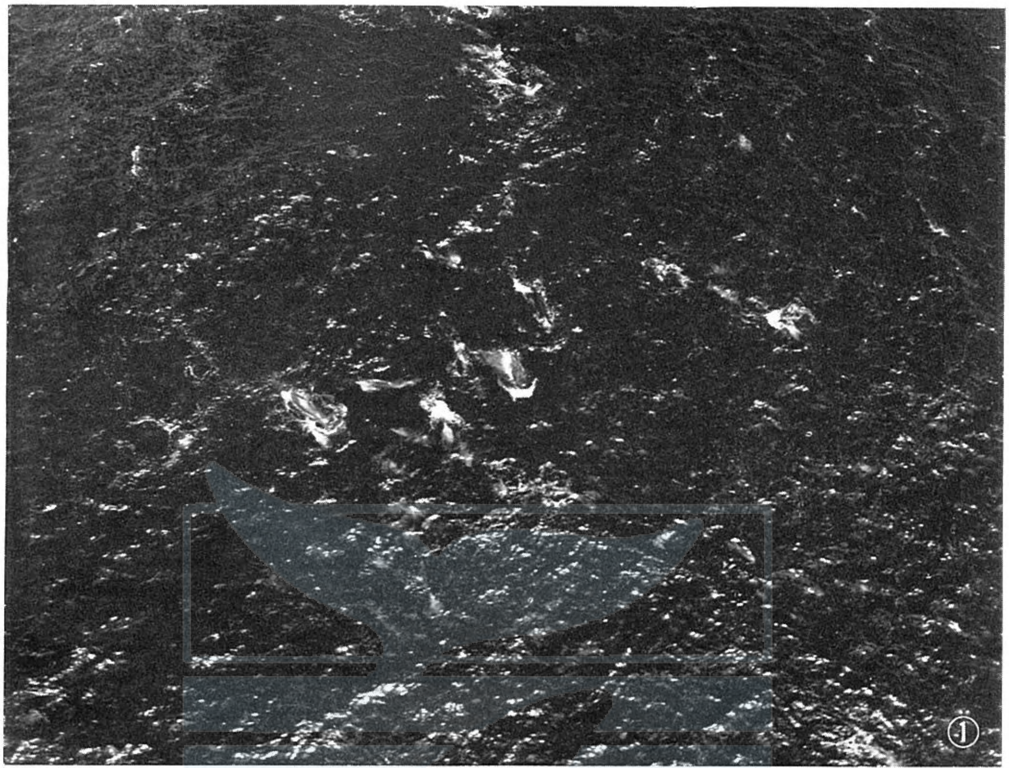

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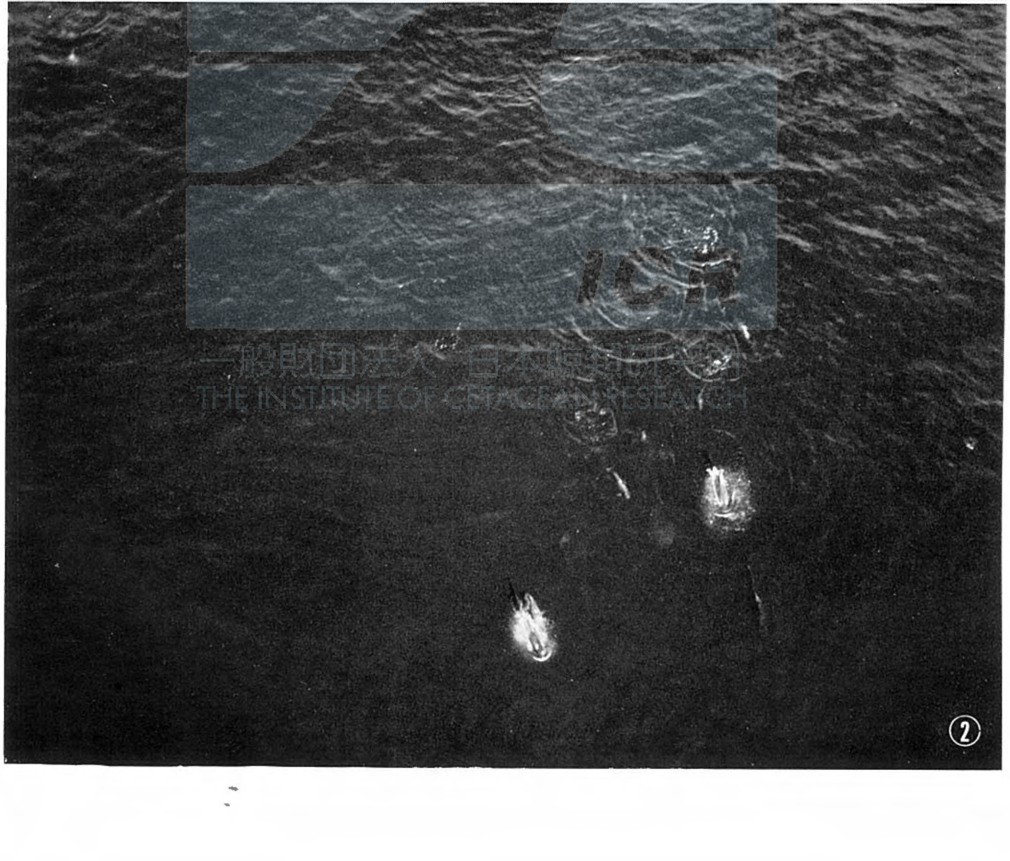

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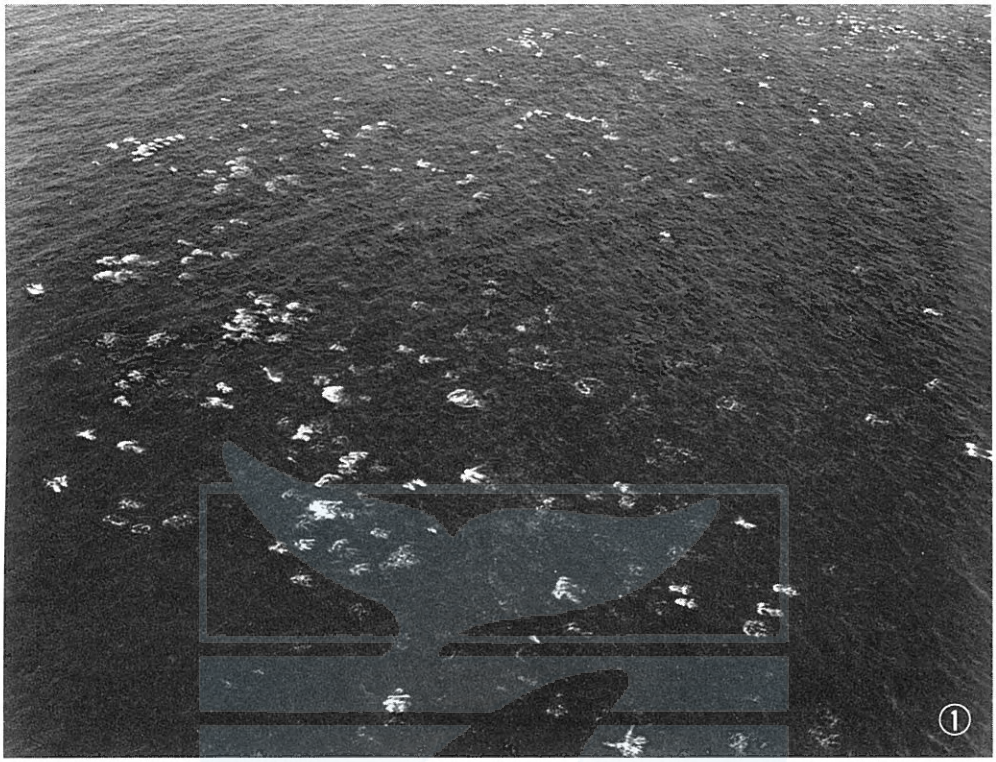

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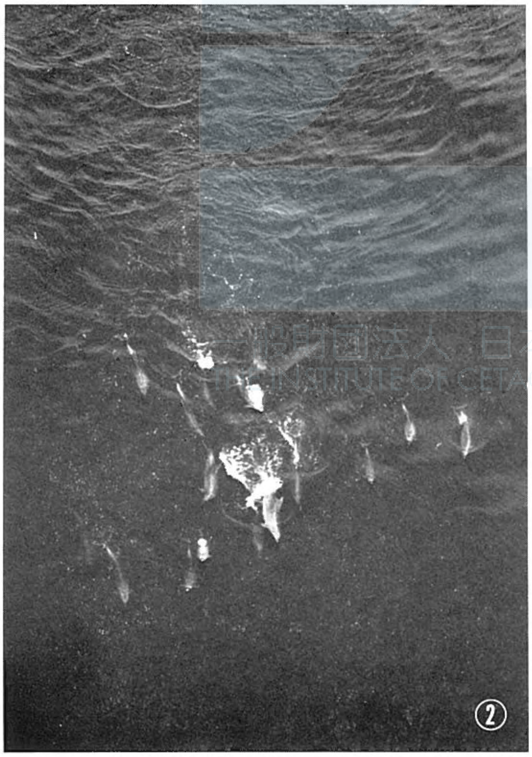

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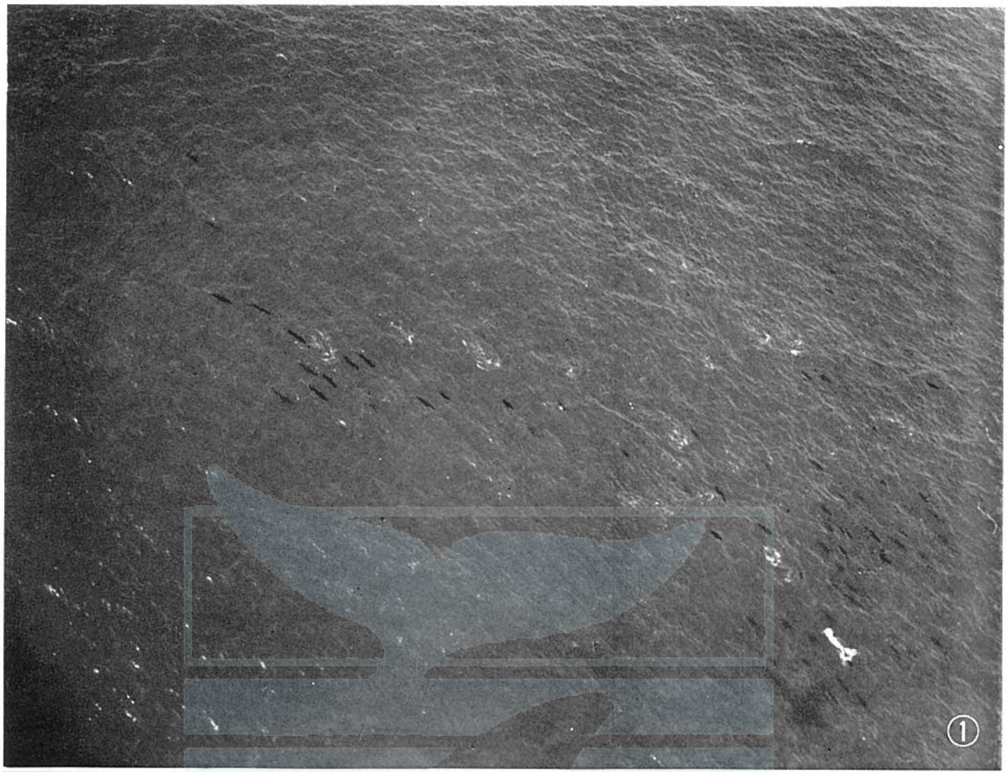
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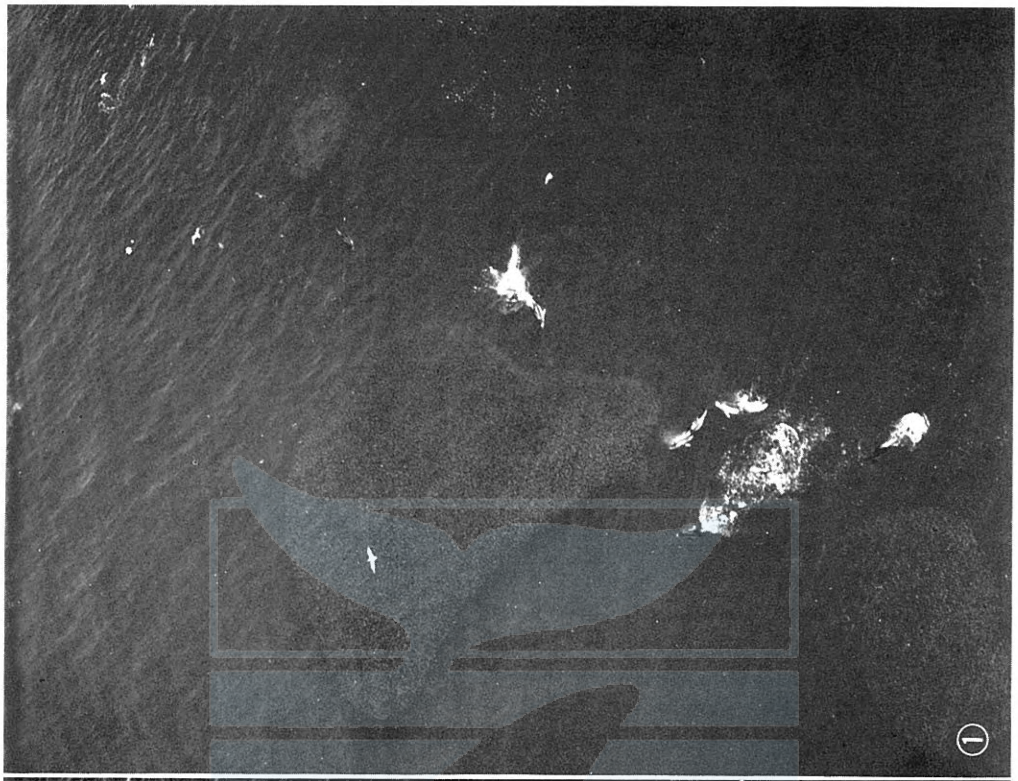

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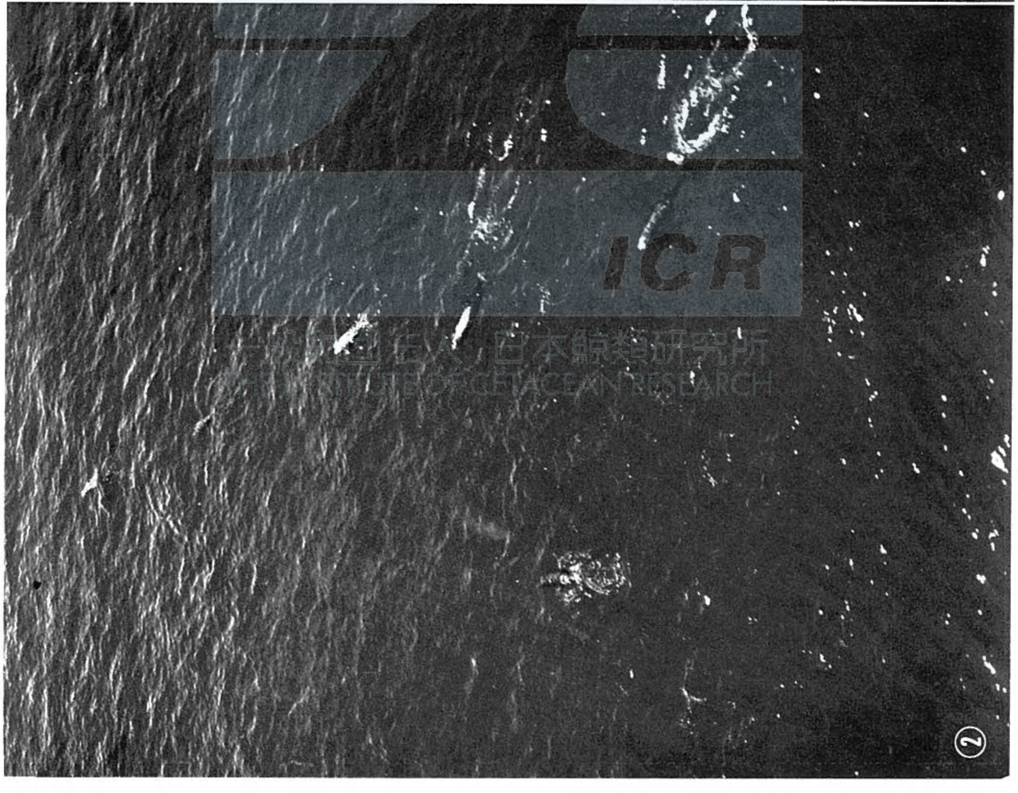

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A COMPARISON OF THE SIZE OF VERTEBRAE AMONG SOME SPECIES OF THE BALEEN WHALES WITH SPECIAL REFERENCE TO WHALE MOVEMENTS

HIDEO OMURA

ABSTRACT

In the baleen whales the caudal region occupies about 30% of the total combined length of the skull and vertebrae, notwithstanding the different size of the skull and regardless of the number of vertebrae. Long distant migrating species and fast swimmers have more developed vertebrae in the posterior portion of the lumbar and in the anterior portion of the caudal regions than in the other species.

INTRODUCTION

In the past the osteological studies of whales were carried out mainly from the taxonomic viewpoint and most of the authors deal with skull in detail, but they placed lesser weight on the vertebrae except their number. Consequently only a few papers report detailed measurements of each vertebra, but now they cover seven species of baleen whales i.e. Greenland right, black right, gray, pygmy blue, sei, Bryde's, and minke whales. In this paper these measurements are treated for the comparison of vertebrae among these species, in a hope that such study may give a basis for the ecological study of baleen whales e. g. feeding, swimming or migration. As to the three remaining important species, ordinary blue, fin, and humpback whales, no material is still available for inclusion in this study.

MATERIAL

In order to compare the size of vertebrae among different species it is desirable to use fully grown up or physically matured specimens, because it is well established that the proportions of the whale body are changeable during the course of growth in almost all species, but this is not possible at present. The materials used in this study are shown in Table 1. As seen in this table the Greenland right and gray whale specimens are very small and young. Nishiwaki and Kasuya (1970a, 1970b) presume on their ages about 1.36 years for the Greenland right whale and between one and two years for the gray whale. In addition to this for the size of the vertebral body they present only the length of the centra and no figure of their height and breadth is given. Accordingly these two species are treated separately from others in detailed calculation of the size of vertebrae.

Among the other species only the black right and pygmy blue whale specimens are physically matured, since all of the vertebral epiphyses are fused completely to

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TABLE 1. LIST OF MATERIALS USED IN THIS STUDY

Species	Common name	Sex	Body length (m)	Maturity	Author
Balaena mysticetus	Greenland right whale	M	6.4	Very young	Nishiwaki and Kasuya 1970a
Eubalaena glacialis	Black right whale	M	17.1	Physically mature	Omura *et al.*, 1969
*Eschrichtius robustus**	Gray whale	F	9.0	Very young	Nishiwaki and Kasuya, 1970b
Balaenoptera musculus brevicauda	Pygmy blue whale	M	18.6	Physically mature	Omura *et al.*, 1970
B. borealis	Sei whale	F	12.9	Physically immature	Omura, 1959
B. edeni	Bryde's whale	F	13.5	Physically immature	Omura, 1959
B. acutorostrata	Minke whale	M	7.5	Physically immature	Omura, 1957

* After Kasuya and Rice, 1970.

their centra. Specimens of the sei, Bryde's, and minke whales are all physically immature, though in the latter two specimens sexual maturity was already attained, and for the sei whale the specimen is thought at or approaching puberty.

In the light of the different stages of growth the conclusion derived from these specimens are consequently premature.

LENGTH OF SKULL AND VERTEBRAE

Table 2 shows the lengths of the skull and vertebrae, in actual length in mm as well

TABLE 2. SKULL AND VERTEBRAL LENGTH IN SEVEN SPECIES OF BALEEN WHALES

Species	Skull	Cervical	Dorsal	Lumbar	Caudal	Total
			(Actual figure in mm)			
G. right	1,980	174	820	1,013	1,873	5,860
		(7)	(12)	(10)	(24)	(53)
B. right	5,100	274	2,479	2,576	4,658	15,087
		(7)	(14)	(10)	(25)	(56)
Gray	2,000	338	1,489	1,911	2,736	8,474
		(7)	(14)	(12)	(23)	(56)
P. blue	4,860	618	2,949	2,750	4,737	15,914
		(7)	(15)	(14)	(27)	(63)
Sei	3,062	425	2,116	2,942	3,768	12,313
		(7)	(14)	(13)	(22)	(56)
Bryde's	3,480	441	2,125	3,272	3,374	12,692
		(7)	(13)	(13)	(21)	(54)
Minke	1,520	241	1,100	1,951	2,019	6,831
		(7)	(11)	(12)	(18)	(48)
			(% figure)			
G. right	33.79	2.97	13.99	17.29	31.96	100.00
B. right	33.80	1.82	16.43	17.08	30.87	”
Gray	23.60	3.99	17.57	22.55	32.29	”
P. blue	30.54	3.88	18.53	17.28	29.77	”
Sei	24.87	3.45	17.19	23.89	30.60	”
Bryde's	27.42	3.48	16.74	25.78	26.58	”
Minke	22.25	3.53	16.10	28.56	29.56	”

Figures in parentheses show number of vertebrae.

as their proportional length, for seven species of the baleen whales. For the vertebrae the length of each centrum are added, dividing into four regions i. e. cervical, dorsal, lumbar, and caudal. The total length of the vertebrae in this table does not denote, therefore, the total length of the back bone *in situ*, because spaces between vertebrae are neglected.

Fig. 1 shows the proportional length of the skull and each region of vertebrae against the combined length of the skull and vertebrae, comparing each species. As seen in this figure the skull length is greatest proportionally in the Greenland right and black right whales and it occupies 34% or one third of the total length in both species. In the other species only the pygmy blue whale exceeds 30% and the smallest figure is 22% of the minke whale. Thus in the proportional length of the skull there is a big difference by species. For the Greenland and black right whales the huge size of the skull can be explained by the different type of feeding (skimming) than the other species (swallowing or both types combined, Nemoto 1959), but it is thought rather difficult in the other species at least at present to explain the slight difference among them in connection with feeding.

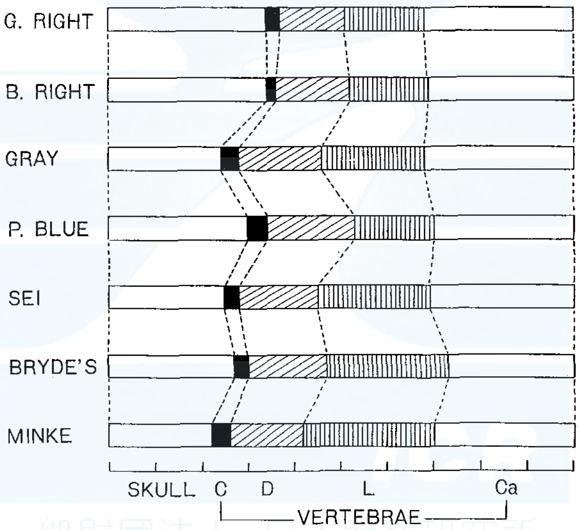

Fig. 1. Proportional length of skull and vertebrae in seven species of baleen whales.

The pygmy blue whale has comparatively large skull than other species except those of Balaenidae, but before going into detail the material for the ordinary blue whale as well as those of the fin and humpback whales are needed.

On the other hand the proportional length of the caudal region of the vertebrae is almost similar in these species, notwithstanding rather big difference in their number (Table 2). The greatest number of the caudal vertebrae is 27 of the pygmy blue whale and the smallest is 18 of the minke, but the proportional length of this region is quite similar, showing 30% in both species. The smallest percentage figure of this region is 27% of the Bryde's whale, which does not follow long distant migration and living locally. The highest figure is 32% of the Greenland right and gray whales, but both specimens are very young as stated before and there is a possibility of decreasing with growth. In any case it can be concluded that the caudal region occupies about 30% of the combined length of the skull and vertebrae in most of the baleen whales and this length may be required for swimming.

It is also seen from Fig. 1 that the difference in the length of the skull is balanced by the length of the dorsal and lumbar regions of the vertebrae, especially by the latter. The largest number of the lumbar vertebrae is 14 of the pygmy blue whale, but the proportional length of this region of the specimen is 17%, which is the lowest among the balaenopterid whales and lesser than the gray. The proportional length of the dorsal region is roughly proportional to the number of the dorsal vertebrae.

The proportional length of cervical region is smallest in the black right whale, but no remarkable difference in length of this region is noted among the species.

SIZE OF VERTEBRAE

In order to compare the size of each vertebra among the species of the baleen whales I made calculation of the mean length of the centrum using the following formula:

$$\text{Mean length} = \sqrt[3]{axbxc}$$

where a, b and c are the breadth, height and length of the centrum respectively.

The mean length thus calculated can be used as an index of the volume of the centrum. The results of the calculation are shown in Appendix Table 1 for the black right, pygmy blue, sei, Bryde's, and minke whales. The original measurements used in this calculation are given by the authors listed in Table 1.

Then I have calculated the percentage figures of the mean length of each vertebra, using the first lumbar vertebra as a standard. The results are shown in Appendix Table 2. In the table figures for the Greenland right and gray whales are also shown for reference, but in these two species only the length of the centrum was used due to lack of material and hence these figures do not denote the volume of the centra.

Fig. 2 shows the proportional size of each vertebra against the first lumbar in five species of the baleen whales based upon the values shown in Appendix Table 2. As seen in Fig. 2 there is no remarkable difference in the proportional size of vertebra in the cervical and dorsal regions, but quite large difference are present in the posterior portion of the lumbar region and in the anterior portion of the caudal region. The highest value in these regions are those of the minke whale, which follows long distant migration. In this species the lesser number of vertebrae are covered by the well developed vertebrae in these regions.

In comparing the sei and Bryde's whales it is notable that the caudal vertebrae in the anterior portion are much developed in the former than in the latter, due to possibly the difference in extent of the migration between the two species. The sei

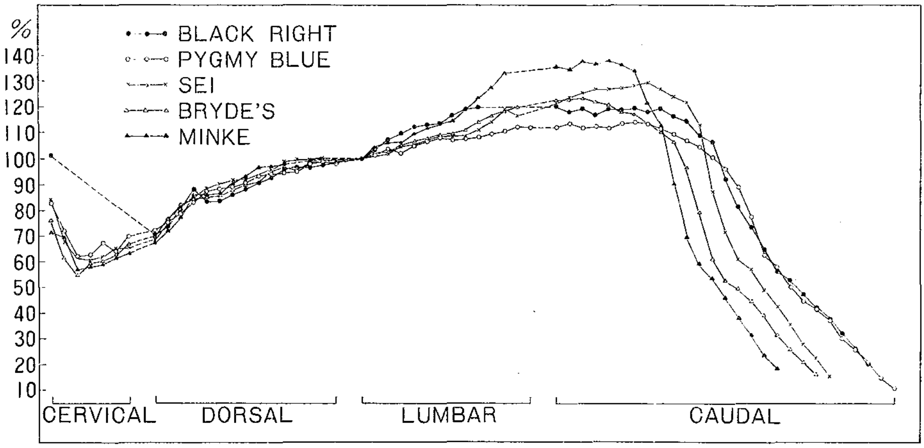

Fig. 2. Comparison of size of vertebra against first lumbar in five species of baleen whales.

whale is migratory, even though extent of its movement is thought lesser than that of the blue and fin whales. In the Antarctic it distribute mostly in the northern part of the whaling ground and in the North Pacific its movement is confined up to the Aleutian chain and very seldomly enters into the Bering Sea, whereas the fin whale penetrates through the Bering Strait into the Arctic basin. But still it has much wider range of migration than the Bryde's whale, which is only a local population. In the offshore waters of Japan the distribution of the Bryde's whale is confined from the Bonin Islands in the south to the east coast of Sanriku in the north and it is seldom to travel beyond 40 degree North Latitude. The highest value of the sei whale is at 7th caudal (128%) and that of the Bryde's whale is at 3rd caudal (124%).

The relation between the black right and pygmy blue whales is also of some interest. In general the curves for the two species show similar tendency, but in

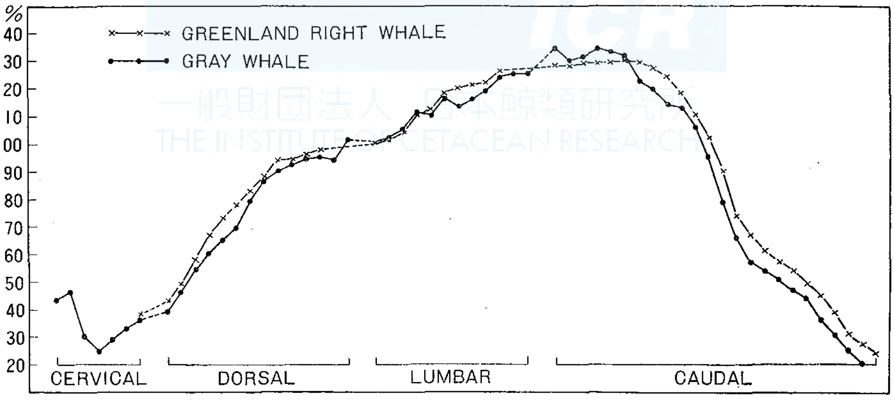

Fig. 3. Percentage length of each vertebra against first lumbar in the Greenland and gray whales.

the black right whale the vertebrae are more developed than the pygmy blue whale in the lumbar region and up to 13th caudal. Both whales are slow swimmer and very little is known of the migration of the pygmy blue whale. It is highly possible, however, that the range of migration is much wider in the black right whale than in the other which is thought to be only a local population.

In conclusion above it can be safely said that in the species which follow long distant migration and in the fast swimmers the vertebrae in the posterior portion of the lumbar and in the anterior portion of the caudal are much developed than the other.

Fig. 3 shows the proportional length of each vertebra of the Greenland right and gray whales. Both curves are similar in general and each corresponding value is smaller in the gray whale than in the Greenland right whale, except those in the caudal region, up to 6th caudal. The Greenland right whale is inhabiting in the Arctic Ocean, whereas the gray whale migrate very long distance between the coast of Mexico and Arctic Ocean, passing through the Bering Strait. It seems rather queer the general agreement of these curves, but since the both specimens are very young and they are presumed below two years, as stated before, and since these curves denote only the lengths of the centra, no definite conclusion may be derived from this figure in relation to movement of whales. Or an explanation may be that that no remarkable difference in the size of vertebrae is present among different species of whales when they are young and the difference in size noted before are developed during the course of growth of the whale body.

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APPENDIX TABLE 1. MEAN LENGTH OF VERTEBRAE OF FIVE SPECIES OF BALEEN WHALES

Mean length = $\sqrt[3]{a \times b \times c}$
where a: breadth; b: height; c: length; of each vertebra in mm.

Vertebral No.	Black right	Pygmy blue	Sei	Bryde's	Minke
C 1	294	233	165	160	87
2		202	133	129	85
3		173	122	116	70
4		175	118	126	71
5		187	121	127	72
6		178	126	133	76
7		196	129	141	78
D 1	205	202	134	147	83
2	214	211	146	157	89
3	231	220	157	167	95
4	253	232	167	177	104
5	241	244	173	179	106
6	243	247	177	180	106
7	250	249	180	185	111
8	257	254	181	188	114
9	265	260	184	192	118
10	272	263	188	198	118
11	276	265	192	200	119
12	279	266	194	201	—
13	281	271	193	206	—
14	283	273	195	—	—
15	—	275	—	—	—
L 1	292	281	197	211	123
2	300	285	199	214	127
3	313	292	201	217	131
4	321	287	206	222	131
5	328	295	207	225	135
6	329	300	211	228	138
7	333	304	214	231	140
8	341	301	215	232	141
9	348	303	215	235	146
10	350	304	219	241	152
11	—	309	225	246	157
12	—	312	235	251	164
13	—	315	230	254	—
14	—	316	—	—	—
Ca 1	352	316	239	259	167
2	345	319	244	260	166
3	349	316	248	261	170
4	343	317	251	258	169
5	350	316	251	256	170
6	348	321	252	251	168
7	349	323	253	248	159
8	345	319	251	241	150

Continued . . .

APPENDIX TABLE 1. Continued.

Vertebral No.	Black right	Pygmy blue	Sei	Bryde's	Minke
Ca 9	350	314	241	233	138
10	341	309	235	225	111
11	336	302	221	204	86
12	319	295	204	167	73
13	312	284	172	129	66
14	270	271	142	111	57
15	239	251	121	105	47
16	215	219	113	95	39
17	189	177	97	83	29
18	164	163	84	67	23
19	154	141	70	55	—
20	138	133	55	44	—
21	123	118	45	34	—
22	109	105	31	—	—
23	93	85	—	—	—
24	77	72	—	—	—
25	60	59	—	—	—
26	—	42	—	—	—
27	—	31	—	—	—

APPENDIX TABLE 2. PERCENTAGE LENGTH OF EACH VERTEBRA AGAINST FIRST LUMBAR

Mean length, shown in Appendix Table 1, are used for comparison, except last two columns in which species only vertebral lengths are available.

Vertebral No.	B. right	P. blue	Sei	Bryde's	Minke	(G. right)	(Gray)
C 1	100.68	82.92	83.76	75.83	70.73	157.30	42.86
2		71.89	65.51	61.14	69.11		45.71
3		61.57	61.93	54.98	56.91		30.00
4		62.28	59.90	59.72	57.72		25.00
5		66.55	61.42	60.19	58.54		28.57
6		63.35	63.96	63.03	61.79		32.86
7		69.75	65.48	66.82	63.41	38.20	36.43
D 1	70.21	71.89	68.02	69.67	67.48	42.70	39.29
2	73.29	75.08	74.11	74.41	72.36	49.44	46.43
3	79.11	78.29	79.70	79.15	77.24	58.43	53.57
4	86.64	82.56	84.77	83.89	84.55	67.42	60.00
5	82.53	86.83	87.82	84.83	86.18	73.03	65.00
6	83.22	87.90	89.85	85.31	86.18	77.53	68.57
7	85.62	88.61.	91.37	87.68	90.24	83.15	79.29
8	88.01	90.39	91.88	89.10	92.68	87.64	85.71
9	90.75	92.53	93.40	91.00	95.93	94.38	90.00
10	93.15	93.59	95.43	93.84	95.93	94.38	92.14
11	94.52	94.31	97.46	94.79	96.75	95.51	93.57
12	95.55	94.66	98.48	95.26	—	97.75	95.00
13	96.23	96.44	97.97	97.63	—	—	93.57

Continued . . .

APPENDIX TABLE 2. Continued.

Vertebral No.	B. right	P. blue	Sei	Bryde's	Minke	(G. right)	(Gray)
14	96.92	97.15	98.98	—	—	—	101.43
15	—	97.86	—	—	—	—	—
L 1	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	102.74	101.42	101.02	101.42	103.25	102.25	102.14
3	107.19	103.91	102.03	102.84	106.50	104.49	105.00
4	109.93	102.14	104.57	105.21	106.50	111.24	110.71
5	112.33	104.98	105.08	106.64	109.76	112.36	110.00
6	112.67	106.76	107.11	108.06	112.20	117.98	116.43
7	114.04	108.19	108.63	109.48	113.82	120.22	112.86
8	116.78	107.12	109.14	109.95	114.63	121.35	115.71
9	119.18	107.83	109.14	111.37	118.70	122.47	118.57
10	119.86	108.19	111.17	114.22	123.58	125.84	123.57
11	—	109.96	114.21	116.59	127.64	—	125.00
12	—	111.03	119.29	118.96	133.33	—	125.00
13	—	112.10	116.75	120.38	—	—	—
14	—	112.46	—	—	—	—	—
Ca 1	120.55	112.46	121.32	122.75	135.77	128.09	133.57
2	118.15	113.52	123.86	123.22	134.96	128.09	130.00
3	119.52	112.46	125.89	123.70	138.21	129.21	131.43
4	117.47	112.81	127.41	122.27	137.40	129.21	133.57
5	119.86	112.46	127.41	121.33	138.21	129.21	132.86
6	119.18	114.23	127.92	118.96	136.59	130.34	131.43
7	119.52	114.95	128.43	117.54	129.27	130.34	122.14
8	118.15	113.52	127.41	114.22	121.95	126.97	119.29
9	119.86	111.74	122.34	110.43	112.20	123.60	114.29
10	116.78	109.96	119.29	106.64	90.24	117.98	112.86
11	115.07	107.47	112.18	96.68	69.92	110.11	106.43
12	109.25	104.98	103.55	79.15	59.35	102.25	95.00
13	106.85	101.07	87.31	61.14	53.66	89.89	79.29
14	92.47	96.44	72.08	52.61	46.34	74.16	66.43
15	81.85	89.32	61.42	49.76	38.21	67.42	57.14
16	73.63	77.94	57.36	45.02	31.71	60.67	54.29
17	64.73	62.99	49.24	39.34	23.58	57.30	50.71
18	56.16	58.01	42.64	31.75	18.70	53.93	47.14
19	52.74	50.18	35.53	26.07	—	49.44	44.29
20	47.26	47.33	27.92	20.85	—	44.94	36.43
21	42.12	41.99	22.84	16.11	—	39.33	30.71
22	37.33	37.37	15.74	—	—	31.46	25.00
23	31.85	30.25	—	—	—	26.97	unknown
24	26.37	25.62	—	—	—	23.60	—
25	20.55	21.00	—	—	—	—	—
26	—	14.95	—	—	—	—	—
27	—	11.03	—	—	—	—	—

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FURTHER STUDIES ON TWO SKELETONS OF THE BLACK RIGHT WHALE IN THE NORTH PACIFIC

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ABSTRACT

Two skeletons of the black right whale were studied, supplementing our previous report. In the skull, studied together with four specimens reported before, the proportional length of the rostrum increases and the rostrum becomes more curved downwards with age, whereas the skull breadth decreases its proportion slightly. The numbers of vertebrae of these specimens were erroneously reported in the previous paper, but now they are corrected. In one specimen the 1st dorsal vertebra united to the mass of cervicals. Sexual difference in the form and size of the pelvic bone is suggested.

In our previous paper (Omura *et al.* 1969) are also included the two black right whales taken in 1968 in the Okhotsk Sea. They are a male and a female of 15.20 and 12.60 m in length respectively (Whale nos. 68A and 68B). The skeletons of these whales had been burried for about two years in the sand of the beach at Mombetsu in Hokkaido, where the whales were processed. In July 1970 we dug out the bones from the sand and sent them to Taiji Whale Museum in Wakayama prefecture, after cleaning. In December of the same year we made observations and a series of measurements of the skeletons, and results of which are reported in the present paper. The specimen 68A is now being kept at the museum and the 68B specimen was sent to Landessammlungen für Naturkunde in Karlsruhe, West Germany, where it is planned to mount the skeleton for display.

The skull of the specimen 68A was broken into three major portions, i.e. the beak, and right and left cranial portions, and many small flagments, being hit at the time of taking by a harpoon. But the major broken parts are in such a good condition that the skull could be restored, and thus enabling us to make some of the series of the measurements. The skull of the specimen 68B is complete.

SKULL

The results of the skull measurements are shown in Appendix Table 1, together with the calculated percentages of each measurement against their skull length as well as those of skull breadth.

We have now the skull measurements for six specimens of the black right whale in the North Pacific as listed in Table 1, and some selected measurements of these specimens are compared in Fig. 1. As seen in Fig. 1 the smallest and the largest

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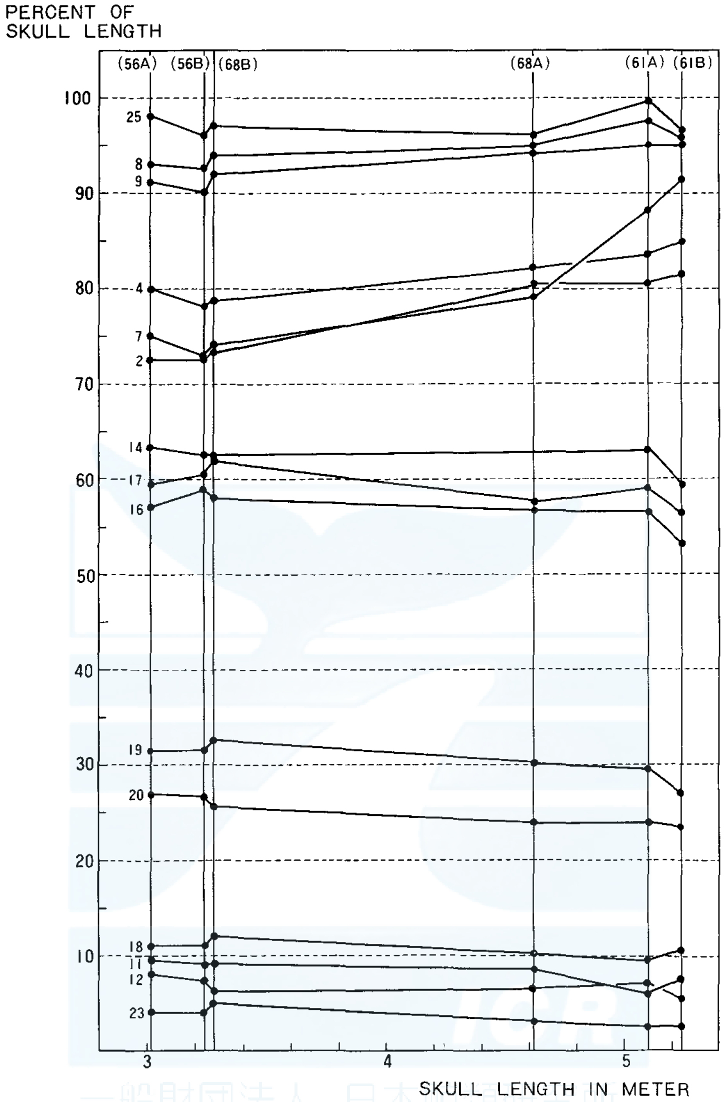

Fig. 1. Proportional growth of bones in the skull of the black right whale in the North Pacific. Numerals in the figure indicate measurement number in Appendix Table 1, but see also text.

skulls are those of the specimens 56A and 61B, being their lengths 3,022 and 5,240 mm respectively. The other four specimens are not distributed evenly between these lengths, but rather biassed towards the extremities. It is suggested from Fig. 1, however, some trends of the changes of the proportional lengths of various parts of the skull with the growth or age of the whale. These changes can be grouped into two categories.

TABLE 1. LIST OF THE SKULL SPECIMENS OF THE BLACK RIGHT WHALE IN THE NORTH PACIFIC USED FOR COMPARISON

Specimen no.	Body length	Sex	Skull length	Maturity	Author
	cm		mm		
56A	1,165	F	3,022	Sexually immature	Omura, 1958
56B	1,240	M	3,230	,, ,,	,, ,,
61A	1,710	M	5,100	Physically mature	Omura *et al.* 1969
61B	1,700	M	5,240	,, ,,	,, ,, ,,
68A	1,520	M	4,620	Sexually immature	Present paper
68B	1,260	F	3,270	,, ,,	,, ,,

1. Proportional length increases with the age.

In this category are included: length of maxillaries at superior border, straight (no. 2); length of premaxillaries, straight (no. 4); anterior end of nasals to end of rostrum, on curve (no. 7); length from tip of premaxillaries to posterior end of pterygoid (no. 8); and length from tip of premaxillaries to posterior end of palatines, medial (no. 9).

2. Proportional length decreases or practically no change with the age.

In this category are included: breadth of skull, orbits (no. 14); breadth of skull at orbital processes of maxillaries (no. 16); breadth of skull at squamosals (no. 17); greatest breadth of occipital bone (no. 19); height of supraoccipital bone, from foramen magnum (no. 20); breadth of rostrum at middle (no. 18); length of nasals (no. 11); breadth of two nasals distally (no. 12); greatest breadth of foramen magnum (no. 23); and length of mandible, straight (no. 25).

The measurements which belong to the first category are those concerned with the length of the beak or longitudinal growth of the facial region of the skull, and the measurements in the second category are mainly those concerned with the width or transverse growth of the skull. The proportional growth with age of the maxillaries and premaxillaries are very conspicuous, whereas the width of the skull at various parts stay fairly constant or show rather decrease. The proportional increase of the curved length from the anterior end of nasals to end of rostrum is quite striking. This may be attributable to the fact that the proportional size of the nasals decreases slightly with age, but it is also possible that the beak itself becomes more curved downwards. The proportions of the greatest breadth of the occipital bone and the height of the supraoccipital bone decrease slightly with age. In the breadth of the foramen magnum is shown also similar trend.

Practically no change is observed in the percentage length of mandible in relation to age.

VERTEBRA

The numbers of vertebrae were erroneously reported in the previous paper (Omura *et al.* 1969) in Table 30 as having 57 and 55 vertebrae respectively. These numbers were counted at the time of dismembering of the whale carcasses when some meat and other soft parts still attached on the surface of bones. These numbers are now corrected as follows:

68A. C 7, D 14, L 10, Ca 27, Total 58.
68B. C 7, D 14, L 10, Ca 26, Total 57.

In the specimen 68A epiphyses are only fused to the centra in the caudal region from 13th caudal onwards except the last three which are not united. From a histological examination of the testes this whale was assigned as immature (Omura *et al.* 1969), but it is possible that the whale was at the stage of approaching puberty, judged from the weights of testes. In the specimen 68B none of the epiphyses united to their centra.

The most interesting feature of these vertebrae is that of the cervicals of the specimen 68A. In this specimen the centrum of the first dorsal vertebra has completely fused to the united mass of cervicals, making an appearance as if this is the last cervical and in this specimen there present eight cervicals, as shown in Fig. 2. But it has transverse processes of not differing from other specimens, and it is possible

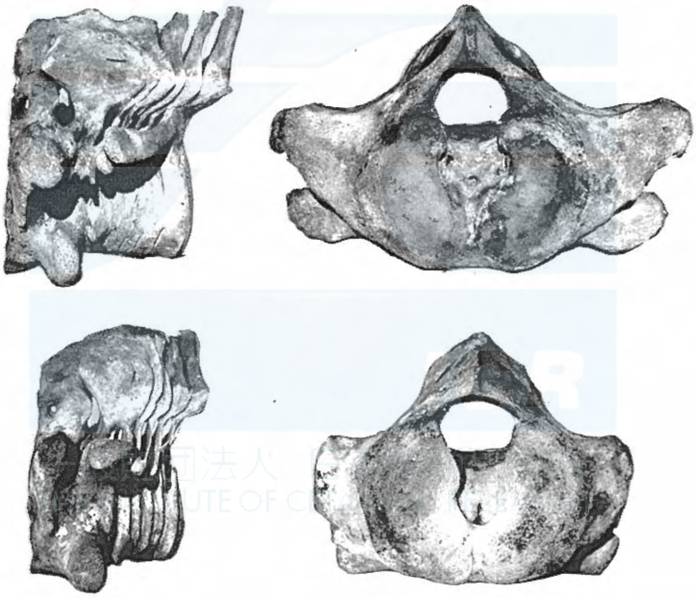

Fig. 2. Cervicals of the black right whale in the North Pacific.
Upper: specimen 68 A. In this specimen the 1st dorsal vertebra has fused to the mass of cervicals.
Lower: specimen 68 B.
Left: lateral view. Right: frontal view.

that the first ribs articulate at these processes. In the specimen 68B, only seven cervicals united into a mass of bones as usual.

Measurements of each vertebra are shown in Appendix Table 2 for the both specimens.

RIBS AND STERNUM

In the specimen 68A fourteen pairs of ribs are present. But in the 68B there present one small rib in addition to fourteen pairs. This rib is small and slender, and its length is only about a half of the preceeding one and rudimental. On the transverse processes of the 22nd vertebra there are no trace of facet for articulation of rib. Thus we assigned the number of dorsal vertebrae as fourteen and that of lumbar ten as stated before, but if we count fifteen dorsals then the number of lumbars becomes nine. In any case the total number of vertebrae is the same. The straight lengths of ribs are shown in Table 2.

TABLE 2. STRAIGHT LENGTH OF RIBS OF THE SPECIMENS 68A AND 68B (in mm)

	68A		68B	
Rib no.	Right	Left	Right	Left
1	1,375	1,335	790	680+*
2	1,715	1,740	1,195	1,095
3	1,805	1,810	1,480	1,465
4	1,910	2.000	1,615	1,600
5	2.010	2,070+*	1,690	1,675
6	2,105	1,950+*	1,755	1,740
7	2,095	2,090	1,830	1,795
8	2,050	2,010	1,755	1,730
9	1,920+*	1,940+*	1,675	1,655
10	1,900	1,860+*	1,645	1,565
11	1,785	1,805	1,555	1,550
12	1,665	1,690	1,505	1,495
13	1,525	1,510	1,320	1,325
14	930	975	1,135	1,160
15	—	—	—	500

* Partly broken.

The sternum of the specimen 68B was missed at the time of treating the carcass, and that of 68A is 510 mm long and 381 mm width with no special feature.

PELVIC BONE AND FEMUR

Pelvic bones of these two specimens are of some interest, suggesting a sexual difference in the form and size (Fig. 3). The bones of the male specimen 68A are quite similar to those of the specimens 61A and 61B, both male, as reported by Omura *et al.* (1969). The length and the breadth at tuberculum laterale of the right and left bones are 447, 83 and 440, 76 mm respectively. On the other hand in the female specimen 68B the form is different and the length is much shorter in relation to its breadth. The corresponding figures of the right and left bones are 207, 67 and 201, 55 mm respectively. Further the angle between the cranial and caudal processes is greater in 68A than in 68B. Hosokawa (1951) found a marked sexual difference in the form of pelvis in the fin and blue foetuses. Jonsgård (1970) has also reports that the pelvic bone may be useful for sex determination, and perhaps also for age determination of the minke whale in the North Atlantic.

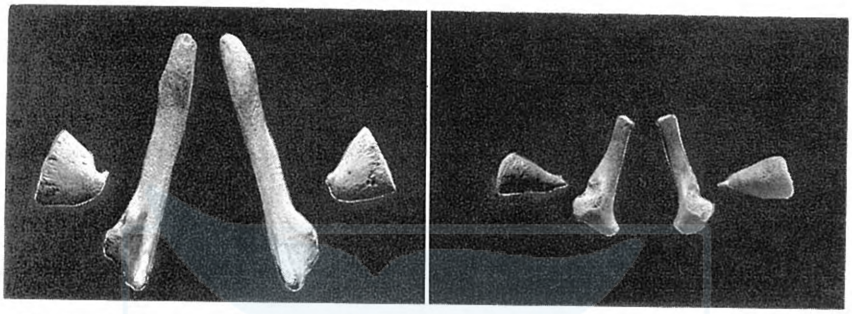

Fig. 3. Pelvic bones (inner) and femur (outer) of the black right whale in the North Pacific.
Left: specimen 68 A (male). Right: specimen 68 B (female).

The femur too somewhat different between the two specimens. The lengths and breadths of the right and left bones of the 68A are 106, 123 and 107, 129 mm respectively, but in the 68B the bones are much longer and more pointed. The corresponding figures in this specimen are 115, 77 and 123, 75 mm. In both specimens the femur is very light and has a sponge-like structure and not differs from that of the specimens 61A and 61B in this respect.

HYOID BONE

Hyoid bones of the both two specimens are of no special feature, except that in the combined bone of basihyal and thyrohyals of the specimen 68B. In this bone the basihyal has not been fused completely with left thyrohyal and the suture is very loose. Omura (1958) reports also in the specimen 56B the sutures are still visible though these bones are united completely. Measurements of hyoid bones are shown in Table 3.

TABLE 3. MEASUREMENTS OF HYOID BONES OF THE SPECIMENS 68A AND 68B (in mm)

Measurements	68A	68B
Straight length	744	578
Height at middle	165	98
Length of stylohyal R.	379	256
„ „ L.	389	263

SCAPULA, HUMERUS, RADIUS, AND ULNA

The bones are of no special feature and measurements of these bones are shown in Table 4.

TABLE 4. MEASUREMENTS OF SCAPULA, HUMERUS, RADIUS, AND ULNA OF THE SPECIMENS 68A AND 68B (in mm)

	68A		68B	
	Right	Left	Right	Left
Scapula				
Breadth	1,152	1,129	942	936
Height	948	933	764	747
Humerus				
Length	628	629	523	520
Breadth at middle	264	261	238	229
Radius				
Length	674	678	571	580
Breadth at middle	243	234	172	161
Ulna				
Length at middle	536	524	459	465
Breadth at middle	124	119	98	98

CARPALS AND PHALANGES

Each five carpals were saved from right and left flippers of the both specimens. The phalangeal formulae for the specimens 68A and 68B are I_3, II_5, III_6, IV_4, V_4 and I_2, II_5, III_5, IV_4, V_4 respectively.

CHEVRON BONE

Thirteen chevron bones were preserved from the specimen 68A. Among these the 1st, 12th, and 13th are not united of the right and left laminae. For the 68B specimen are present twelve chevrons and in which 1st, 2nd, 11th, and 12th are not united.

ACKNOWLEDGEMENTS

Our sincere thanks are due to the staff of the Taiji Whale Museum, Mr. A. Kawamura of the Whales Research Institute, Mr. T. Miyodori and personnel of the Taiyo Gyogyo K. K. who assisted our works. They all helped us greatly in preparation of the specimens as well as in measurements.

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APPENDIX TABLE 1. SKULL MEASUREMENTS OF THE BLACK RIGHT WHAIE IN THE NORTH PACIFIC

	Measurements		68A			68B		
			in mm	% of length	% of breadth	in mm	% of length	% of breadth
1.	Length of skull, straight		4,620	100.0	159.8	3,270	100.0	161.7
2.	Length of max. at superior border, straight		3,710	80.3	139.2	2,425	74.2	119.9
3.	Length of max., following curve of sup. external border		3,865	83.7	145.0	2,520	77.1	124.6
4.	Length of premax., straight		—	—	—	2,567	78.5	127.0
5.	Length of premax., along dorsal convexity		4,045	87.6	151.8	2,675	81.8	132.3
6.	Length of rostrum, straight		—	—	—	2,516	76.9	124.4
7.	Anterior end of nasals to end of rostrum, on curve		3,650	79.0	137.0	2,410	73.7	119.2
8.	Length from tip of premax. to posterior end of pterygoid		4,380	94.8	164.4	3,080	94.2	152.3
9.	Length from tip of premax. to post. end of palatines, median		—	—	—	3,020	92.4	149.4
10.	Length from tip of premax. to ant. end of palatines, median		—	—	—	2,610	79.8	129.1
11.	Length of nasals, median		391	8.5	14.7	295	9.0	14.6
12.	Breadth of 2 nasals distally		308	6.7	11.6	197	6.0	9.7
13.	Breadth of 2 nasals proximally		276	6.0	10.4	287	8.8	14.2
14.	Breadth of skull, orbits		—	—	—	2,038	62.3	100.8
15.	Breadth of skull at ant. and dist. ends of orbital process of frontal		—	—	—	2,121	64.9	104.9
16.	Breadth of skull at orbital processes of maxillaries		—	—	—	1,904	58.2	94.2
17.	Breadth of skull at squamosals		2,665	57.7	100.0	2,022	61.8	100.0
18.	Breadth of rostrum at middle, straight		—	—	—	391	12.0	19.3
19.	Greatest breadth of occipital bone		1,392	30.1	52.2	1,061	32.5	52.5
20.	Height of supraoccipital bone, from foramen magnum		1,112	24.1	41.7	836	25.6	41.3
21.	Transverse breadth of occipital condyles		353	7.6	13.2	370	11.3	18.3
22.	Height of occipital condyle	R	288	6.2	10.8	304	9.3	15.0
		L	285	6.2	10.7	305	9.3	15.1
23.	Greatest breadth of foramen magnum		129	2.8	4.8	109	3.3	5.4
24.	Greatest height of foramen magnum		145	3.1	5.4	161	4.9	8.0
25.	Length of mandible, straight	R	4,460	96.5	167.4	3,180	97.3	157.3
		L	4,425	95.8	166.0	3,185	97.4	157.5
26.	Length of mandible, on curve	R	4,775	103.4	179.2	3,395	103.8	167.9
		L	4,675	101.2	175.4	3,370	103.1	166.7
27.	Depth of mandible at coronoid	R	468	10.1	17.6	381	11.7	18.8
		L	463	10.0	17.4	373	11.4	18.4
28.	Depth of mandible at condyle	R	502	10.9	18.8	378	11.6	18.7
		L	490	10.6	18.4	387	11.8	19.1

APPENDIX TABLE 2. MEASUREMENTS OF VERTEBRAE OF THE BLACK RIGHT WHALE IN THE NORTH PACIFIC (in mm)

1. Specimen 68A

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Note
				Breadth	Height	Length	
1	C 1	789	502			248	
2	2						
3	3						
4	4						
5	5						
6	6						
7	7						
8	D 1	685	518	307	250	67	Fused to cervicals
9	2	694	529	296	251	88	
10	3	692	564	281	240	101	
11	4	664	593	275	237	117	
12	5	623	604	276	236	125	
13	6	617	598	277	235	133	
14	7	625	604	280	236	141	
15	8	624	616	287	239	155	
16	9	668	623	304	240	169	
17	10	692	622	322	244	181	
18	11	694*	620	313	244	170	* Estimated
19	12	746	626	345	248	185	
20	13	818	626	335	248	193	
21	14	947	647	340	255	203	
22	L 1	1,039	665	337	274	206	
23	2	1,104	681	339	285	210	
24	3	1,114	—**	338	288	215	** Spinous process broken
25	4	1,119	701	338	294	217	
26	5	1,121	732	342	309	225	
27	6	1,128	720	346	305	229	
28	7	1,122	739	344	304	236	
29	8	1,111	714	351	312	239	
30	9	1,041	718	360	323	240	
31	10	1,081	699	359	312	241	
32	Ca 1	983	702	367	343	242	
33	2	933	671	364	347	245	
34	3	867	669	354	354	240	
35	4	786	—**	350	351	241	** Spinous process broken
36	5	689	630	354	356	238	
37	6	606	608	346	361	234	
38	7	570	580	352	364	232	
39	8	511	568	346	355	232	Incomplete foramen on t. process
40	9	478	545	351	354	221	T. processes perforated.
41	10	436	518	346	352	216	
42	11	398	482	342	345	205	
43	12	366	451	340	337	198	
44	13	347	405	325	328	185	T. process ends

Continued . . .

APPENDIX TABLE 2. Continued.

1. Specimen 68A

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Note
45	14	332	365	301	304	171	Epiphyses fused to centra from 13 th caudal, except last 3
46	15	299	315	282	275	147	
47	16	—	—	257	247	132	Neural canal disappear
48	17	—	—	216	205	123	
49	18	—	—	194	185	115	
50	19	—	—	172	172	108	
51	20	—	—	162	157	103	
52	21	—	—	138	139	93	
53	22	—	—	122	123	82	
54	23	—	—	102	103	71	
55	24	—	—	85	83	63	
56	25	—	—	65	63	55	
57	26	—	—	45	47	47	
58	27	—	—	30	30	24	

2. Specimen 68B

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum Breadth	Centrum Height	Centrum Length	Note
1	C 1	600	451			213	
2	2						
3	3						
4	4						
5	5						
6	6						
7	7	273	464	273	223	41	
8	D 1	484	460	269	224	78	
9	2	620	459	285	220	72	
10	3	466	471	271	218	99	
11	4	445	494	249	214	113	
12	5	495	514	250	210	122	
13	6	484	520	249	210	129	
14	7	482	517	256	210	140	
15	8	478	519	258	214	149	
16	9	490	516	267	216	161	
17	10	496	510	274	216	165	
18	11	538	507	290	214	168	
19	12	568	489	309	217	172	
20	13	631	489	313	215	177	
21	14	714	486	317	216	180	
22	L 1	750	503	299	225	182	
23	2	727	526	295	239	189	
24	3	718	544	293	251	188	
25	4	703	564	292	264	199	
26	5	758	565	295	272	202	

Continued . . .

APPENDIX TABLE 2. Continued.

2. Specimen 68B

Serial no.	Vertebral no.	Greatest breadth	Greatest height	Centrum			Note
				Breadth	Height	Length	
27	6	750	552	298	263	279	
28	7	725	577	293	266	205	
29	8	718	562	293	258	211	
30	9	716	570	304	282	226	
31	10	693	567	305	282	227	
32	Ca 1	674	567	309	295	235	
33	2	643	555	312	291	235	
34	3	617	561	314	299	237	
35	4	585	553	314	306	235	
36	5	560	557	315	314	236	
37	6	520	535	319	328	237	
38	7	496	534	321	334	236	Foramen on left t. process
39	8	461	517	324	334	233	Both t. processes perforated
40	9	418	503	339	333	229	
41	10	387	475	327	335	222	
42	11	360	452	338	332	219	
43	12	337	418	324	318	203	T. processes end
44	13	—	382	312	305	196	
45	14	—	326	300	272	181	
46	15	—	—	259	246	151	Neural canal disappear
47	16	—	—	231	223	128	
48	17	—	—	194	191	117	
49	18	—	—	173	171	109	
50	19	—	—	161	157	105	
51	20	—	—	152	143	95	
52	21	—	—	131	127	87	
53	22	—	—	115	107	75	
54	23	—	—	102	89	65	
55	24	—	—	84	70	56	
56	25	—	—	61	53	57	
57	26	—	—	39	38	31	

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OSTEOLOGICAL NOTE OF AN ANTARCTIC SEI WHALE

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ABSTRACT

This is a report of measurements on the skeleton of a male sei whale caught in the Antarctic.

The skeleton of a sei whale (*Balaenoptera borealis*) was collected in the Antarctic Ocean for the purpose of exhibits at the Taiji Whale Museum.

Taiji is the place where ancient Japanese whaling commenced. It is famed that Taiji whalers first established their revolutionary method of taking whales, in which whales are entangled in a net to prevent them from escape and killed with hand harpoons. Until now, Taiji Town, Wakayama Pref., has yielded many gunners and crew of factory ships and catcher boats.

When The Whale Museum was constructed by the demand of town people, various specimens were collected as varid and many as possible in the districts far and near.

Catch data of this whale is as follows:

Date of catch	Feb. 18, 1967
position of catch	58°-53′S, 83°-09′E
water temperature at the time	1.8°C
air temperature at the time	2.0°C
body length	15.3 m
sex	female
number of corpus luteum and albicans	R. 0, 3 L. 1, 3
fetus: body length	268 cm
sex	male
name of the catcher boat	the Kyo-maru No. 10.
name of the sender	Mr. K. Sakamoto

The skeleton had arrived Yokohama from the Antarctic whaling ground in April 1967 and has been buried in the sandy ground of Tokai University campus, Orido in Shimizu City, Shizuoka Pref. It was excavated on Sept. 9, 1968 and it takes 15 days to be cleaned and measured.

This report is merely a record of measurements on the skeleton of the sei whale, not a comparative study, and we did not find peculiar characters in the skeleton, so no discussion were done.

Measurements of the skull are shown in Table 1 and the dorsal, lateral and ventral views are shown in Plate I. As it is seen in the Plate I, the tip of rostrum was broken at the time of excavation, but most of the fragments were secured.

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Some errors were made after it was measured and photographs were taken. When the exhibition was arranged, waiting for its repairement, the broken pieces had been kept aside. But one of the laborer took it for rubbish and threw it into the reclaiming hole. Though we looked for, it could not be found again. Now the skull is appeared in original shape repaired with a unit of another tip from the Antarctic.

Measurements of vertebra are shown in Table 2, as well as in Plate II. The vertebral formula is

$$C\,7+D\,13+L\,14+Ca\,22=56$$

All epiphyses of the vertebrae are ankylosed to the centrum, but still, gaps are seen in the Dorsal and Lumbar vertebrae. Compared with the spinal processes of *B. edeni*, those in this species are less slanted to the backward.

In the 2nd to 6th cervical vertebrae the upper and lower lateral processes are united at the tip to form a loop, but in the 1st and 7th they are separated.

There are 13 pairs of ribs and the 1st rib has bilateral head, this character is common with *B. borealis* as seen in Fig. 6 of Plate II. Measurements of ribs are shown in Table 3.

There are fourteen lumbar vertebrae.

There are twenty one caudal vertebrae as shown in Fig. 4 and Fig. 5 of Plate II. It is certain that one more vertebra might have existed at the extreme rear, but seems to have been lost at collection. In the 1st caudal vertebra, the facet where chevron bone attached to is clear and was easy to be distinguished as seen in Fig. 7 of Plate II. Ten pairs of chevron bones are present, none of which has laminae separating to both side. Their measurements are shown in Table 4.

The hyoid bones are slender in shape and the basihyal and the thyrohyals are combined. Measurements of this bone is shown together with Fig. 1. There are no special feature on the specific consideration.

The sternum has short processes and is roughly star-like in shape as shown in Fig. 2. This bone is 28 cm in length and about 45 cm in breadth. Right posterior arm was broken off.

Pelvic bones were missed at collection.

The scapula is shown in Fig. 3 with measured data. The acromion and the colacoid are well developed. Fortunately, both sides of humerus, radius and ulna were collected and are present, the phalangial bones were cleaned up at The Whales Research Institute and transported to Taiji, but they were lost during the preparation of exhibition. Measurements of the above three are shown in Table 5.

We express sincere gratitude to Director Hideo Omura of The Whales Reseach Institute and to Prof. M. Iwashita and the stuff members of the Faculty of Marine Science and Technology of the Tokai University for help in burying and cleaning the skeleton at their campus. Our gratitude are also to the director, Mr. T. Higashi, and the stuff members of the Taiji Whale Museum for cooperation throughout the study.

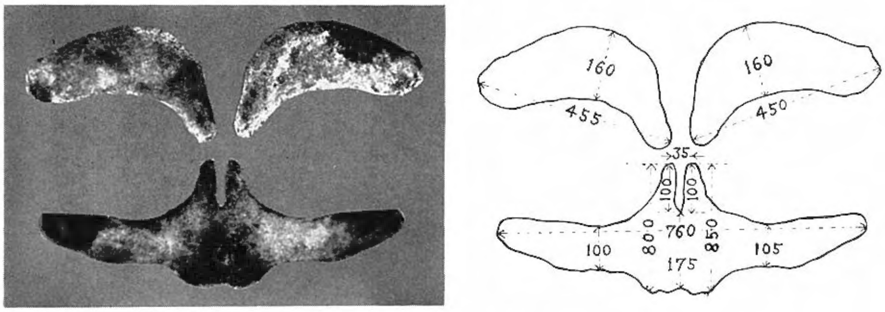

Fig. 1. Hyoid bones and their measurements of the Antarctic sei whale.

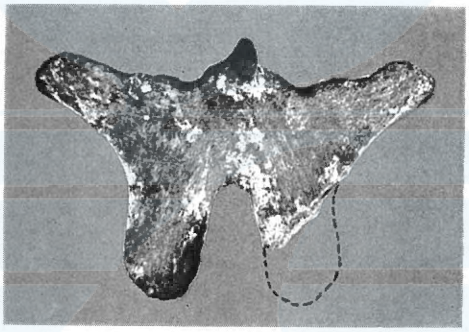

Fig. 2. Sternum of the Antarctic sei whale.

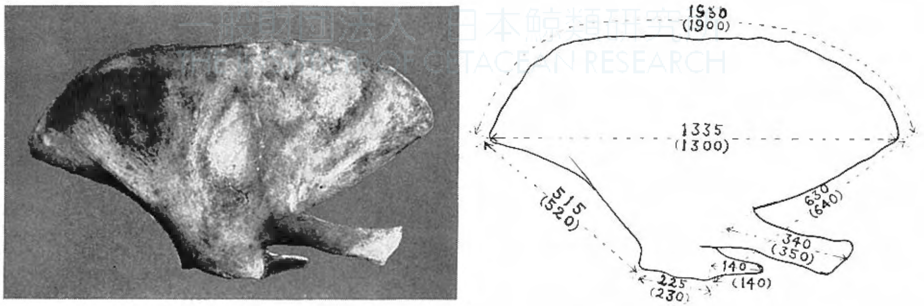

Fig. 3. Scapula and the measurements of the Antarctic sei whale (data of right scapula is in parentheses).

TABLE 1. SKULL MEASUREMENTS OF THE ANTARCTIC SEI WHALE

Measurements	Actual length (mm)	% of skull length	% of skull breadth
Length of skull, straight	3790	100.0	231.1
Length of beak	2630	69.4	160.4
Length of premaxillary, straight	R. 2980	78.6	181.7
	L. 2960	78.1	180.5
Length of maxillary along upper surface	R. 2860	75.5	174.4
	L. 2860	75.5	174.4
Tip of premaxillary to posterior end of maxillary	R. 3010	79.4	183.5
	L. 3010	79.4	183.5
Tip of premaxillary to vertex	2987	78.8	182.1
Tip of premaxillary to tip of nasals (mesial)	2635	69.5	160.7
Tip of premaxillary to anterior end of palatines (mesial)	2700	71.2	164.6
Tip of premaxillary to posterior end of palatines (mesial)	3260	86.0	198.8
Tip of premaxillary to posterior end of pterygoid	3470	91.6	211.6
Tip of premaxillary to anterior end of maxillary	R. 80	2.1	4.9
	L. 90	2.4	5.5
Length of supraoccipital from foramen magnum	800	21.1	48.8
Greatest breadth of skull, squamosal	1640	43.3	100.0
Breadth of skull, frontal	1550	40.9	94.5
Breadth of skull, maxillary	1420	37.5	86.6
Breadth of beak at base	990	26.1	60.4
Breadth of beak at middle	620	16.4	37.8
Breadth across premaxillaries, greatest	370	9.8	22.6
Breadth across premaxillaries, at base of beak	280	7.4	17.1
Breadth across premaxillaries, at middle of beak	260	6.9	15.9
Breadth across maxillaries at posterior ends	320	8.4	19.5
Breadth of pterygoids	280	7.4	17.1
Breadth of palatines	480	12.7	29.3
Breadth between tympanic bullae, outer	550	14.5	33.5
Length of nasals mesially	260	6.9	15.9
Length of nasals, laterally	R. 310	8.2	18.9
	L. 290	7.7	17.7
Breadth of nasals at anterior ends	170	4.5	10.4
Breadth of nasals at posterior ends	87	2.3	5.3
Breadth of orbit (frontal wing)	R. 260	6.9	15.9
	L. 260	6.9	15.9
Breadth of occipital between aquamosal sutures	1190	31.4	72.6
Breadth across occipital condyle	300	7.9	18.3
Height of occipital codyle	R. 210	5.5	12.8
	L. 210	5.5	12.8
Breadth of foramen magnum	110	2.9	6.7
Height of foramen magnum	145	3.8	8.8
Breadth across mastoid process, tip to tip	1280	33.8	78.1
Breadth across mastoid process, greatest	1460	38.5	89.0
Length of mandible, straight	R. 3460	91.3	211.0
	L. 3470	91.6	211.6
Length of mandible, along outer curve	R. 3610	95.3	220.1
	L. 3630	95.8	221.3
Height of mandible at coronoid	R. 400	10.6	24.4
	L. 390	10.3	23.7
Height of mandible at processus articularis	R. 275	7.3	16.8
	L. 294	7.8	17.9
Height of mandible at middle	R. 270	7.1	16.5
	L. 270	7.1	16.5

TABLE 2. MEASUREMENTS OF VERTEBRAE OF THE ANTARCTIC SEI WHALE (cm)

Serial No.	Vertebral No.	Greatest breadth	Greatest height	Centrum		
				Breadth	Height	Length
1	C 1	54.0	34.0	30.0	21.0	11.0
2	2	79.0	35.0	31.0	18.0	8.0
3	3	73.0	31.0	26.0	19.0	6.0
4	4	78.0	36.0	25.0	20.0	6.0
5	5	75.0	38.0	24.0	20.0	6.5
6	6	71.0	43.0	24.0	20.0	7.0
7	7	71.0	45.0	25.0	20.0	8.0
8	D 1	72.0	46.0	26.0	20.0	9.0
9	2	73.0	49.0	27.0	20.0	11.0
10	3	73.0	56.0	27.0	20.0	14.3
11	4	80.0	61.0	28.0	20.0	16.0
12	5	86.0	64.0	27.0	19.0	17.0
13	6	94.0	67.0	26.0	19.0	18.3
14	7	99.0	76.0	26.0	19.0	19.7
15	8	104.0	73.0	26.0	19.0	20.6
16	9	106.0	75.0	26.0	20.0	21.3
17	10	107.0	76.0	26.0	20.0	21.7
18	11	108.0	78.0	26.0	20.0	22.2
19	12	109.0	79.0	27.0	20.0	22.4
20	13	103.0	82.0	27.0	20.0	23.2
21	L 1	108.0	84.0	27.0	21.0	23.7
22	2	107.0	85.0	27.0	22.0	24.2
23	3	102.0	88.0	28.0	22.0	24.5
24	4	108.0	87.0	28.0	22.0	25.3
25	5	106.0	89.0	28.0	22.0	25.7
26	6	108.0	90.0	28.0	23.0	26.3
27	7	105.0	91.0	29.0	24.0	26.9
28	8	103.0	91.0	29.0	24.0	27.3
29	9	101.0	90.0	29.0	24.0	27.9
30	10	100.0	90.0	29.0	24.0	28.6
31	11	99.0	90.0	30.0	25.0	29.5
32	12	94.0	90.0	30.0	25.0	30.0
33	13	89.0	90.0	31.0	26.0	30.2
34	14	82.0	87.0	31.0	26.0	30.6
35	Ca 1	78.0	85.0	31.0	27.0	30.4
36	2	72.0	81.0	32.0	27.0	30.6
37	3	69.0	75.0	32.0	28.0	30.7
38	4	63.0	69.0	32.0	27.0	30.8
39	5	59.0	62.0	32.0	28.0	30.7
40	6	50.0	53.0	32.0	29.0	29.9
41	7	48.0	44.0	32.0	28.0	29.8
42	8	40.0	40.0	32.0	28.0	29.2
43	9	36.0	37.0*	31.0	28.0	28.0
44	10	30.0	34.0	28.0	27.0	26.7
45	11	28.0	31.0	26.0	26.0	25.0
46	12	25.0	27.0	24.0	22.0	19.5
47	13	21.0	22.0	20.0	19.0	14.4

Continued . . .

TABLE 2. Continued.

Serial No.	Vertebral No.	Greatest breadth	Greatest height	Centrum		
				Breadth	Height	Length
48	14	19.0	18.0	17.0	15.0	11.9
49	15	17.0	15.0	15.0	13.0	10.9
50	16	14.0	14.0	13.0	12.0	10.0
51	17	11.0	11.0	10.0	10.0	8.8
52	18	9.0	9.0	9.0	8.0	7.0
53	19	7.0	7.0	7.0	6.0	6.1
54	20	5.0	4.0	5.0	4.0	5.3
55	21	4.5	3.0	4.5	3.0	4.0
56	22	lost				

*: has some deficit

TABLE 3. STRAIGHT LENGTH OF RIBS OF THE ANTARCTIC SEI WHALE (cm)

Rib No.	right	left
1	89	88
2	148	151
3	181	201
4	197	209
5	176+	209
6	208	205
7	204	200
8	198	190
9	181	181
10	170	170
11	158	146
12	148	146
13	139	135

TABLE 4. MEASUREMENTS OF CHEVRON BONES OF THE ANTARCTIC SEI WHALE (mm)

No.	Length	Height	Breadth, (greatest)
1	110	240	170
2	120	300	160
3	150	300	210
4	140	310	210
5	150	180	180
6	140	230	190
7	130	230	180
8	130	190	160
9	120	160	140
10	120	120	130

TABLE 5. MEASUREMENTS OF HUMERUS, RADIUS AND ULNA OF THE ANTARCTIC SEI WHALE (mm)

	Length at center	Breadth at middle
Humerus		
Right	410	160
Left	410	160
Radius		
Right	680	85
Left	670	85
Ulna		
Right	720	70
Left	740	70

EXPLANATION OF PLATES

PLATE I

Fig. 1. Dorsal view of the skull of the Antarctic sei whale.
Fig. 2. Lateral view of the skull of the Antarctic sei whale.
Fig. 3. Ventral view of the skull of the Antarctic sei whale.
Fig. 4. Dorsal view of the mandibles of the Antarctic sei whale.

PLATE II

Fig. 1. Lateral view of the cervical vertebrae of the Antarctic sei whale.
Fig. 2. Lateral view of the thoracic vertebrae of the Antarctic sei whale.
Fig. 3. Lateral view of the lumbar vertebrae of the Antarctic sei whale.
Fig. 4. Lateral view of the caudal vertebrae (1st 12th) of the Antarctic sei whale.
Fig. 5. Lateral view of the caudal vertebrae (13th 21th) of the Antarctic sei whale.
Fig. 6. Caudal view of the 1st right side rib of the Antarctic sei whale.
Fig. 7. Ventral view of the vertebrae of the Antarctic sei whale from 13th lumbar to 2nd caudal, showing attachment facets for chevrons.


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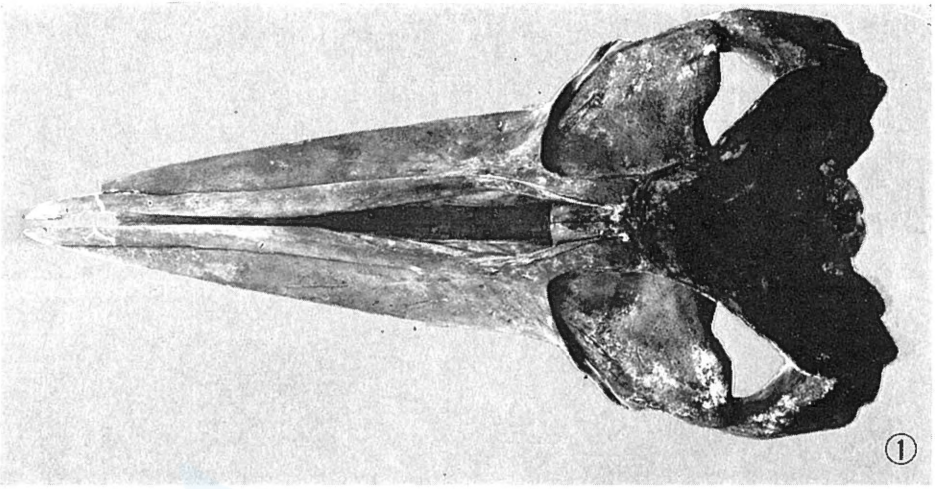

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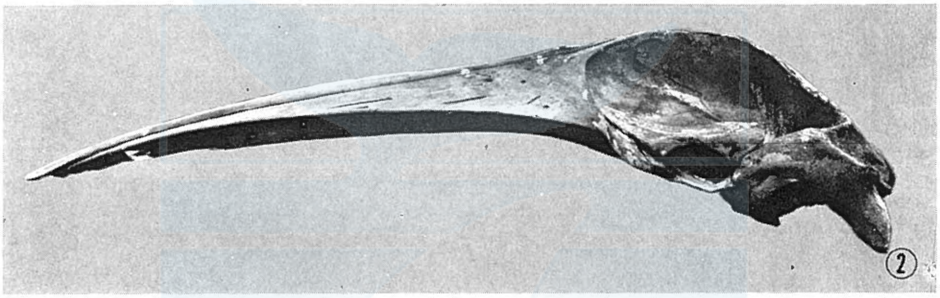

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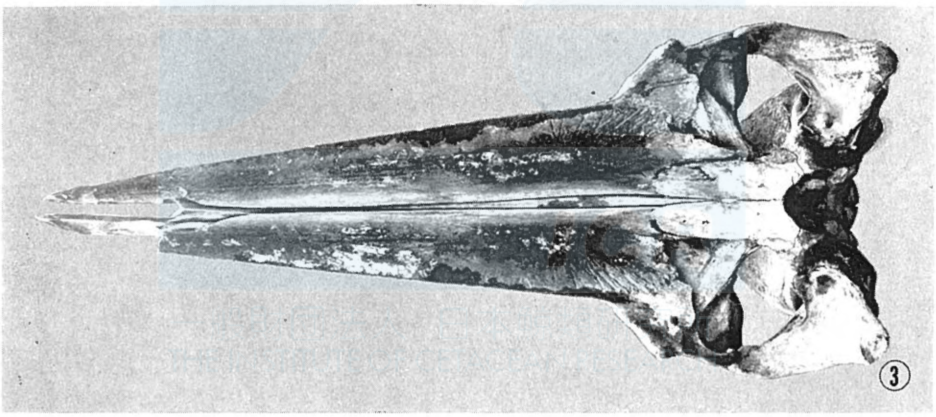

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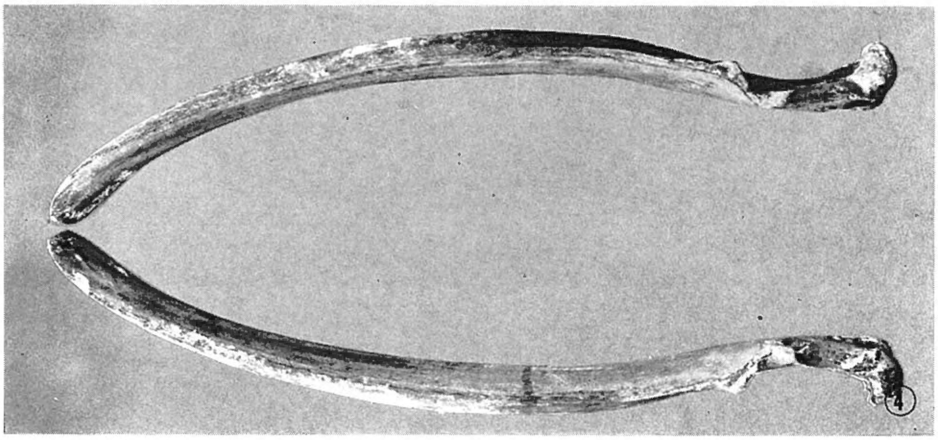

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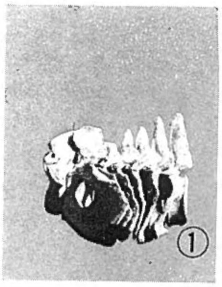
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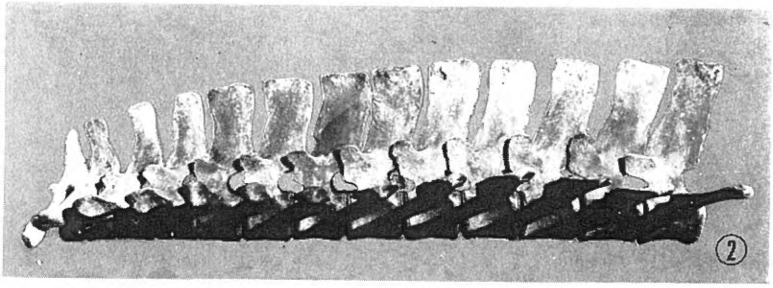
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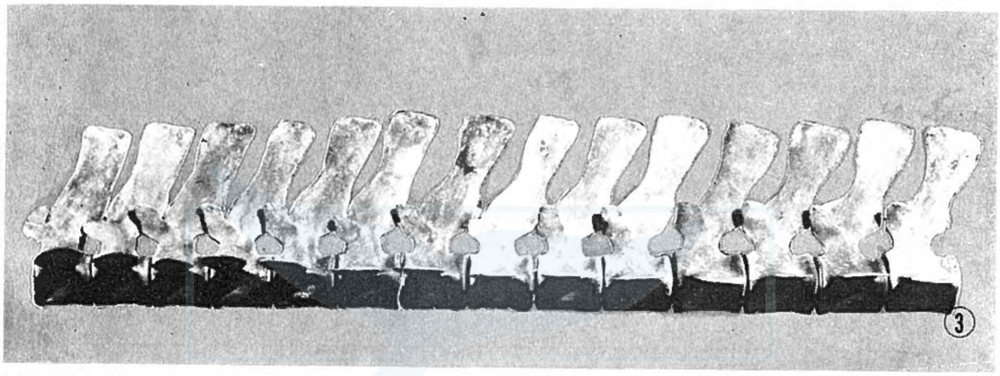
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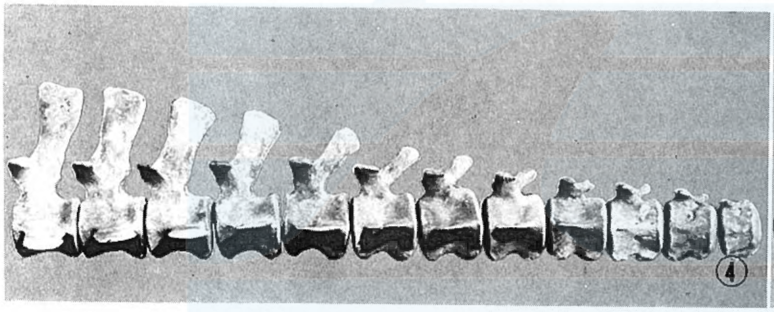
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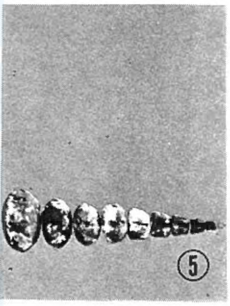
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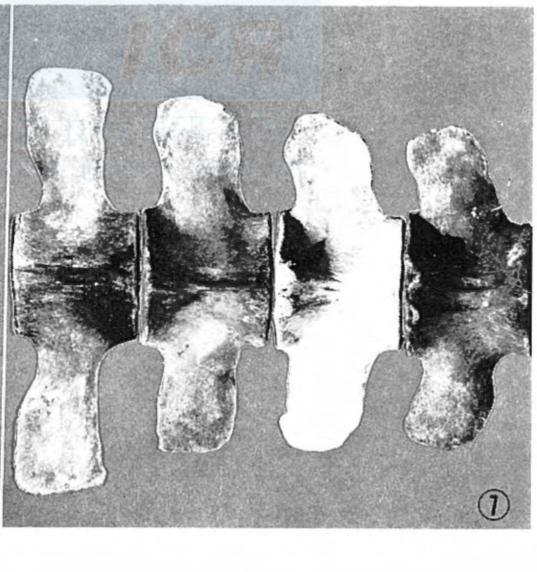
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SOME OBSERVATIONS ON THE CETACEAN STOMACHS, WITH SPECIAL CONSIDERATIONS ON THE FEEDING HABITS OF WHALES

HIROSHI HOSOKAWA* AND TOSHIRO KAMIYA**

ABSTRACT

Macro- and microscopical observations on the sei, fin, blue and sperm whale stomachs are described and discussed on the base of comparative-anatomical and functional viewpoint. The compartmentalization of the cetacean stomach is a unique character in the animal kingdom and it must be attributed to the aquatic life of the group. An attempt has been made to establish the relationship between the anatomical features of the cetacean stomach and its physiological function.

INTRODUCTION

In the latter half of the seventeenth century Tyson (1680) described the complicated stomach of the common porpoise. About one hundred years later Hunter (1787) remarked that the cetacean stomach revealed generally a highly characteristic feature of this group of animals, divided into several compartments. He noticed, furthermore, that it resembled very closely those of cattles and sheep, and he supposed the whales probably belonged to the ruminants, or had at least an intimate phylogenetical relationship with the ungulata. Thereafter, many anatomists directed their attention to the cetacean stomach and numerous reports were published, dealing directly or incidentally with this special feature of cetacean anatomy. Though it was soon ascertained that the cetacean stomach was, in spite of its resemblance to the ruminant one, quite different from the latter, its extraordinarily complicated structure remained for a long time without a clear comparative-anatomical explanations, not to speak of its physiological interpretation. The specifical differences in form of stomachs among all different kinds of whales were so extreme that it was very difficult to abstract the standard figure of them. We will quote here, for example, various numbers of stomach-chambers recorded by many authors for Mystacoceti. In most cases, the research materials of these authors were adult or fetal minke whale (*Balaenoptera acutorostrata*), though some of them studied the blue whale (*B. musculus*) or fin whale (*B. physalus*). Schulte alone used a fetus of the sei whale (*B. borealis*).

Hunter (1787) 5, Cuvier (1805) 4, Meckel (1829) 3,

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* The late Professor of the Department of Anatomy, Faculty of Medicine, University of Tokyo, he deceased on the way to this work in 1967.

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Eschricht (1849) 3, Murie (1865) 4, Carte & Macalister (1868) 5,
Perrin (1870) 4, Weber (1888) 3*, Pilliet (1891) 4,
Turner (1892) 5, Schulte (1916) 4*, Slijper (1962) 3*.
*without counting the duodenal ampulla.

At the end of the nineteenth century, however, Weber (1888) and Jungklaus (1898) published very splendid works on this problem and the macroscopic anatomy of the cetacean stomach was brought to a general conclusion. Thus, Weber classified the stomach of toothed whales, based on the development of its first compartment covered with the oesophageal mucous membrane, into the following 5 types: 1) Ziphiidaes-type, 2) Hypothetic intermediate-type, 3) Phocaena-type, 4) Globicephalus-type and 5) Lagenorhynchus-type, and he explained that these types had developed one by one in the order of their number from the most primitive Ziphiidaes type. On the other hand, according to Jungklaus, who endeavoured to use generally the comparative-anatomical characteristics of the cetacean stomach, not only of the toothed whales but also of the baleen whales, the most remarkable peculiarity of the cetacean stomach distinguishing itself from the same of other mammals did not lie in its mere complexity caused by the compartmentalization but consisted in the fact that the glandular stomach itself was separated into two divisions, one of those being provided with the peptic or fundus glands and the other with the pyloric glands. The latter divisions were, moreover, apt to be divided into two or more secondary compartments. On the difference between the Odontoceti and Mystacoceti stomachs he stated that in the latter the constrictions between each divisions or compartments were not so sharp as in the former. Jungklaus's conclusion of the characteristic feature for cetacean stomach is quite right from the comparative-anatomical standpoint, as was confirmed afterwards by Beddard (1900). From the physiological standpoint, however, we suppose that the complexity of the cetacean stomach, which is caused not only by the compartmentalization of the glandular portions but also by the oesophageal dilatation etc. has a great significance. Against this background information we will, in the present paper, try to present a detailed histological picture of the cetacean stomach.

MATERIALS

Baleen whale:

Sei whale (*Balaenoptera borealis*): 14.0 m male, 14.6 m female, 15.7 m female, 16.2 m female.
Fin whale (*Balaenoptera physalus*): 21.3 m female.
Blue whale (*Balaenoptera musculus*): 23.8 m male.

Toothed whale:

Sperm whale (*Physeter catodon*): several adults, of which one 11.0 m long female and one 15.6 m long male were studied with special attention.

OBSERVATIONS

Stomach of the baleen whale

It is composed of four compartments arranged in series. The first compartment, into which the oesophagus opens, is nothing but a dilated sack at the lower end of the oesophagus and the fourth division is the extraordinarily developed duodenal ampulla, into which opens the combined duct of the liver and of the

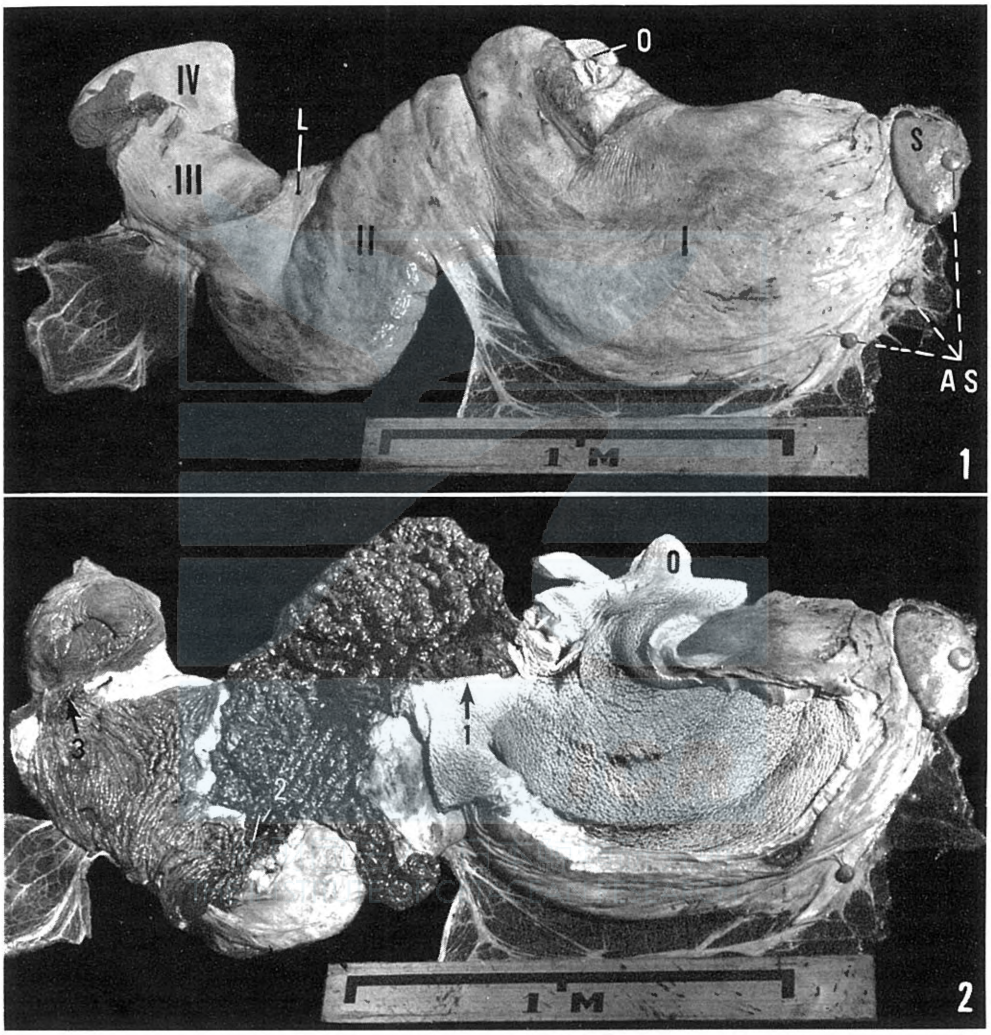

Fig. 1. Ventral view and frontal section of the stomach of a sei whale, 14.0 m male. The Roman numerals showing the first (I) to the fourth (IV) compartments and Arabic numerals with arrow showing boundary between the each compartments.
O: oesophagus S: spleen AS: accessory spleen L: gastro-phrenic ligament

pancreas. The other two, namely the second and the third, are real gastric compartments providing with digestive glands. Between these two, however, there is another small division developed especially in the fetal stage. In the female sei whale of 15.7 m length the largest compartment is the third one, measuring 110 cm and 85 cm respectively in the transverse and longitudinal diameters in relation to the axis of the digestive canal, followed by the fourth (85 × 75 cm) and the second (80 × 80 cm) in that order, and the first compartment is still smaller. Communication between the first and the second chambers is through a not so strong constriction. Where the second chamber leads into the third through the small connecting division, there exist two semilunar valves separating the two compartments. The third compartment opens into the fourth through the narrow passage constricted sharply by the pyloric sphincter (Fig. 1).

Macroscopical features of the mucous membrane: (Plate I)

The mucous membrane of the oesophagus is lined by the thick, graywhite and cornified epithelium folded with numerous longitudinal, fine furrows. The same epithelium clothes the inner surface of the first compartment too, and there are many reticular folds of several millimeter in width, which are ramified and anastomosed to each other. These reticular folds disappear, when the wall of the stomach is stretched, so that they are formed by the undulation of the whole wall. It is clear, therefore, that this compartment is able to contract and dilate to a considerable extent by the aid of the mural muscle strata. Where the first compartment leads into the second one, the mucous membrane changes its character abruptly, there is a distinct lineal boundary between the oesophageal epithelium of the former and the gastric lining of the latter (Plate I-1). This is covered by the soft, mucous epithelium of dark gray colour with some tone of yellow. Its surface is smooth for 2–3 cm from the line separating the oesophageal epthelium and the gastric lining referred to above, followed by thick reticular folds, about 1 cm in width, resembling the convolution of the human cerebrum. These folds do not disappear even when the stomach is stretched; that is to say that they are formed in the mucous membrane itself merely for the purpose to increase the inner surface of the stomach. The second compartment has, therefore, no anatomical feature to contract or dilate itself extensively. In the lower half of the second compartment the reticular folds are reduced as the compartment approaches the third one, in which the surface of the mucous membrane is quite smooth and without any furrows or folds. It is coloured yellowish gray, with some tone of pink. The duodenal ampulla is clothed also with smooth, soft membrane, coloured brownish red and it continues with that of the small intestine, without any constriction or valve. For the female sei whale (15.7 m long) the first compartment has the thickest wall measuring 2.5 (–3.0) cm, containing very well-developed muscular strata. The wall of the remaining three are somewhat thinner and measure about 1.2 (1.0–1.5) cm. The wall of the small intestine is 0.8–1.0 cm thick. For the male blue whale of 23.8 m length the walls of the first, second, third and fourth compartments were 4.0 cm, 2.0 cm, 1.5–2.0 cm (mucosa: 0.5, muscularis: 0.9, serosa: 0.1) and 1.3 cm (mucosa: 0.3, muscularis: 0.7, serosa: 0.3) respectively.

Histological structure: (Plate II)

Oesophagus is lined by an extensively stratified flat epithelium of about 1 mm in thickness. The most superficial layer of the epithelium (25–30 μ) is completely cornified and the cells have no trace of nucleis in contrast to the case in humans. The next layer of about 25 μ has cells containing rudimentary nuclei. These two layers are followed by a third layer, 4–5 cells in thickness the cytoplasm of the cells staining deep red with eosin and the nuclei are shriveled, indicating probably the commencement of the cornification of cells. The next layer is composed of several strata of large cells, occupying the greater part of the epithelium. While the cells of the upper portion of this layer are situated with their axis almost parallel to the surface of the epithelium, those of lower part make a right angle with the same especially in the areas between the papillae. While the nuclei of the former are smaller and stain deeply, those of the latter are larger and stain lightly. The deepest layer is bounding to the propria, and composed of crowded cells of small size. The connective tissue, propria, of about 3–4 mm in thickness, contains many vessels and fat-cells and forms high papillae, which are very well-developed, and the thickness reaches as high as 95% of the total thickness of the epithelium (in the case of humans oesophagus it is only 50%). The density of the papillae is also larger in the cetacean oesophagus than in the human case.

The smooth muscle fibres of the lamina muscularis mucosae are arranged not so orderly as in other mammals, but are scattered irregularly. This unsystematic arrangement of the muscularis mucosae is noticed not only in the oesophagus but also in every compartment of the stomach and throughout the intestine, thereby losing the significance of the the name of " lamina ". The submucosa, formed by loose connective tissue, has nothing special to be described. The muscularis presents an inner, circular and an outer, longitudinal layer of muscle bundles. In the upper portion of the oesophagus it consists exclusively of striated fibres, but in the middle and lower parts the muscularis is composed wholly of smooth fibres. Between the inner and outer layers there are scattered nerve fibres and ganglia, analogous to Auerbach's plexus, which we come across in the intestines. The outer surface of the muscularis is covered with a thick membrane of connective tissue reinforced by elastic networks (adventitia).

The histology *the first compartment* of stomach is not very different from that of the oesophagus, in spite of the slight difference in the relative thickness of the corresponding layers or strata. It is quite obvious that this compartment is nothing but a dilated sack of the lowest part of the oesophagus.

The second compartment. The simple cylindrical epithelium lines the entire inner surface of this compartment, including the gastric pits. It is composed of light cells having distinct boundaries between each other. Nuclei of these cells are small-sized, deeply stained and are situated at the base of the cells. At the floor of the gastric pits open numerous gastric glands occupying the propria and we can discriminate two kinds of glands, the cardiac and the fundus glands.

The cardiac glands. Contrary to the earlier belief that the cetacean stomach is destitute of the cardiac glands, we found cardiac glands to exist in the stomach of a blue whale, occupying the narrow zone adjacent to the border-line at the junction between its first and the second compartments. They are quite like the pyloric glands of the third compartment in their structure, both being of the tubulo-alveolar nature and composed of light cells of one kind.

The fundus glands. This type of gastric glands, branched tubular in nature, are extended in the greater part of the mucous membrane of the second compartment, situated within the propria and are 2–3 mm in thickness (in humans it is at most about 1.0 mm). The zymogenic cells of this gland, 6–7 μ in diameter, are characteristic with the fairly coarse granules they contain, which stain with basic dyes in the same way as the chromatin of the nucleus. The second kind of cells found in this gland, the parietal cells, are much more developed than in the human stomach. They differ from the chief cells in being considerably larger (10–20 μ in diameter) and in their spherical or pyriform shape, containing sometimes two or more nuclei. Frequently, especially in the lower part of the gland, they do not reach the lumen of the tube, being connected with it by a narrow pedicle. The most striking characteristics of these cells are their strong affinity for acid dyes. Numeral ratio between the zymogenic and the parietal cells is about 3: 1 and this index shows, compared with that of 5–6: 1 in the human case, that the cetacean stomach has plenty of parietal cells, which are said to secrete hydrochloric acid. This peculiarity of the cetacean fundus glands must have some important meaning for the gastric function of this animal. Mucous neck cells are situated near the openings of the glands into the gastric pits and can be discriminated easily by their light cellular body and somewhat shriveled nucleus, lying aside at the bottom of the cells.

The propria consists mainly of reticulated tissue, containing many free cells or aggregated lymphatic cells.

The muscularis mucosae, which separates the propria from the underlying submucosa, does not form a well-defined layer and is divided into the following four groups of muscle bundles; 1) muscle-fibres scattered in the propria, some of which extend along the fundus glands up to the superficial layer underlying the epithelium, 2) fibre-bundles running in the same direction as the reticulated folds of the mucous membrane, 3) and 4) two muscle bundles in the deeper layer, which run independently of the direction of the reticulated folds, crossing each other at almost right angles.

In the loose connective tissue of the submucosa run arteries provided with very thick walls, just like the case in the cattle.

As muscularis was stripped of in our materials it was not possible to examine it histologically.

The third compartment. The simple cylindrical epithelium clothes the inner surface, where numerous gastric pits are developed. Glands of this compartment that extend into the propria are the pyloric glands. They are of the branched tubulo-alveolar nature, and the glandular epithelium here presents great differences from that of the fundus glands as these are composed of only one kind of cells. Although these cells differ slightly from the zymogenic cells of the fundus glands, they resemble the latter in all essential particulars so much so that we may take them for the same.

The propria of this compartment does not differ from that of the second chamber. The muscularis mucosae also resembles that of the second one, but the first group of muscle-bundles is more developed in this compartment and the second group is lacking, while the third and fourth groups are only weakly developed.

In the submucosa there are scattered fat-cells, vessels, nerve-cells and fibres. The muscularis is stripped off.

The fourth compartment (duodenal ampulla). The histology of the fourth compartment in the oral half is not very different from that of the third compartment and in the anal half in their structure leads into the small intestine.

Stomach of the sperm whale

As refered to in the introduction, the constrictions between adjacent gastric compartments in the sperm whale are marked more sharply than in the baleen whales, and we can easily discern four compartments. The first and second compartments are very large, each measuring 140 × 140 cm for an adult male of 15.6 m length, and the third and fourth are somewhat smaller, measuring 130 × 60 cm and 130 × 100 cm respectively.

The inner surface of the first compartment is covered with the same, yellowish white epithelium as is the case with that of the oesophagus. There are, however, no well-developed folds, the inner surface here being provided only with the irregular reticular fine furrows, especially in the region between the opening of the oesophagus and the passage into the second compartment. The oesophageal epithelium of the first compartment stands out distinctly from the soft, mucous membrane of the second one. The surface features of the latter resemble that of the sei whale, having been provided with the reticular folds, which diminish in the areas near the first and third compartments. The third and fourth compartments are clothed by a similar smooth membrane as in the sei whale, though in the fourth come into sight semilunar folds as it approaches the opening into the small intestine.

Thickness of walls of different compartments. The thickness of the wall of the first compartment is 2.5–3.0 cm (mucosa 0.7, muscularis 1.7, serosa 0.4) of the second compartment 2.5–3.0 cm (mucosa 0.8, muscularis 1.4, serosa 0.7), and each of the third and fourth compartments 1.0–1.5 cm. It was not possible to do histological studies of the stomach of this whale, as it is very difficult to get seasonably fresh materials to be used for microscopical work.

DISCUSSION

1. *Cetacean stomach seen from the comparative-anatomical viewpoint:*

To understand the physiological meaning of the complicated feature of the cetacean stomach, we may first briefly review the comparative anatomy of the stomach in the animal kingdom. Fishes have stomachs of various shapes. Amphibians and reptiles have also gastric sacks and the birds posses in addition to the crop, dilated sack of the oesophagus, glandular and muscular stomachs. As to the mammals though the monotremata and a small group of rodentia are said to have no glandular stomach, almost all others have glandular stomach, where three distinct regions or areas can be identified, namely the cardiac glandular, the gastric or fundus glandular and pyloric glandular. Besides, there very often are also the oesophageal, non-glandular region or expansions. According to the combinations of these regions among mammals, there are many types of stomachs, and Ellenberger (1926) classified them into the following groups:

1) Simple stomach composed merely of glandular regions
    a) simple form lacking in cardiac sacks
        i) shaped like a simple sack, e.g. phoca;
        ii) provided with swelling of fundus, e.g. carnivora, insectivora, many rodentia, chiroptera, apes and man;
    b) complex form provided with one or more cardiac blind sacks, e.g. sirenian, large kangaroos and pig;
2) Complicated stomach composed not only of glandular regions but also of oesophageal region or expansions (always possess the cardiac area).
    a) simple form . . . the glandualr and oesophageal regions make altogether a simple stomacheal sack.
        i) provided with not so large fundus, e.g. horse and tapir.
        ii) provided with conspicuously large fundus, e.g. mouse and rat.
    b) complex form . . . the oesophageal ampulla makes one or more forestomachs independently of the glandular, real stomach, e.g. cetacean and ruminantia.

From this classification it is clear that the complexity of the mammalian stomachs is caused mainly by two reasons by the expansion of the fundus or cardiac blind sacks, and by the oesophageal forestomach that can be divided again into two or more compartments. In view of these facts, the cetacean stomach, of which the complexity lies in the subdivisions of the glandular stomach itself, is an exceptional case in the animal kingdom. Though Ellenberger in his classification grouped the cetacean stomach with the ruminantia, we see now that there is a distinct difference between these two. In the latter, though it is composed also of four compartments, the first three, rumen, reticulum and omasum, are clothed with the oesophageal epithelium and only the last one, abomasum, represents the real digestive part of the stomach. Thus in the ruminantia the stomach may be regarded as being primarily divided into two regions, the last of which only is the digestive region, and the first, non-digestive, being again sharply divided up into three compartments. In the cetacea, on the other hand, the stomach, although divided primarily into two parts like that of the ruminantia, shows a further subdivision of the digestive region which may be exceedingly complicated in the Ziphiidae, while the non-digestive region is not divided at all.

2. *On the function of the cetacean stomach, with considerations on its interrelation to the food-catching modus of whales:*

Anatomical features of various organs in the animal body are generally formed and elaborated by two components, the external or the environmental and the internal or the hereditary. While the latter moment defines the hereditary features, the former modifies often the anatomical structures so as to be adapted to the environments of the animal. And such organs, under the influence of the environment, can get strongly modified in their shape, size and structure. We consider the stomach to furnish an example of this latter kind, as this organ is apt to be modified according to the alimentary life of its possessor.

From this view-point the complicated stomach of the cetaceans seems to be intimately related to its alimentation, especially with its mode of food-catching in the aquatic environment. Weber (1885) mentioned already that the complexity of the stomach of the cetaceans was caused by the impossibility of their chewing in the aquatic medium, which seemed to be quite acceptable to us. He, however, did not explain the reason for the cetacean inability to masticate food. We would therefore, like to put forward our view-point here to explain this.

Judging from the anatomy of the cetacean oral cavity, it is evident that the whales do not masticate their food. To say nothing of the baleen of Mystacoceti, the numerous teeth of Odontoceti are also far from being suited for mastication, for they are conical homodont teeth, not to adapted for chewing, although aparently well-suited for biting foods. The case of sperm whale and *Ziphius* also is not much different from that of Mystacoceti, as the former has only ten and several teeth in the mandible and that with wide diastema in between the teeth, and the latter possess only one or two pairs of teeth in the rostral end of the mandible. The mandibular articulation and masticatory muscles of whales, together with the poor development of their lips also lend support to the above view, which is further augmented by the poor development of the salivary glands indicating that the cetacean mouth is not anatomically and physiologically meant for mastication. Thus deprived of the function of mastication, the cetacean mouth is devoted, we believe, exclusively to prehension of food.

Of the two major functions of mouth in higher animals, namely prehension and salivary digestion, the cetacean mouth seems to be primarily concerned with the former function. This can be explained by the aquatic environment and food-habit of these animals, as they require a large quantity of food, and like the ruminantia, they cannot be expected to waste their time between catching and swallowing of food. This feature needs a large stomach with compartments given to different functions like storing, grinding and digestion. Thus the complex stomach of whales with its four compartments is very well adapted for their aquatic life.

SUMMARY

Some of the notable findings on the anatomy of the cetacean stomach are summarized as follows:

1. The cetacean stomach is composed of four serially arranged compartments, of which the first one is a oesophageal sack, the second one has numerous fundus glands, the third one possesses many pyloric glands and the last one represents a well-developed duodenal ampulla.

2. Between the second and the third compartments there is, moreover, a small communicating division, which is prominent especially in the fetal stages.

3. The first compartment is clined with an extensively stratified flat epithelium, of which the superficial layer is completely cornified and the cells have no trace of nucleus, just like in the oesophagus.

4. The wall of the first compartment is the thickest of the four, and contains very well-developed muscular strata. This compartment has undoubtedly a considerable contractibility.

5. Despite the general belief that the cetacean stomach is destitute of cardiac glands, we found them in an adult blue whale stomach in the narrow region adjacent to the boundary between the first and the second compartments.

6. The fundus glands of the second compartment have extraordinarily numerous parietal cells. They may have some intimate relation with the gastric function of whales.

7. The smooth muscle fibres of the lamina muscularis mucosae of all the four compartments are scattered irregularly, and as such do not deserve to be called " lamina ".

ACKNOWLEDGEMENT

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EXPLANATION OF PLATES

Plate I.

Mucous membrane of the stomach of a fin whale, 21.3 m long female. (×3 natural size)

Fig. 1. Boundary between the first (left) and the second compartments.
Fig. 2. Boundary between the second (left) and the third compartments.
Fig. 3. Boundary between the third (left) and the fourth compartments.

Plate II.

Histological section of the stomach of a fin whale, 21.3 m long female. The Roman numerals showing the first to the fourth compartments. (×4 natural size)

Fig. 1. Boundary between the first and the second compartments.
Fig. 2. Boundary between the second and the third compartments.
Fig. 3. Boundary between the third and the fourth compartments.
S: sphincter muscle

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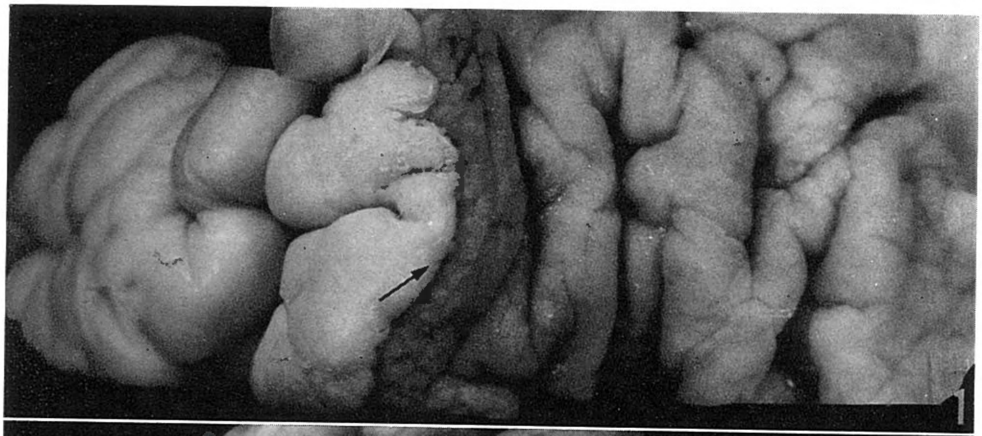
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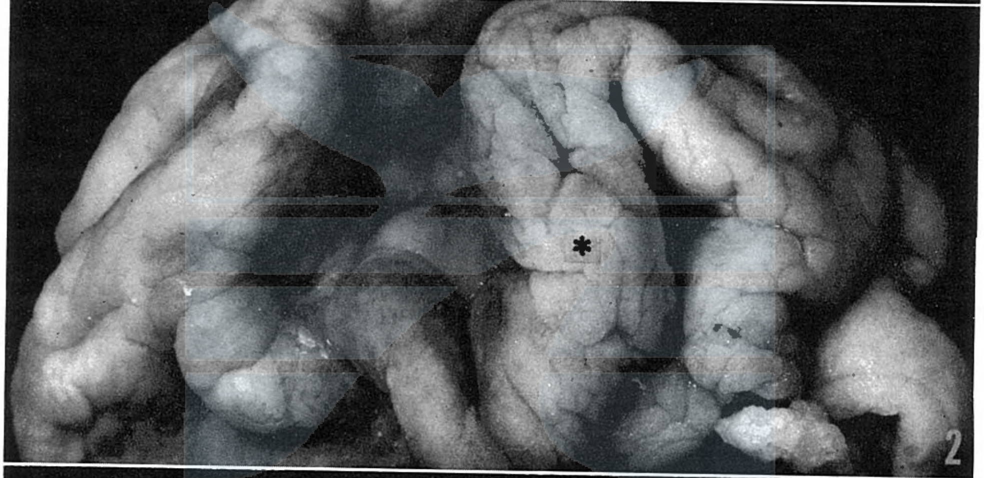

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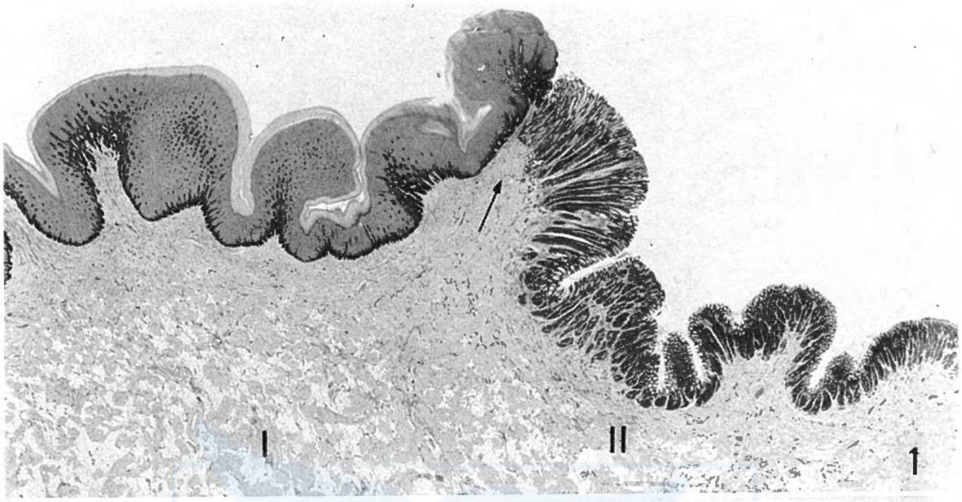

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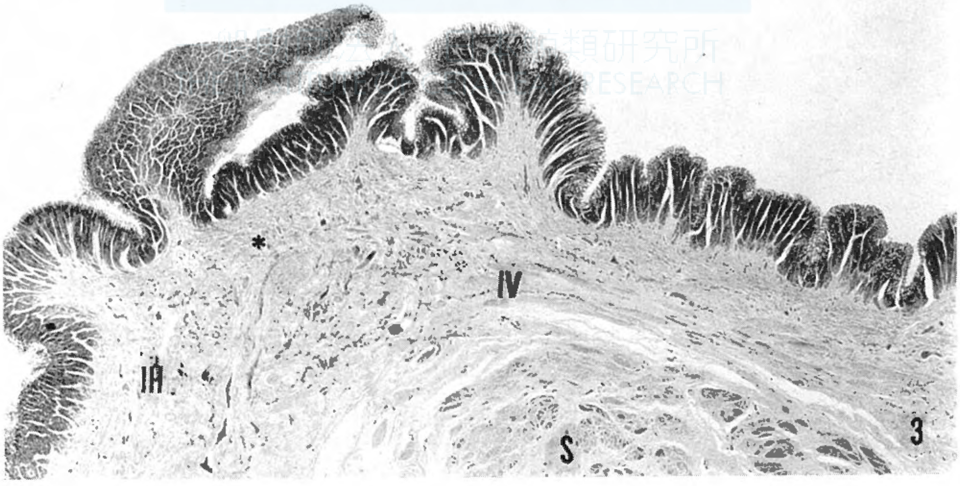

3

INFLUENCE OF INCREMENTAL LINES UPON THE COMPRESSIVE STRENGTH OF SPERM WHALE DENTIN

ARMAND A. LUGASSY*, EDWARD KOROSTOFF** AND
JOSEPH L. RABINOWITZ***

ABSTRACT

Compressive properties of sperm whale dentin were measured as a function of orientation of incremental lines. With respect to the general incremental lines' direction, three specimen orientations were selected: longitudinal, oblique (45°) radial and transverse radial. The machined cylindrical specimens were compressed in a mechanical testing machine. A load cell provided with the force values developed on the samples and a displacement transducer yielded the corresponding deformation values. The resulting stress-strain curves provided with values of proportional limits, ultimate compressive strengths and elastic moduli for each of the specimen orientation investigated. It was found that while the ultimate compressive strength values did not differ statistically with specimen orientation, proportional limits and elastic moduli showed some significant differences. Based on a possible functional adaptation, a theory has been formulated which correlates the results obtained with the growth patterns found in sperm whale dentin.

INTRODUCTION

Calcified tissues in vertebrates display a combination of structure and properties which reflect an adaption for their function in the living systems. Bones are designed to provide the adequate framework for sustentation of the body weight and muscular action. Teeth of ruminants display flat occlusal surfaces allowing grinding of grass and seeds whereas carnivorous animals have teeth which tear flesh and fracture bones. Some dentitions may only be used to shear and retain as in the case of some fish, aquatic reptiles and other sea going mammals.

Sperm whales' teeth are characterized by their conical shape, their continuous growth patterns and their funnel-shaped attachment to the jaw. They are not known to be used for chewing, however they can be utilized for snapping and retaining prey in the mouth. This investigation concerns itself with the influence that incremental line orientation in dentin have upon its resistance under compressive stresses. In light of the present findings, it is suggested that growth patterns and compressive stresses interact in the growing organ to explain the differences in the measured properties.

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MATERIALS AND METHODS

Sperm whale teeth were chosen because of their large dimensions and easy availability. The teeth were obtained through a marine life dealer and, as soon as received, they were inspected for any apparent defects. They were then placed in individually labelled plastic bags and stored in the freezing compartment of a refrigerator at $-18°C \pm 1°C$ until ready for machining. In this study a single tooth was selected as it provided enough specimens. It also was felt that this choice would restrict the variability inherent to the use of several teeth taken at random.

A sperm whale tooth is shown in figure 1. It has a short crown and a comparatively long root. The outer aspect of the tooth is covered by a thick layer of cementum (Ohsumi et al., 1963). Because of its regular texture and amplitude, the dentin in the cervical area, shown in figure 2(A), was chosen to prepare the various types of specimens used. This region of the tooth was divided in several horizontal sections. Each section was used to machine three specimens in different orientations. With respect to the incremental lines, the specimen orientation was as follows: longitudinal, oblique (45°) radial and transverse radial as shown in figure 2(B). A total of 6 specimens in each group was produced in this manner.

The dentin specimens were turned with a jeweler's lathe at low speed. Each cutting pass was made small to avoid any mechanical damage to the material. The specimens were moistened with a drip of Krebs-Ringer phosphate buffer solution during this procedure. This precaution was taken to avoid overheating and also provided proper lubrication for the cutting of the dentin. The specimens' end faces were ground flat at right angle to their principal axis. This procedure was carried out by inserting the samples in holes of slightly greater diameter made in a flat

Fig. 1. Bucco-lingual view of a sperm whale tooth.

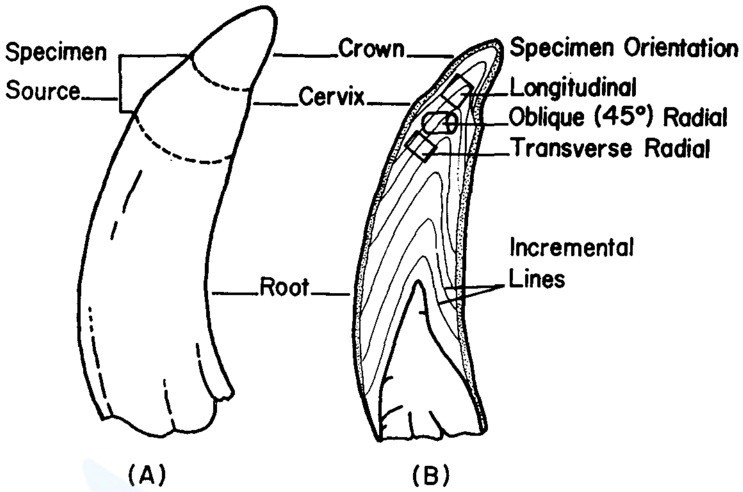

Fig. 2. Sperm whale tooth: (A) Specimen source and (B) Specimen orientation with respect to the incremental line direction.

hardened steel slab of a given thickness. The finished specimens were of the following dimension: diameter=0.085 in., length=0.158 in. Before the actual tests, the specimens were placed in labelled jars filled with Krebs-Ringer phosphate buffer solution and stored in a refrigerator at a temperature of about 3°C.

The dentinal tubules' main direction in the various specimens studied are

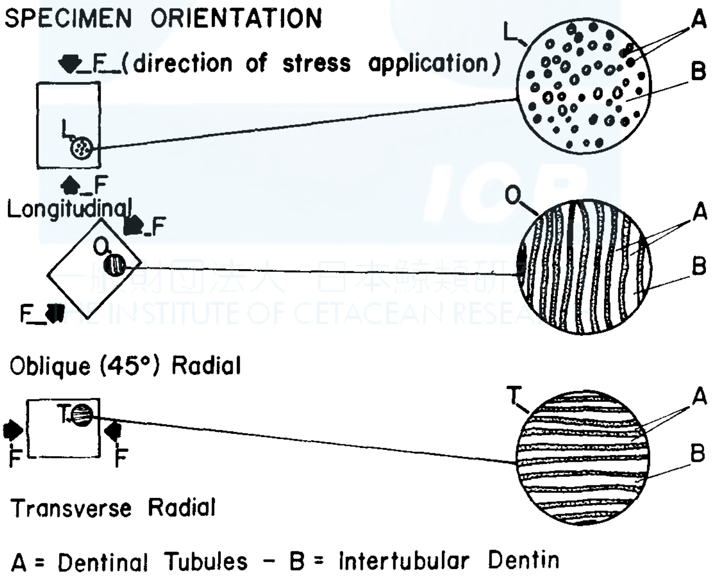

Fig. 3. Dentinal tubule alignment in three types of specimen orientation.

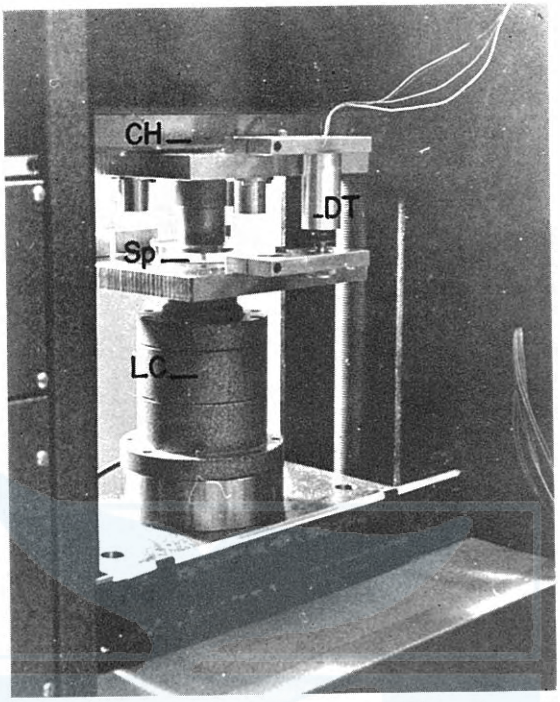

Fig. 4. Photograph of the compression apparatus: (SP) Specimen, (LC) Load cell, (DT) Displacement transducer, (CH) Crosshead.

represented in figure 3. This result was obtained by making a series of longitudinal sections in each specimen after completion of testing and examining the thin ground sections under standard and polarized light microscopy. Essentially, it was observed that the dentinal tubules were directed at right angle with respect to the general orientation of the incremental lines. The orientation of the incremental lines in each type of specimen was assessed by direct inspection.

Deformation and fracture of the specimens was performed in an Instron mechanical testing machine (Fig. 4). The load signals were taken from the testing

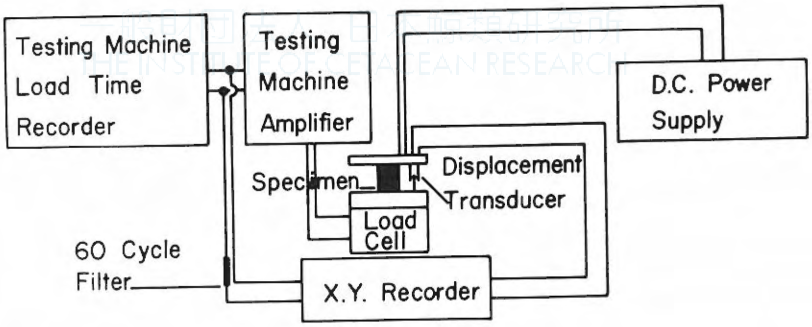

Fig. 5. Block diagram of the circuitry used in the compression tests.

machine amplifier and fed to the y axis of an x-y recorder. The deformation values were measured by a displacement transducer and its output fed to the x axis of the x-y recorder (Fig. 5). Both loads and corresponding deformation values were simultaneously plotted on the recorder and later converted into engineering stress and strain values by using the formulae: P/A_0 and $\Delta L/L_0$ respectively, where P=load, A_0=original cross sectional area, ΔL=change in length and L_0=original specimen length. Because of the comparative character of the study, data analysis, according to a true stress-true strain relationship, was not felt to be relevant and therefore was not performed.

Before the tests, the refrigerated dentin specimens were allowed to warm up and come to equilibrium with the ambient temperature. Once again their dimensions were checked. The deformation to failure was conducted at a constant cross-head speed. This portion of the experiment was carried out with the specimen immersed in Krebs-Ringer phosphate buffer solution to avoid the possibility of specimen moisture loss during the test. The water and inorganic content of the specimens were obtained by desiccation and ashing respectively, as shown in Table 1.

TABLE 1. COMPOSITION OF SPERM WHALE DENTIN

Oven Dried (105°C)	Ashing (1100°C. for 24 hours)	
Water % of wet weight	Organic Matter % of dry weight	Inorganic Matter % of dry weight
14.72	28.55	71.45

RESULTS

The results listed in Table 1 represent the composition of sperm whale dentin. The water content is representive of the hydration water as well as the water found in the dentinal tubules. It is however recognized that some chemically absorbed water still remained in the material and was not displaced at the selected drying temperature (Eastoe, 1967). A more detailed analysis showed that the inorganic matter was mostly composed of calcium and phosphorus, whereas the organic phase was found to be proteinic in nature.

In Table 2 the results for the elastic modulus, proportional limit and ultimate strength of various specimen orientations are given along with the strain rate at which each group of experiments was carried out.

TABLE 2. MECHANICAL PROPERTIES OF SPERM WHALE DENTIN SPECIMENS UNDER COMPRESSION

Specimen Orientation:	Longitudinal	Oblique (45°) Radial	Transverse Radial
Ultimate Strength (psi)	29300*±4400**	28000±4500	26000±1500
Proportional Limit (psi)	4400±1500	3700±700	3700±600
Elastic Modulus (psi)	$(7.8\pm1.3)\times10^5$	$(4.3\pm1.4)\times10^5$	$(2.9\pm1.5)\times10^5$
Strain Rate (sec^{-1})	$(64.6\pm1.0)\times10^{-5}$	$(55.9\pm6.6)\times10^{-5}$	$(64.6\pm8.1)\times10^{-5}$

* Mean ** Standard Deviation

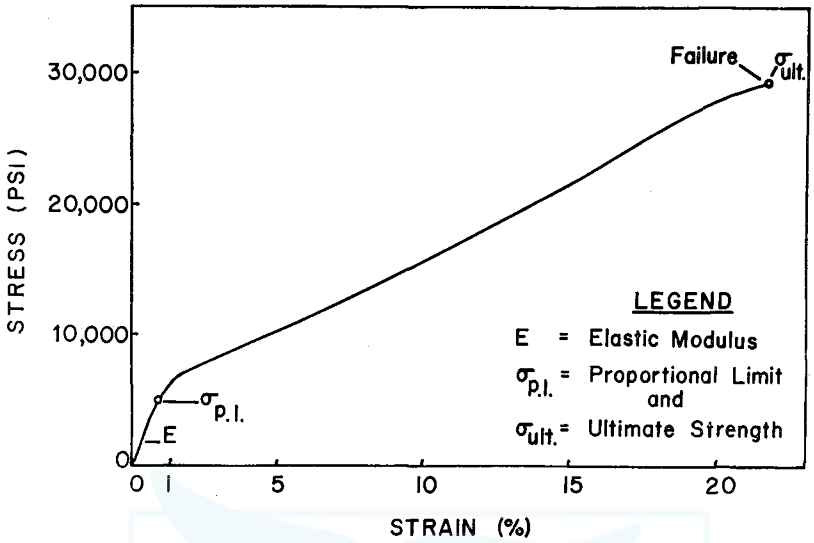

Fig. 6. Typical stress-strain curve with salient features and representative values obtained with various specimen orientations.

A general view of the stress-strain curve is given in figure 6. Its salient features and stress values result from graphing several curves obtained by testing various specimens in the different orientations. The linear portion of the curve is representative of the elastic modulus, the proportional limit was measured at the onset of a plastic strain of about 3×10^{-1}, and the ultimate strength, which here is also the stress at failure, was obtained at maximum plastic strain.

DISCUSSION

It was felt that the determination of the chemical composition of sperm whale dentin (Table 1) would be of help in explaining, in part, some of its properties and provide a base of comparison with other calcified tissues which have been more extensively studied. Although some resemblance was found with bovine cortical bone (Lugassy, 1968), major similarities between the properties exhibited by these two materials were not readily apparent. This left the possibility of other factors such as structural arrangements of the various phases in the material to be of significant influence upon the properties observed. This suggestion will be further developed in the discussion.

In Table 2 a trend towards increasing values seems to exist when comparing the results obtained for the elastic moduli, proportional limits and ultimate strengths of the transverse radial, oblique (45°) radial and longitudinal specimens, respectively. However, when statistically analyzed the above data showed that except for the following: elastic modulus values of the longitudinal and transverse radial, longitudinal and oblique (45°) radial specimens, and proportional limit values of the longitudinal and transverse radial, and oblique (45°) radial and transverse radial specimens, there was no difference at the 5% significance level between the average stress values of the various group compared. No apparent reason could be found, including the effect of lower strain rate values obtained with the oblique (45°) radial specimens or the possible misalignment of the incremental lines in the samples for the lack of significant difference existing between the elastic modulus of the oblique (45°) radial and transverse radial specimens, and the proportional limit of the longitudinal and oblique (45°) radial specimens. Further study on these particular points is contemplated in the near future.

Microstuctural organization has been found to significantly influence the type of mechanical response observed with calcified tissue (Ascenzi et al., 1966; Evans et al., 1966; Lugassy, 1968). It has also been recognized that during formation, the types of mechanical stimuli exerted on developing bone will condition its resulting structure.

In the case of sperm whale dentin, it is felt that the vertical forces applied on the teeth during their growth have some influence over the dentin formed. These forces transmitted to the pulp would be resolved as shear stresses at the level of the odontoblastic layers. In the present case, it is suggested that the shear stress lines are, in effect, conditioning the formation and orientation of the incremental lines through their angulation with respect to the main axis of the tooth. To some extent, they could constitute the mechanical stimuli. With respect to the rate of deposition, nature and composition of dentin in the incremental lines, it would appear that they are related to the mode of life and feeding cycles of these mammals (Ohsumi et al., 1963).

The difference between the mechanical response of the longitudinal and transverse radial specimens could be explained as follows: When deformed at right angle with respect to the growth patterns, the weaker areas where calcification has been poor or incomplete would influence the overall response of the sample tested. However, in the case of a longitudinal specimen, because of their regularity and uniformity, the incremental lines seem to act as a nest of reinforcing lines tending to increase the resistance of the structure to the effects of vertical stress application. Mechanically this response would be best related to the straight line portion of the stress-strain curve found under the proportional limit in figure 6.

When sperm whale dentin is subjected to large deformations, corresponding to the stress-strain curve section above the proportional limit in figure 6, it is felt that the structural changes in the material produced by slippage and flow are of such magnitude that the influence of the incremental lines become of insignificant effect as revealed by the relatively similar ultimate strength values of the various specimen groups tested. The above mechanism points to the viscoelastic character of the response of sperm whale dentin (Lugassy, 1968; Lugassy et al., 1969), and its strain rate dependency. These reasons explain the strain rate values given in Table 2.

Low strain rate fractures of other calcified tissues, such as those occurring in bovine cortical bone, have been characterized by shear surfaces oriented at a 45° angle with respect to the axis of stress application. In sperm whale dentin comparable fracture surfaces have been observed and appear to have not been influenced by the orientation of the incremental lines or the relatively large strains occurring at failure.

CONCLUSION

The influence of incremental lines upon the mechanical properties of sperm whale dentin has been studied and representative values given. It was found that except for a difference between the elastic moduli of the longitudinal and transverse radial, and longitudinal and oblique (45°) radial specimens, and the proportional limit of the longitudinal and transverse radial, and oblique (45°) radial and transverse radial specimens, there was no statistical difference at the 5% significance level for the other properties studied including: ultimate strengths, proportional limits and elastic moduli of these and other groups of specimens. Although it is recognized that other factors may strongly influence the structural anisotropy of calcified tissues, it is felt that in the case studied, for small deformations, the presence of incremental lines offer the means of optimal resistance of sperm whale teeth to stresses applied on them vertically and also explains their growth patterns and the mechanical properties measured. Within these limits, sperm whale teeth seem to have been structurally adapted for their functions in their selective environment.

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BAIRD'S BEAKED WHALES CAUGHT ON THE COAST OF JAPAN IN RECENT 10 YEARS

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ABSTRACT

It seems there has been no sign of decrease on the stock of Baird's beaked whale on the coast of Japan in recent years. This may be the result of reduction in number of catcher boats. The length distribution of the whales caught recently shows a good balance. That is, nearly 80% of the whales were sexually matured. A migrating population of this species appears at Boso Peninsula in May, reaches Hokkaido some time between July and August and comes back again to Kinkazan off shore in the fall and then leaves Japan. They are likely to prefer waters deeper than 1,000 m. On the Sanriku coast, the whales eat deepwater fish, but on the coast of Hokkaido, they eat nearly exclusively squid.

It can be presumed that the whales caught in the Abashiri area in May through June should be *Hyperoodon ampullatus*.

INTRODUCTION

There are few countries in which the whaling industry catches Baird's beaked whales as a harvest and utilize fresh or dried meat for human consumption, and oil extracted from blubber, bones and viscera are used as well as sperm whale oil.

Biological study has been done on Baird's beaked whales caught in the period of 1948–1952 by Omura *et al.* (1955). Present study was done on the whales caught in the period of 1960–1969. However, data were fewer in the early half period and considerable number in the latter half. Because of this unbalance, our consideration was done mainly on the data in the latter five years 1965–1969.

CATCH RECORDS AND ITS ANALYSIS

About 25 years ago, the smaller species whaling industry in Japan made much profit from harvests of minke, pilot and beaked whales. And number of catcher-boats gradually increased; in the mean time, number of catch per boat become less and less. So the whalers competed each other by extra equipment which often was a 50 tons boat with 50 mm caliber guns. The result was a folly, they need extra catch to pay for such expences. It was not enough for them to catch only those previously permitted species from certain amount of populations migrating to the coast of Japan. They began to poach banned whales such as the sperm

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TABLE 1. NUMBER OF CATCHER-BOATS AND NUMBER OF BAIRD'S BEAKED WHALES CAUGHT IN JAPANESE WATERS IN 1948–1969

Years	Number of catcher-boats	Number of whales caught	Number of whales per catchers
1948	—	76	—
1949	—	95	—
1950	80	197	2.5
1951	68	242	3.6
1952	65	382	5.9
1953	58	270	4.7
1954	54	230	4.3
1955	47	258	5.5
1956	54	297	5.5
1957	46	186	4.0
1958	35	229	6.5
1959	32	186	5.8
1960	25	147	5.9
1961	23	133	5.8
1962	20	145	7.3
1963	19	160	8.4
1964	18	189	10.5
1965	16	172	10.8
1966	16	171	10.7
1967	15	107	7.1
1968	8	117	14.6
1969	7	134	19.1

TABLE 2. NUMBER OF BAIRD'S BEAKED WHALES CAUGHT IN JAPANESE WATERS IN 1965–1969.

		Areas					
Years	Sex	I	II	III	IV	Total	Sex ratio
1965	Male	41	37	11	13	102	59.3
	Female	27	23	8	12	70	40.7
	Total	68	60	19	25	172	
1966	Male	62	33	6	5	106	62.0
	Female	23	21	11	10	65	38.0
	Total	85	54	17	15	171	
1967	Male	35	17	6	6	64	59.8
	Female	23	10	8	2	43	40.2
	Total	58	27	14	8	107	
1968	Male	36	15	5	1	57	48.7
	Female	44	12	4	0	60	51.3
	Total	80	27	9	1	117	
1969	Male	44	22	2	3	71	53.0
	Female	47	10	2	4	63	47.0
	Total	91	32	4	7	134	
Total	Male	218	124	30	28	400	57.1
	Female	164	76	33	28	301	42.9
	Total	382	200	63	56	701	
Sex ratio	Male	57.0	62.0	47.6	50.0	57.1	
	Female	42.9	38.0	52.4	50.0	42.9	

and the sei whales by those well equipped boats. The fact became a serious problem for the Fisheries Agency of the Government. To stop that devastating catch, the Agency recomended whalers to change their whaling objectives from the smaller whales to the larger ones. As a measure, they gave a certain quota equally to a group of ten 50 tons boats and a single 500 tons boat. In those days larger species whaling promised considerable interest, many whalers converted to the larger species whaling. The small boat, therefore, reduced in number and the catch per small boat was recovered accordingly.

As shown in Tables 1 and 2, the number of Baird's beaked whales caught was 30–40 thirty to forty years ago, and as many as 250–300 about twenty years ago, the peak of which was 382 in 1952. Then, unpleasant tendencies began to appear in the CPUE (catch per unit effort) by the influence of thoughtless catch. Number of total catch also began to decrease. However, some recovery appeared in recent 10 years as 130–170. Analyzing these recent statistics, it may safe to say that the stock is somehow stabilized than ever. In Fig. 1, although the number of total catch in each year is vary, there is no tendency of decrease. And the number of catch per boat (CPUE) is still increasing as a result of the reduction.

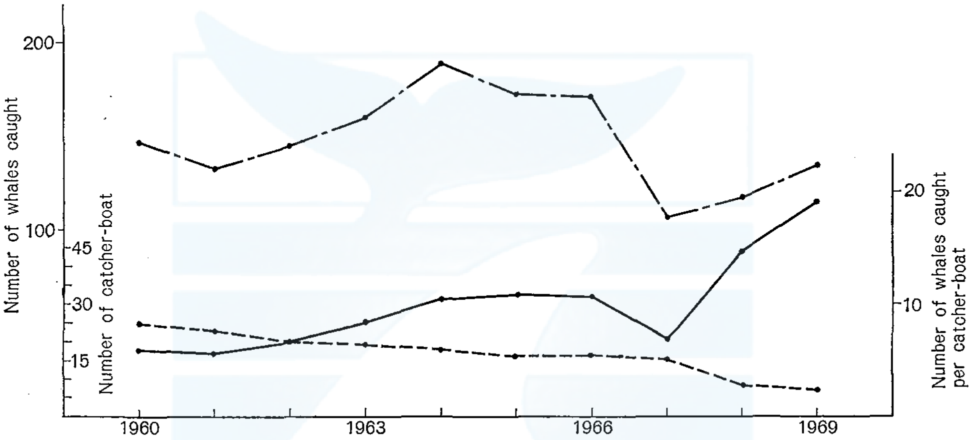

Fig. 1. Number of Baird's beaked whales caught and number of catcher-boats in Japanese waters according to the years.

There are two land stations in Area I, four in Area II and one in Areas III and IV respectively.

Distribution of positions of catch is shown in Fig. 2. To analyze conditions of the stock, the coastal waters was divided into some area as Omura *et al.* formerly did (1955). On the other hand, there is no catch in the coast of the Sea of Japan. It may because of that the smaller species whaling boat owners have given up the area.

In Area I whaling operation was done by the whalers from the stations in Boso Peninsula (Bosyu). Operation period of that area is appeared to be longest

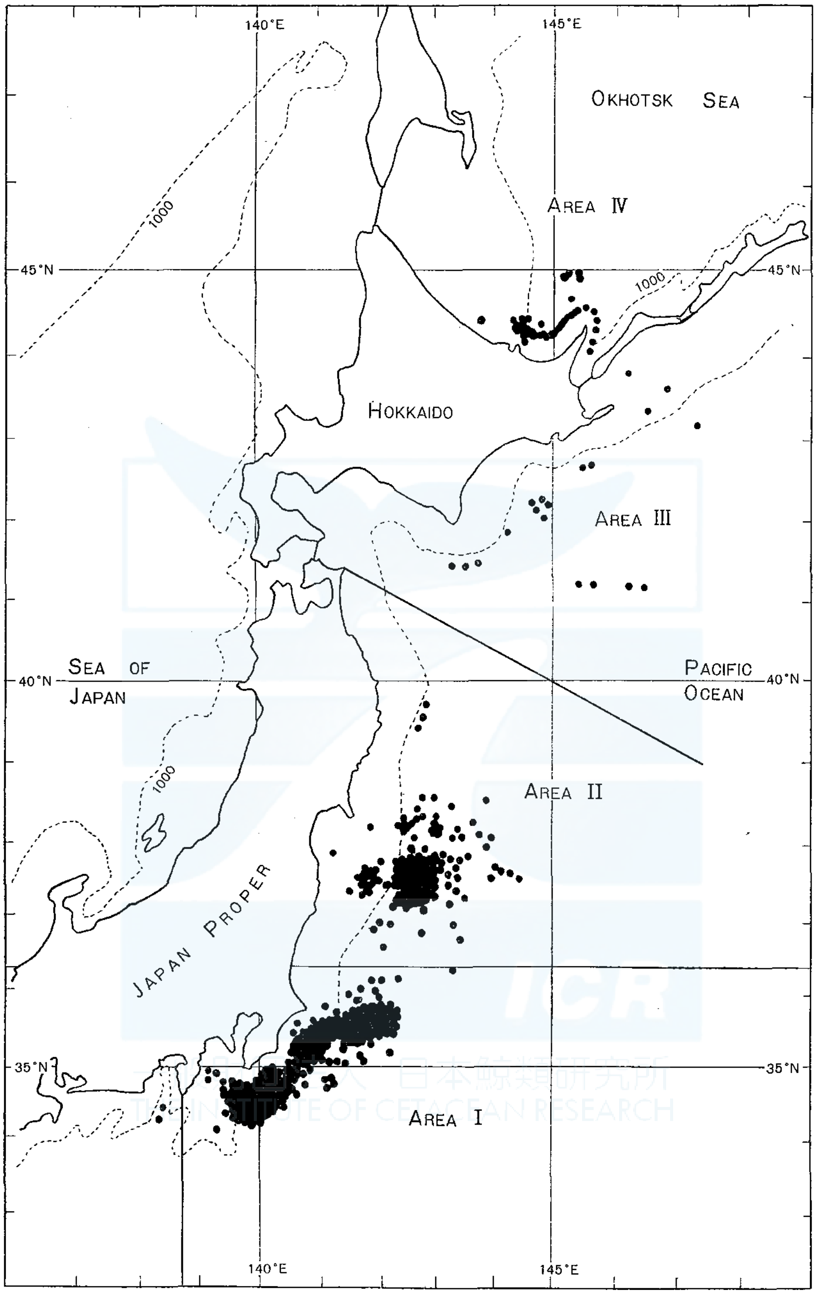

Fig. 2. Positions of Baird's beaked whales caught in Japanese waters in 1965–1969.

of all others, which is from May to Dec. Area II was of the whalers from the stations in Oshika Peninsula, Miyagi Pref. Although no catch is seen at Nemuro station in Area III by Omura *et al*, there are some catch records in recent years on the coast of Nemuro in the present map. The waters of Hokkaido is divided into two, the Pacific coast as Area III and the Okhotsk coast as Area IV, by the line between Kunashiri and Etolov Island. As shown in Table 3 and Fig. 3, catch appeared in Area I and II in May first. Male is superior in total number as about 57%.

TABLE 3. MONTHLY CATCH OF BAIRD'S BEAKED WHALES IN JAPANESE WATERS BY THE AREA, IN 1965–1969.

		Areas				
Months	Sex	I	II	III	IV	Total
May	Male	3	0	—	—	3
	Female	2	2	—	—	4
	Total	5	2	—	—	7
June	Male	32	4	—	0	36
	Female	20	0	—	1	21
	Total	52	4	—	1	57
July	Male	46	5	—	0	51
	Female	55	0	—	1	56
	Total	101	5	—	1	107
August	Male	65	37	3	2	107
	Female	49	13	2	0	64
	Total	114	50	5	2	171
September	Male	34	33	16	8	91
	Female	20	30	22	7	79
	Total	54	63	38	15	170
October	Male	23	20	9	14	66
	Female	11	11	7	14	43
	Total	34	31	16	28	109
November	Male	12	21	2	4	39
	Female	7	13	2	5	27
	Total	19	34	4	9	66
December	Male	3	5	—	—	8
	Female	0	6	—	—	6
	Total	3	11	—	—	14
Total	Male	218	124	30	28	400
	Female	164	76	33	28	301
	Total	382	200	63	56	701

Females seem to migrate to those areas earier than males do, number of males incleases after July.

Distance between the positions of catch and the land stations is shown in Table 4: 50% of catch are within 1–30 miles. This may partly because of that whaling boats are so small that they have to be towing whales to a station within a day. Even the most distant catches Area about 120 miles from a land station and the distant catches are scarce. The distance of most abundant catches are 1–30 miles in Area IV, 91–120 miles in Area III, 61–90 miles in Area II and 1–30

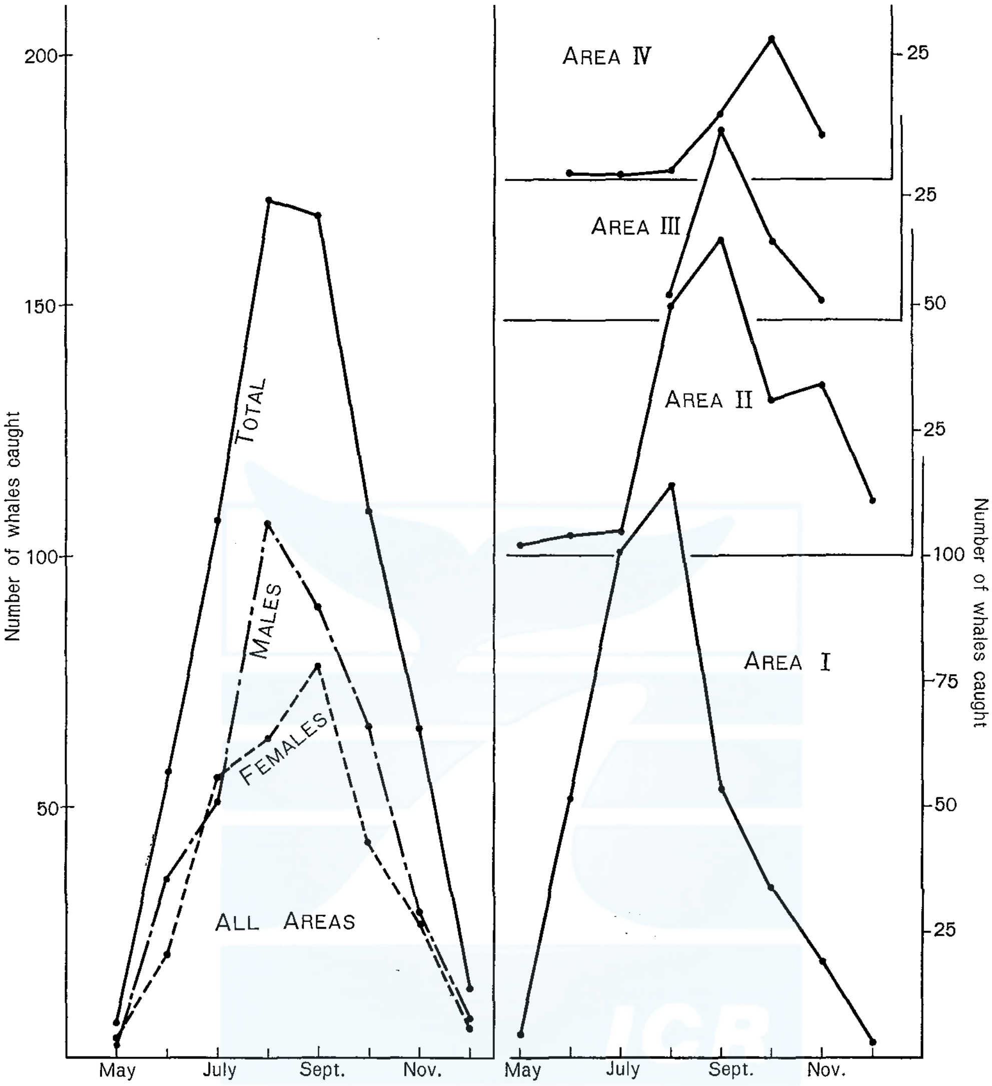

Fig. 3. Number of Baird's beaked whales caught by the area and months in 1965–1969.

TABLE 4. DISTANCE BETWEEN LAND STATIONS AND THE POSITIONS OF BAIRD'S BEAKED WHALES CAUGHT IN JAPANESE WATERS IN 1965–1969.

Distance in miles	Areas				Total	Percentage
	I	II	III	IV		
1–30	295	10	5	42	352	50.2%
31–60	81	62	5	2	154	22.0
61–90	2	107	—	—	109	15.5
91–120	—	15	44	—	59	8.4
120<	—	6	—	—	6	0.9
unknown	4	—	5	12	21	3.0
Total	382	200	63	56	701	

miles in Area I. If the distance of abandant catch and the water depth of the positions are put into a map together as in Fig. 2, positions of catch are abandant in the waters deeper than 1,000 m. On the Abashiri and Boso coasts where the 1,000 m depth contour line is close to the shore, positions of catch are appeared to be near to the shore. Whereas on the Kushiro and Kinkazan coasts where the contour line is far from the shore, the positions of catch are at distance.

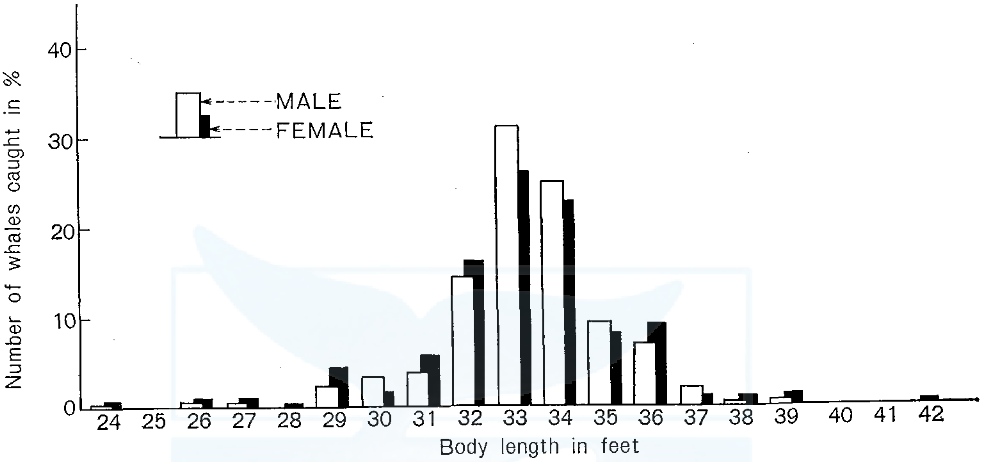

Fig. 4. Size distribution of Baird's beaked whales caught in Japanese waters in 1965–1969.

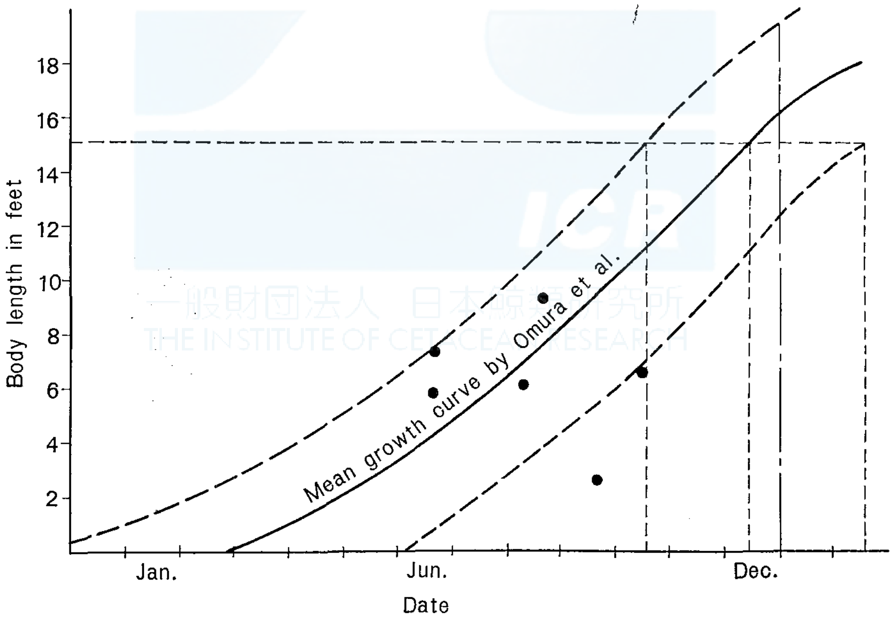

Fig. 5. Recorded foetuses of Baird's beaked whals by the date in 1965–1969.

DISTRIBUTION OF BODY LENGTH

Distribution of body length of the whales caught is shown in Fig. 4. The smallest length of both sexes are appeared to be equal as 24 feet and the largest length of those are 39 feet in male and 42 feet in female. Many individuals are seen within the range of 33–34 feet. Roughly, larger lengths are of females. According to Omura *et al.*, the Baird's beaked whale attains sexual maturity at the length within 32–33 feet by males and 33–34 feet by females. Considered on this condition, it can be said that 80% of males and 70% of females among all the whales caught are matured.

RECORD OF FOETUSES

Records of foetuses found in the present study are shown in Fig. 5. Six in the season from June to Oct.: in Area I, two in June, two in Aug., one in Sept. and in Area IV, one in Oct. As the records are so scarce, that they are shown in the additional points on the growth curve drawn by Omura *et al* (1955).

FOOD

701 stomachs were examined; 55% of all, namely 383 stomachs contained food remains and 30% are empty ones. 15% are the stomachs without description because abdomens of whales are cut open immediately after catch to prevent them from decomposition, so, the contents are washed away. There were various kinds of food remained in the stomachs as shown in Fig. 5. Most are deep-water fish and squid. There are 24% of unidentified species of food because they have already been digested.

TABLE 5. STOMACH CONTENTS OF BAIRD'S BEAKED WHALES CAUGHT IN JAPANESE WATERS IN 1965–1969.

kinds of stomach contents	number of whales	percentage
deep-sea fish	156	40.7
squid	111	28.9
mackerel	15	3.9
sardine	5	1.3
flat fish	1	—
pollack	1	—
saury	1	—
unidentified	93	24.2

Distribution of food by area is shown in Fig. 6. Squid is found mostly in Areas IV and III, squid and deep water fish are in Area II and deep-water fish is in the waters south of Area III. Occurrence of squid and deep-water fish is shown in Table 6 by month. Squid is frequent in Area IV from Aug. to Nov., also in Area III from Aug. to Nov. Naturally, in Areas III and IV, fishing season of squid begins in July. The whales which had squid in their stomach and caught in Area II, are supposed to have been migrating from north. In Area II, there are records of mackerel and sardine as well as squid and deep-water fish. Whales

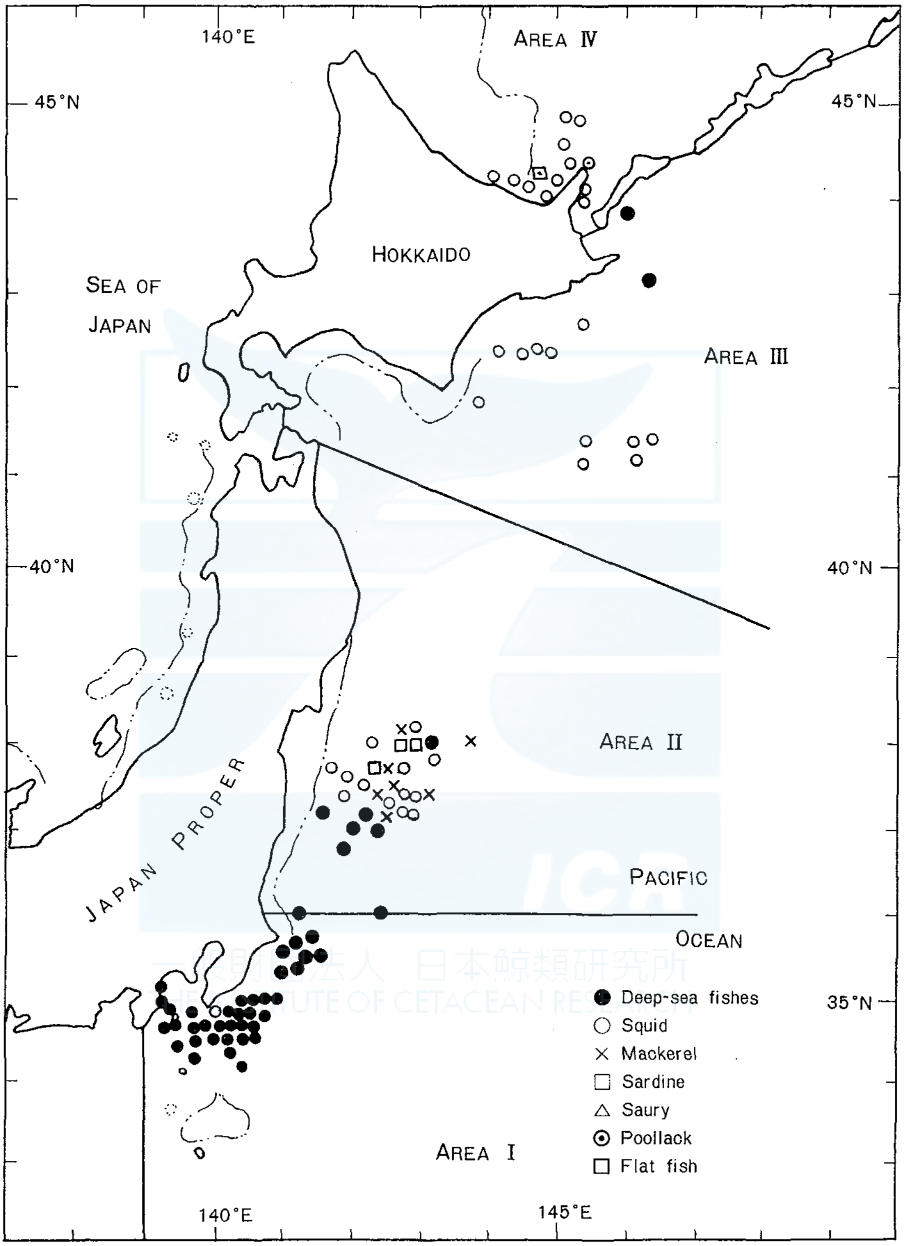

Fig. 6. Position of Baird's beaked whales caught with stomach contents in Japanese waters in 1965–1969.

seem to eat common species of the areas without intentional choice. Species of deep-water fish and its fishing season could not be investigated, however, it seems that it is likely to be abundant at Boso off shore. Records of deep-water fish appear in Area I first and to Areas II and III as time passing by. Whales of the present population seem to migrate north in spring living on deep-water fish and then coming back south doing on squid.

TABLE 6. NUMBER OF STOMACHS OF BAIRD'S BEAKED WHALES CAUGHT IN JAPANESE WATERS WITH CONTENTS OF SQUID OR DEEP-SEA FISH, BY THE AREA AND THE MONTH, IN 1965–1969.

	Areas							
	I		II		III		IV	
Food	squid	deep-sea fish	squid	deep-sea fish	squid	deep-sea fish	squid	deep-sea fish
May		5						
June		14						
July	1	25		2				
August		41	10	3	3	2	2	
September		25	9	3	25	4	12	
October		3						
November		18	1	2	13		24	
December		7		1	4		8	

SUMMARY

1. Whaling of the Baird's beaked whale in recent years indicates an agreeable number of catch from the stock as about 150 whales annually, which is a certain decrease from the number of 250–300 about-twenty years ago. On the other hand, number of whales caught per catcher-boat has increased because of reduction of the boats in number.

2. Length distribution of whales caught shows a good balance: nearly 80% of the whales attained at sexual maturity and the male is superior in number. So that it may safe to say that the stock is well protected.

3. The largest body length investigated was 39 feet of male and was 42 feet of female in the present study.

4. The positions of whales caught are mainly in the waters deeper than 1,000 m. It seems that the whales do not migrate to the shallow waters. In the whaling season, the whales are found at Boso first and migrate to Kushiro through Kinkazan in the season from July to Oct., then they come back to Kinkazan from Aug. to Oct.

5. The whaling commences in Abashiri sometime in May or June, this is simultaneous with that of Boso. Considering the fact, Abashiri population is supposed to be different from that of Boso. Abashiri population is considered to be as *Hyperoodon ampullatus*. Further study is required.

ACKNOWLEDGEMENT

Our gratitude are due to the members of the Whaling Inspection Group of the Fisheries Agency for presenting the data used in this report.

Thanks are also due to the stuff members of the Biology of Fisheries Resources Division of the Ocean Research Institute, the University of Tokyo and Mr. S. Machida of the Whales Research Institute for their helpful advices.

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EXPLANATION OF PLATES

Bird's-eye view of Baird's beaked whales swimming in the waters off Sanriku coast taken by Mr. S. Takashima of the Suisan Koku Co. (Fishery Aviation Co.): Copyright of these photographs is reserved by the company.

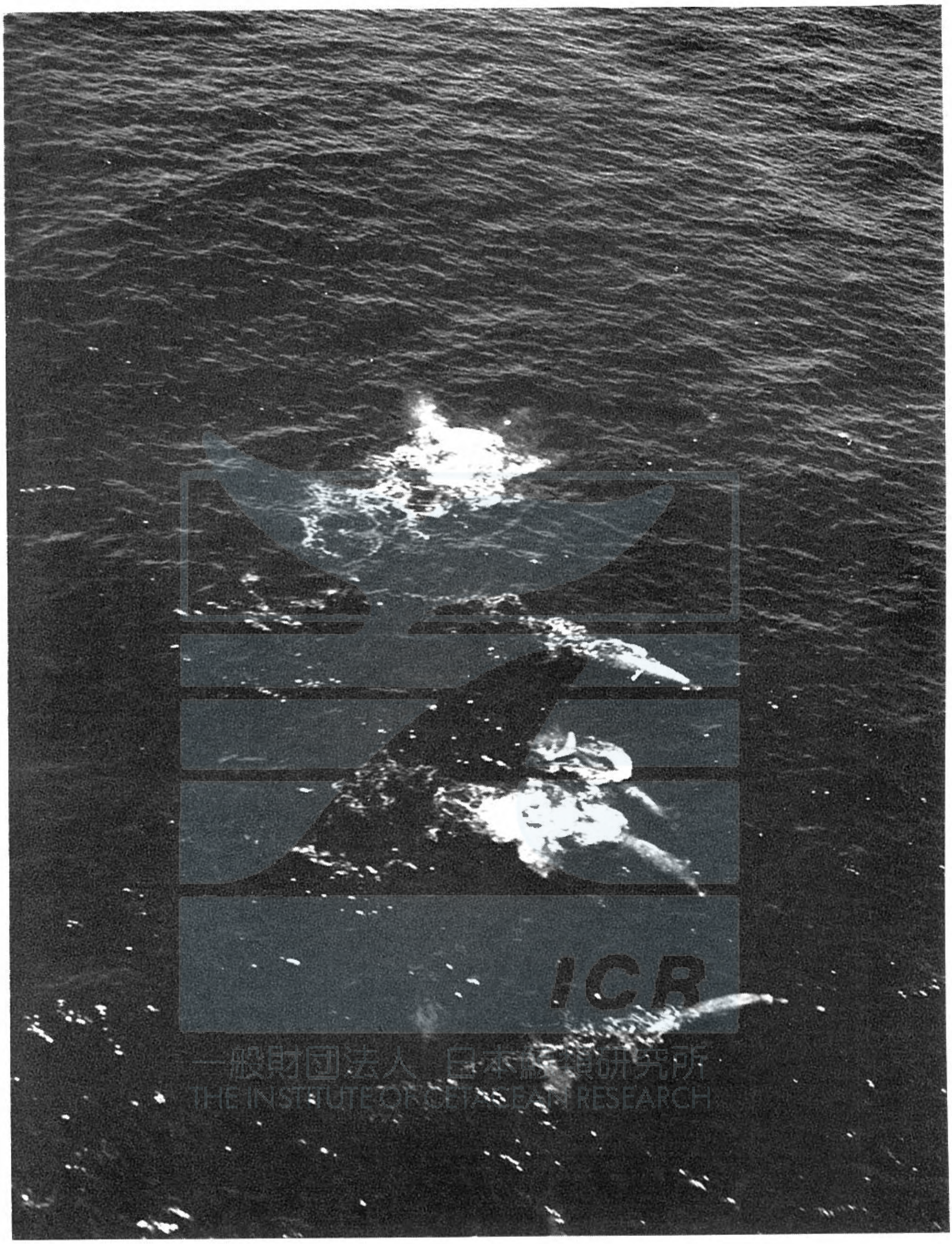
PLATE I

	Date	July 26, 1956
	Position	35°–50′N
		141°–20′E

PLATE II

upper figure	Date	July 22, 1970
	Position	38°–45′N
		143°–20′E
lower figure	Date	Sept. 12, 1961
	Position	39°–50′N
		143°–50′E

The others were taken at the same area by and presented in *The Scientific Reports of the Whales Research Institute*, No. 23 (1971) by T. Kasuya.



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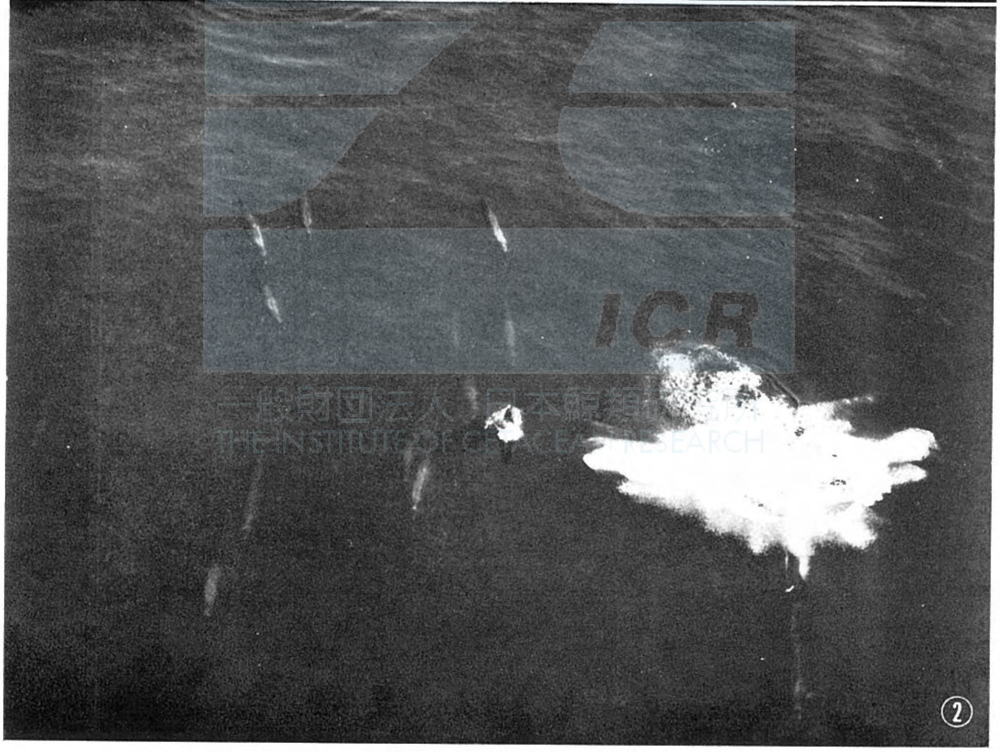

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THE UNDERWATER SOUND OF GANGES RIVER DOLPHINS *(PLATANISTA GANGETICA)*

KAZUHIRO MIZUE,* MASAHARU NISHIWAKI**
AND
AKIRA TAKEMURA*

ABSTRACT

Various types of underwater sound emitted by the Ganges river dolphin were studied. Clicks were 87% of all, seems to be a method of echo-location. Bursts were 5%, far more frequently than that of sea dolphins, must be a means of communication. Twitterings or chirps appeared on the sonargram in a stratified zone, are a pattern of burst. The sounds like mewing of cat and creaking boat, were both appeared in a stratified zone. Among those appeared in a stratified zone, some were proved to be quick repetition of clicks, others did not appear in a click pattern however play back speed was reduced.

INTRODUCTION

From the view points of various field, Ganges river dolphin (*Platanista gangetica*) was studied by Japanese scientists in Pakistan from October 1969 through March 1970. The basecamp of the expedition was set at Mymensingh, East Pakistan throughout the period. During the period, 20 individuals were caught by the local fishermen. Among them, 4 living individuals were transported to Tokyo by air on February 4. This is an analysis on the underwater sound emitted by them.

On the other fresh water dolphins, the Amazon river dolphin (*Inia geoffrensis*) and the buffeo negro (*Sotalia fluviatilis*), reports were presented by Shevill (1962), Caldwell and Evans (1962). According to the reports, the above two species of dolphins did not emit whistles but only clicks. However, Shevill wrote about his susticion that *Sotalia* might emit whistles on some occasions.

Among the four species known as the members of the family Platanistidae, only the Ganges river dolphin is believed to be blind and has a distinct swelling wall on the maxillary bones. Examination with a flashlight on and off at 10 cm distant from the dolphin's eyes, showed no sign of reaction. Of course anatomical and histological studies on those dolphins have been carrying on until present day, but the results have not been completed yet. Because of this species of dolphins are supposed to be blind, we consider that they must rely much more on the guidance of the underwater sound than the other dolphins with clear eyesight do.

An address about the experiment was given by M. Nishiwaki at the Seventh Annual Conference on Biological Sonar and Diving Mammals held at the Stanford Research Institute on October 23, 1970. Although Proceedings of the conference will be published, this report have to claim the originality.

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No. 23, 1971. 123–128.

METHOD OF THE STUDY

An indoor freshwater pool was set at a quiet place in the pine tree forest near by Kamogawa Beach, about 60 miles distant from Tokyo. The pool was 7 m long, 4 m wide and 2 m deep. Inside of the pool was covered with plastic. The pool was heat and sound proofed by the method of stuffing artificial fiber wool between the cement base and the plastic cover. Water and air temperature was kept constantly about 23°C.

As the pool had been so prepared that four individuals of *Platanista* and those of two *Inia* were kept in it. Sex and body length of those were:

Platanista	No. 1	118 cm	female
,,	No. 2	121	,,
,,	No. 3	127	,,
,,	No. 4	126	male
Inia	No. 1	210	,,
,,	No. 2	203	female

After the dolphins had grown accustomed to the pool, recording of the underwater sound was carried out.

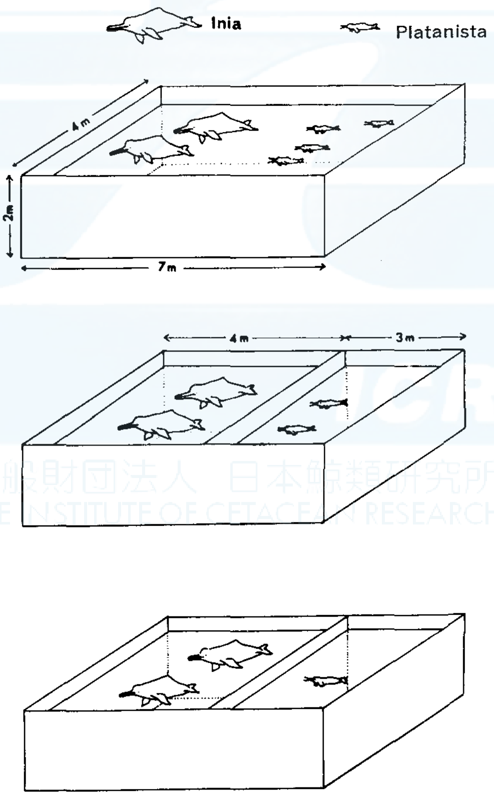

Fig. 1. Situation of the pool, the Ganges river dolphins were in.

First, the underwater sound emitted by all the dolphins in the pool was recorded twice for total 15 hours. Then the pool was divided into two. This time, one of the two was 4 m long, 3 m wide and naturally 2 m deep. Then, two Ganges river dolphins (126 cm male and 127 cm female) were put into it. The sound emittion by those Ganges river dolphins was recorded for total 5 hours. In the next place, a Ganges river dolphin was placed in the divided rectangular pool (127 cm female) and the sound emittion by it alone was recorded for two hours. The situation was as appear in Fig. 1.

The recording apparatuses were shown in Figs. 2 and 3.

1. Hydrophone, Style St-6501, the Oki Electronics Industry Co., Ltd. made.

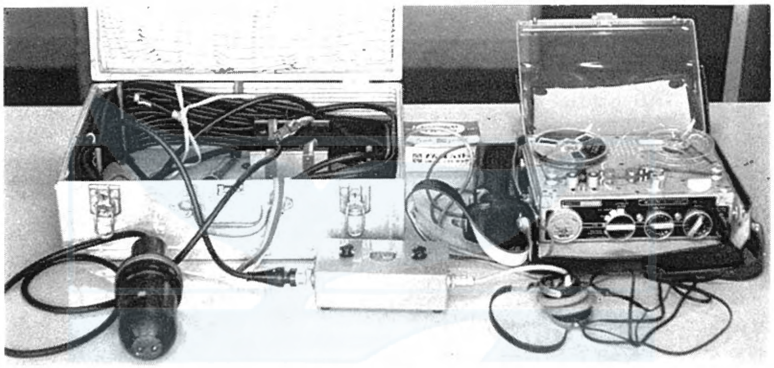

Fig. 2. Recording apparatus.

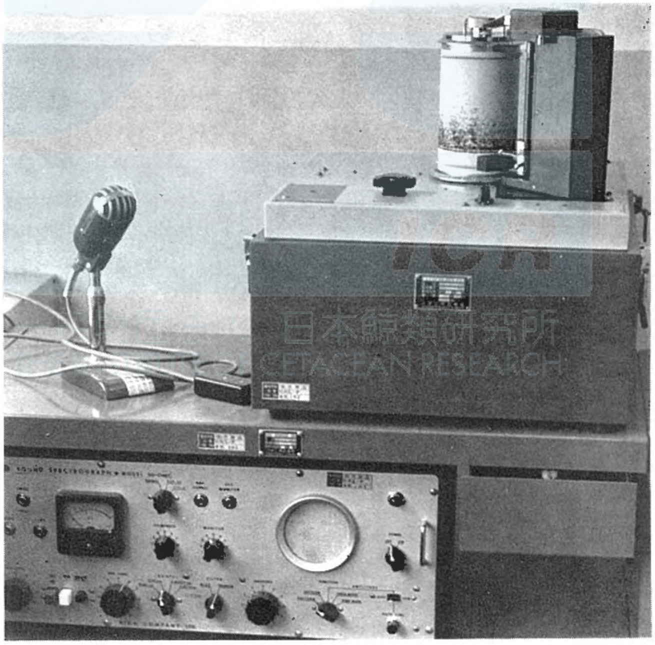

Fig. 3. Sonargraph apparatus.

2. Pre-amplifier, Style St-65, the Oki Electronics Industry Co., Ltd. made.
3. Tape Recorder, Style No. 3, Nagura Electric Co., Ltd. made.
4. Sonargraph, Style SG-04Al, Rion Co., Ltd. made.

Performance of those apparatuses is shown in Fig. 4.

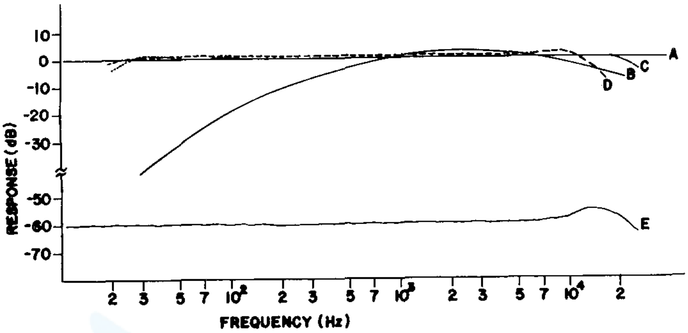

Fig. 4. Performance of the apparatus.

RESULT AND DISCUSSION

1. *Clicks*: The Ganges river dolphins emitted cricks frequently. It was easily presumed that the sound was emitted and received as a sense of echo-location.

Repetition rate of this sound was varied each time as indicated in Figs. 1 and 2 of Plate I. It was five times per second for the most seldom and 100 times for the most frequent. The frequent emittions seem to have been aiming at near by objects and the seldom emittions seem to have been aiming at distant objects. This phenomenon is equal to the dolphins at sea.

It is characteristic of this species, clicks went up to a fairly high wave frequency, which is never reached by the sea dolphins. With our apparatus, as high as 20KHz wave frequency was recorded. However, it is presumed that higher frequency than that can be emitted by this species of dolphins. Shown in Fig. 3 of Plate I.

2. *Bursts*: Although sea dolphins too emit the bursting sound out. It seems there is no special meaning with it. While this species of dolphins emitted bursts not only once but multiple times at a time as usual. Frequency of this sound emittion is next to that of clicks though far less than the latter.

By the Ganges river dolphin, this sound seems to be used as a means of communication as well as following mentioned " twittering " sound. Sonargram of this sound is shown in Fig. 4 of Plate I. Observing the Ganges river dolphins in wild or in the pool, they seemed not to have lived in school but were swimming solitary to and for in the river or in the pool. Communication between one another seemed to have been rather infrequently. Need of communication is far more among sea dolphins than by the solitary individuals.

3. *Twitters*: This is a sound heard like twittering of birds to human ears; it is quite different from burstings. But, generally, there is no difference between the two if the patterns of them appeared in the sonargram were analized. Bursts continued about 0.4 seconds, comparatively longer period of a time, while twitters

continued only about 0.1 second. This sound also seemed to be a means of communication. Sonargram of this is shown in Fig. 5 of Plate I.

4. *Whistles*: This species of dolphins emitted few whistles which are said to be pure tone. How seldom the Ganges river dolphins whistles! Among sea dolphins, the false killer whale (*Pseudorca crassidens*) whistles very often and the bottle-nosed dolphin (*Tursiops gilli*) seems to do conversation by the help of this whistles. However, we can hardly admit that the Ganges river dolphins are able to converse by means of their whistles. This sound may be emitted spontaneously by the Ganges river dolphin. Sonargram of this is shown in Fig. 6 of Plate I.

5. *Stratiform sound*: In the sonargram, it was found a group of sounds which were appeared in parallel laminations. As it is well known, many species of sea dolphins emit this stratiform sound spontaneously at times of mating, menacing others of taking food etc. The Ganges river dolphins sometimes emitted a sound like mewing of a pussy and some other times a sound like a creaking boat. The sonargram indicated these in the patterns of stratiform sound. Watkins (1967) considered this type of sound to be a very quick repetition of clicks.

Fig. 1 of Plate II shows this type of sound playback at the natural speed of tape-rotation. Fig. 2 of Plate II shows the same sound at half rotation speed, that is, the wave frequency was reduced in half cycle. At this speed, the pattern still shows parallel laminations. However, as in Fig. 3 of Plate II, when tape rotation was reduced to 1/4 at speed, analysis of the sound did not appear in parallel laminations. It appeared in the typical clicks pattern. The opinion of Watkins was proved.

But on the other hand, the sound similar to mewing of pussy did not appear in the clicks pattern, even when the speed was reduced to 1/4 (Fig. 5 of Plate II), or even to 1/12 as shown in Fig. 6 of Plate II. It did not appear in the clicks pattern. The sound of this type is emitted by various species of dolphins very often and the sound of the killer whale (*Orcinus orca*) is almost always of this type. We came to conclude that this type of sound of parallel laminations must have been different from what Watkins wrote about. It is yet unknown whether these sounds were spontaneously emitted or not.

In the following, above mentioned variety of sounds are shown in the rate of frequency.

Clicks	87%
Bursts	5%
Twitters –	3%
Whistles –	1%
Stratiform sounds (parallel laminations) .	4%
Total	100%

ACKNOWLEDGEMENT

We extend our sincere appreciation to the stuff of the Kamogawa Sea World for giving us convenience to have kept and have studied the Ganges river dolphins.

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EXPLANATION OF PLATES

Underwater sound emitted by Ganges river dolphin.

PLATE I

Fig. 1. Clicks
Fig. 2. Clicks.
Fig. 3. Clicks.
Fig. 4. Bursts.
Fig. 5. Twitters.
Fig. 6. Whistles.

PLATE II

Fig. 1. Stratiform sound at natural speed of tape-rotation.
Fig. 2. Stratiform sound in Fig. 1 reduced to half speed rotation.
Fig. 3. Stratiform sound in Fig. 1 reduced to 1/4 speed rotation.
Fig. 4. Stratiform sound at natural speed of tape-rotation.
Fig. 5. Stratiform sound in Fig. 4 reduced to 1/4 from natural rotation speed.
Fig. 6. Stratiform sound in Fig. 4 reduced to 1/12 from natural rotation speed.

Fig.4

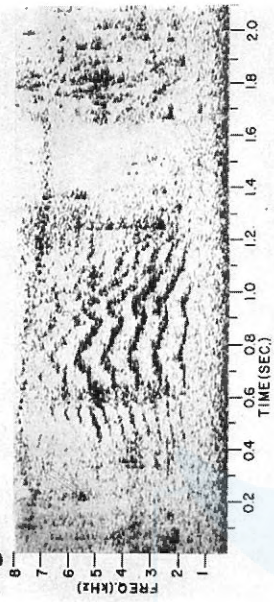


Fig.5

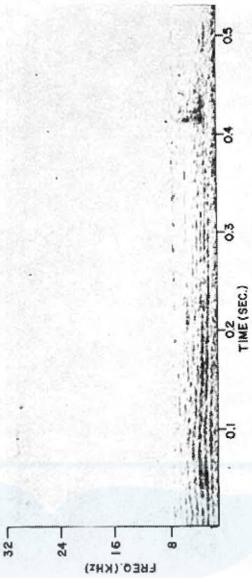
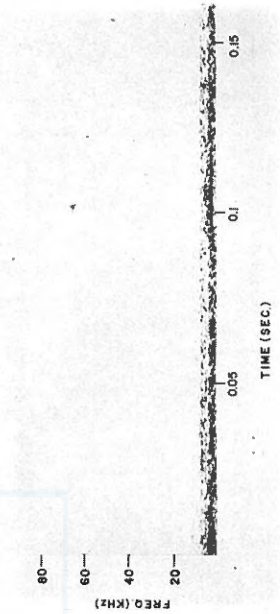


Fig.6



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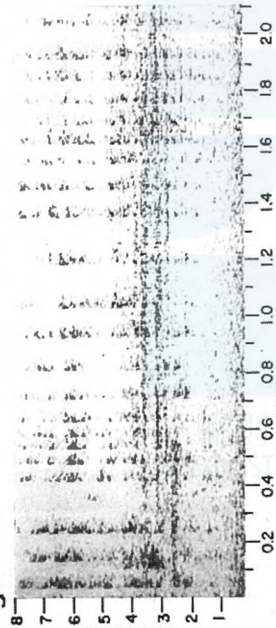

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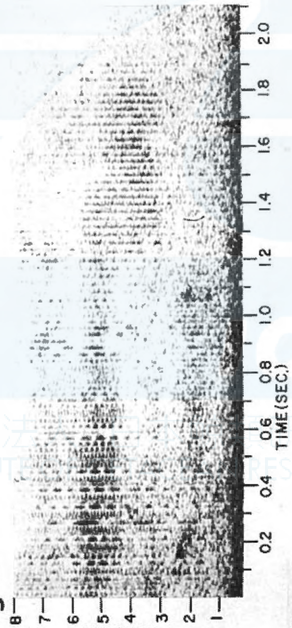

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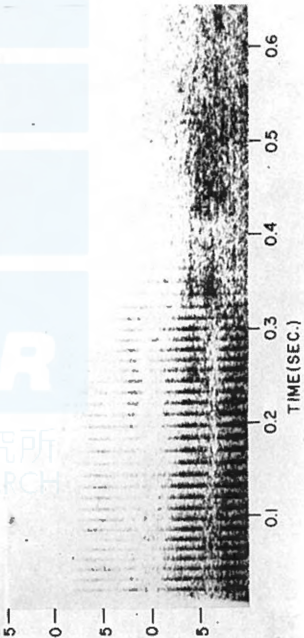

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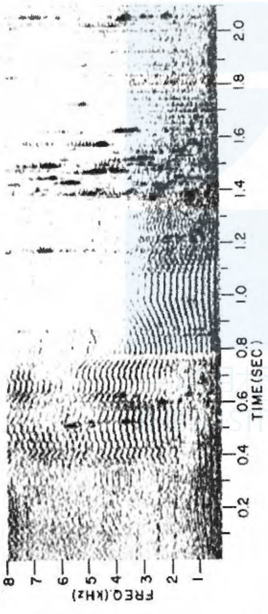

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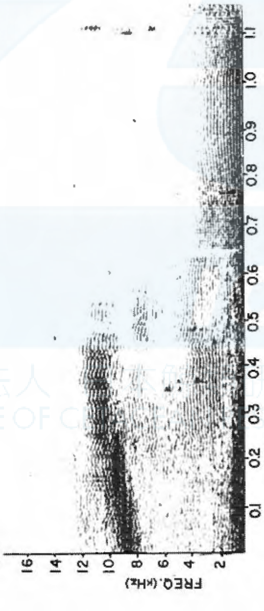

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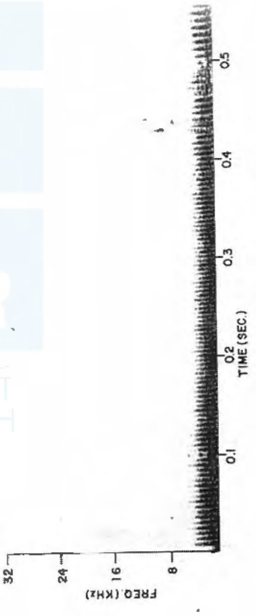

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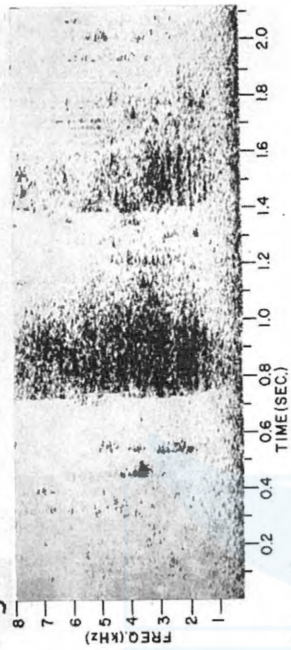

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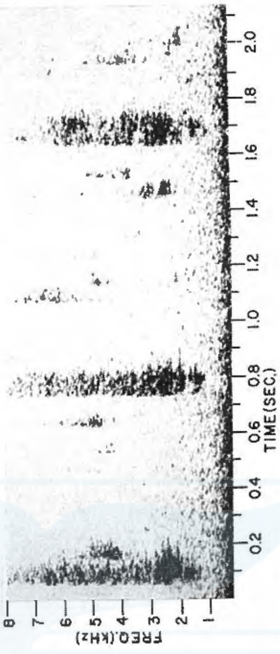

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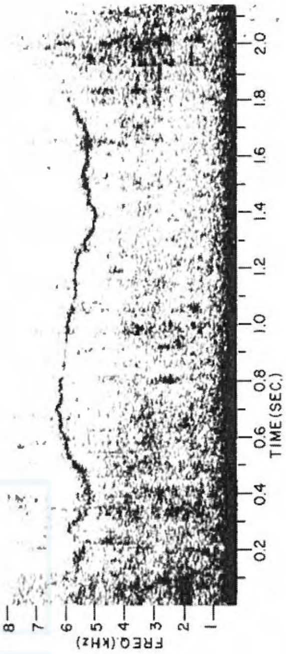

FIRST RECORD OF *MESOPLODON DENSIROSTRIS* FROM FORMOSA

TOSHIO KASUYA* AND MASAHARU NISHIWAKI*

ABSTRACT

Two records of female *Mesoplodon densirostris* are reported. Comments on the external character, skull and flipper of the younger specimen, and that on mandible of the older female are made.

INTRODUCTION

The Blainville's beaked whale, *Mesoplodon densirostris* is one of the rare species of the Odontoceti. Moore (1958) and McCann (1964) suggested that it distributes in the warmer waters. In 1963, Galbreath reported the stranding of two *M. densirostris* at Midway Islands in the central North Pacific, which is the first record in the North Pacific.

Here, are reported two specimens from Formosa, which are the first record of this species from the western North Pacific.

REFERRED SPECIMENS

Followings, referred specimens, are kept in Ocean Research Institute, Univ. of Tokyo.

TK 245: Mandibles with teeth. Collected by M. Nishiwaki in Aug., 1968 at the fish market in Pei-kan town (approximately 23°30′N, 120°25′E). Presumably of adult female, no other data.

TK 256: Female in puberty stage, Body length 3.56 m. Collected by T. Kasuya on April 20, 1968 at the fish market in Pei-kan town. Skull, mandibles with teeth and left flipper were collected.

LOCALITY AND DISTRIBUTION

According to the manager of the fish market in Pei-kan, the whale, TK 256, was brought from Su-aō (approximately 24°35′N, 121°50′E), on the north east coast of Formosa. Mr. Hung-chia Yang of Taiwan Fisheries Research Institute informed us that there are small fishing boats operating mostly with hand harpoons, and that there has been no pelagic tuna boat, which occasionally catch *Mesoplodon* (McCann, 1963, 1964). So we consider that this specimen was caught off the east coast of Formosa by some local fishermen with harpoon. This consideration is supported by a deep injury at just right side of the base of dorsal fin (Plate II, Fig. 3.)

The other specimen TK 245 had been deserted out side the fish market. This

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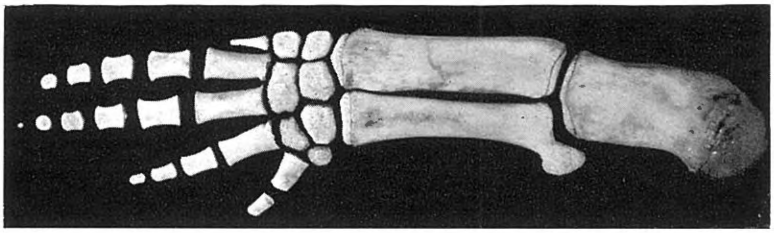

Fig. 1. Dorsal aspect of the bones in the left flipper of *M. densirostris*. TK 256. Proximal epiphysis of ulna is missed.

TABLE 1. LOCALITY OF OCCURRENCE OF *MESOPLODON DENSIROSTRIS*

North Pacific		
1961, Apr., 2 ♀♀,	Midway Islands;	Galbreath (1963)
1968, Apr., 1 ♀,	Formosa;	Present specimen TK 256
1968, Aug., 1 ♀,	Formosa;	Present specimen TK 245
South Pacific		
1869, —, 1,	Lord Howe Island;	Raven (1942), McCann (1964)
1924, —, 1,	Yeppon, Queensland;	Longman (1926) cited in Moore (1958)
1964, Jul., 1 ♂,	West coast of Tasmania;	Guiler (1966)
Indian Ocean		
1839, —, 1 ♂,	Seychells Islands;	Van Beneden and Gervais (1868-1879) cited in Moore (1958)
1872, —, 1,	Algoa Bay, South Africa;	Raven (1942)
1952, —, 2,	Algoa Bay South Africa;	Barnard (1954) cited in Moore (1958)
1963, June, 1 ♂,	5°S, 65°E;	McCann (1963)
1963, Oct., 1 ♂,	24°40′S, 105°35′E;	McCann (1964)
North Atlantic		
1898, Aug., 1 ♀,	Annisquan, Massachusetts;	Allen (1906)
1913, June, 1 ♂,	Corson's Inlet, New Jersey;	Ulmer (1941), Moore (1966)
1917, —, 1,	Madeira Islands;	Harmer (1924) cited in Moore (1958)
1923, —, 1 ♂,	Boque Banks, North Carolina;	Ulmer (1941), Moore (1966)
1925, May, 1,	Long Island, New York;	Raven (1942)
1940, Feb., 1 ♂,	Halifax, Nova Scotia;	Raven (1942)
1944, Oct., 1 ♂,	Bahama Islands;	Moore (1958)

whale was supposed to be caught in the coastal waters of Formosa, but we have no convincing information.

Table 1 shows the localities of 20 records of *M. densirostris*. The present specimens are the latest two, and are the first record from the western North Pacific. As mentioned by Moore (1958) this species seems to inhabit in the warmer waters. The extended range of distribution to the north along the east coast of North America will be a result of the influence of the Gulf Stream. On the other hand, there has been no record of *M. densirostris* in the coast of Japan. Though one was reported from Kyushu by Ogawa (1938), it was reidentified as *M. ginkgodens* (Nishiwaki and Kamiya, 1958). Considering the influence of the Japan current, expectation of the future occurrence of this species in the waters from north of Formosa to the coastal waters of Japan is not unreasonable.

MORPHOLOGY

The external characters of the specimen TK 256, which is a 3.56 m long young female, was observed. No corpus luteum or corpus albicans was found in the ovaries, and diameter of the largest Graafian folicle was about 1 mm. Therefore this whale was considered to be in puberty stage.

The external colouration of the darkly pigmented area was bluish black. However, the whale died several days before the observation, so the colouration will have changed into darker as the common case of the cetaceans. The dorsal and lateral side of the animal was darkly pigmented, which faded gradually into the paler area in the ventral. The throat and chest between two flippers were slaty gray. The ventral area from umbilicus to anus was pure white. The anus, mammaly slit and genital aperture were not pigmented. The tail peduncle and the both surfaces of the tail flukes were darkly pigmented. Though the both sides of the flippers were pigmented, the ventral surface was slightly paler. This pattern of the pigmentation

TABLE 2. EXTERNAL MEASUREMENTS OF *MESOPLODON DENSIROSTRIS*

	Measurements		TK 256 female		Allen (1906) female*	Guiler (1966) male	Raven (1942) male
1.	Total length, tip of upper jaw to tail notch		356 cm	100 %	401 cm	412 cm	439 cm
2.	Length from tip of upper jaw to nostril		46	12.9	—%	—%	11.7
3.	Length from tip of upper jaw to center of eye		51	14.3	—	—	13.9
4.	Length from tip of upper jaw to angle of gape		32	9.0	8.5	—	—
5.	Length from tip of upper jaw to anterior insertion of flipper		94	26.4	—	25.3	23.1
6.	Length from tip of upper jaw to tip of flipper		133	37.4	—	—	—
7.	Length from tip of upper jaw to anterior end of throat groove	L.	24	6.7	6.3	—	—
		R.	20	5.6		—	—
8.	Length of throat groove	L.	34	9.6	—	—	—
		R.	39	11.0	—	—	—
9.	Length from tail notch to center of anus		87	24.4	25.9	20.4	26.5
10.	Length from tail notch to center of reproductive aperture		100	28.1	—	29.6	36.3
11.	Length from tail notch to umbilicus		169	47.5	—	—	52.5
12.	Length from tail notch to anterior insertion of dorsal fin		145	40.7	—	—	—
13.	Length from tail notch to tip of dorsal fin		120	33.7	—	26.5	—
14.	Length from tail notch to anterior insertion of tail flukes		28	7.9	—	—	—
15.	Tail flukes, total spread		80	22.5	23.4	—	23.7
16.	Dorsal fin, height		19	5.3	—	—	—
17.	Dorsal fin, length of base		28	7.9	—	—	—
18.	Flipper, straight length from anterior insertion to tip		41	11.5	—	—	—
19.	Flipper, anterior insertion to tip along the anterior edge		42	11.8	—	—	—
20.	Flipper, straight length from axilla to tip		30	8.4	—	—	—
21.	Flipper, greatest width		12	3.4	—	—	—

* Annisquan specimen, misidentified as *M. bidens*.

nearly coincides with that reported by Allen (1906).

The external measurements of TK 256 and those of other individuals of *M. densirostris* reported by Allen (1906), Raven (1942) and Guiler (1966) are shown in Table 1. The measurements of these 4 individuals fit fairly well.

As seen in Plate II, the mandibular tooth does not erupt and the swelling of the posterior part of the mandible is not so conspicuous as reported by Andrews (1914), Raven (1942) and McCann (1963). This difference is considered to depend on sex and age, especially on the former.

The dorsal fin was nearly triangular and the tip is pointed to the posterior, which resembles more to that of Raven (1942) than that of Andrews (1914). The flippers and the tail flukes showed no significant difference from those of other ziphioid whales.

As seen in Plate I, the genital aperture and the anus are situated in a continual groove.

OSTEOLOGY

Mandible The specimens TK 245 and TK 256 were collected on separate occasions. The mandibles show similar diagnostic features of relative position of the tooth and symphysis, of plateau like elevation of the upper edge of the mandibles around the alveolus, and of the shape of mandibular tooth. Because of above resemblance, these two specimens are considered to be of same species. However, there are some differences between the two specimens. In TK 245 the mandibular length is about

TABLE 3. SKULL DIMENSIONS OF *M. DENSIROSTRIS*

	Measurements	TK 256	Range of *M. densirostris*	Sample size
1.	Total (condylo-basal) length	725 mm	665–770 mm	4
2.	Rostrum, length from level of base of antorbital notches	63.7%	60–64%	4
3.	Rostrum, width between base of antorbital notches	22.3	24–28	4
4.	Rostrum, width at midlength	5.6	8–9	4
5.	Rostrum, depth at midlength	7.0	9–11	3
6.	Rostrum, least breadth proximal to midlength	6.1	6–8	2
7.	Rostrum, depth at same point	8.8	11–12	2
10.	Breadth of premaxillae at expanded proximal ends	16.6	16–20	4
12.	Least breadth of premaxillae opposite anterior nares	12.6	12–16	4
13.	Breadth of premaxillae opposite pemaxillary foramina	11.2	8–9	4
14.	Least distance between the posterodorsal margins of the maxillary foramina	8.4	6–9	4
17.	Distance between posterior border of maxillary foramen and anterior extremity of maxillary protuberance	9.0	8–10	4
21.	Breadth of anterior nares	5.9	4–6	4
34.	Length of vomer visible on palate	13.0	30–31	2
35.	Width at centers of orbits	37.2	40–47	4
37.	Width on zygomatic processes of squamosals	38.1	40–48	3
44.	Width of occipital condyles	11.4	14–15	4
46.	Height, vertex to inferior border of pterigoids	33.8	39–43	4

6 cm longer than that of TK 256 and the plateau around the alveolus is more prominent in TK 245.

Differences are also found in the shape and size of the teeth (Plate IV and Table 4). The pulp cavity of TK 245 is partly closed but that of TK 256 is still perfectly open. The number of growth ridges on the surface of cement, which reflect periodical growth of the tooth, is counted 11 and 8 respectively. If annual accumulation of the growth layers is accepted as in the case of the sperm whale (Ohsumi *et al*, 1963), the age of TK 245 and TK 256 are considered to be about 10 and 7 years old respectively. Accordingly, it is considered that several morphological differences between the two mandibles are due to the difference of age of the animals. As mentioned in the former chapter, TK 256 is a female in puberty stage, so TK 245 is probably a newly matured animal. The condition of the latter tooth, which is small and almost perfectly concealed in the alveolus, suggests this individual to be female.

The mandibular teeth of the present specimens are laterally compressed, and situated far behind the posterior end of mandibular symphysis and on the low plateau. The lateral view shapes an acute-angled triangle, and the anterior edge is slightly shorter than the posterior. The long axis of the tooth is inclined to the anterior direction, but the tip pointed nearly upward. At the top of the tooth, slightly posterior to the center, there is a small denticle which remains perfect because of the unerupted condition of the tooth. These diagnostic features coincide only with *Mesoplodon densirostris* among the known species of the genus *Mesoplodon*. Especially the shape of the tooth coincides with that of the formerly reported female specimens (Allen 1906, Raven 1942, private letter of J. C. Besharse on Midway specimens).

Skull The skull is collected only from TK 256. Several important measurements of the skull are shown in Table 3 with those of the *M. densirostris* in Moore (1958). Though, it shows that the present specimen has slender rostrum, most of the measurements fit with those of the other specimens.

On the present specimen, the length of vomer visible on palate is only 13% of total length of skull while the corresponding measurements of the two other specimens are 30 and 31%. This part is easily influenced by the condition of the maxillae, so the length of vomer visible on palate will not be an important taxonomical character.

On the dorsal view, the mesorostral cartilage is not ossified. The maxillary prominences are low and the prominential notches are shallow. Maxillary foramina opens forwardly in the bottom of the narrow parallel grooves. The lacrimal is visible at the bottom of antorbital notch. The lateral edges of the expansion of the maxillae above the temporal fossa are nearly straight and they open anteriorly. There is a deep notch between the supra narial crests formed by maxillae, premaxillae and frontals (Plate III, top and bottom). As pointed out by Moore (1966) the lateral margins of the left spiracular plate is horizontal in the profile. These characters well coincide with those of other *M. densirostris.*

Flipper The left flipper of TK 256 was collected. Its phalangeal formula is I: 1, II: 5, III: 6, IV: 4, V: 2.

TABLE 4. SKULL DIMENSIONS OF *MESOPLODON DENSIROSTRIS* FROM FORMOSA

		TK 256		TK 245	
	Measurements	mm	percentage of total length*	mm	percentage of total length*
1.	Total (condylo-basal) length	725	100.0	—	—
2.	Rostrum, length from level of base of antorbital notches	462	63.7	—	—
3.	Rostrum, width between base of antorbital notches	162	22.3	—	—
4.	Rostrum, width at midlength	41	5.6	—	—
5.	Rostrum, depth at midlength	51	7.0	—	—
6.	Rostrum, least breadth proximal to midlength	44	6.1	—	—
7.	Rostrum, depth at the same point	64	8.8	—	—
8.	Rostrum, width between prominential notches	95	13.1	—	—
9.	Breadth of premaxillae at midlength of rostrum	27	3.7	—	—
10.	Breadth of premaxillae at expanded proximal ends	120	16.6	—	—
11.	Greatest breadth of premaxillae in front of anterior nares	96	13.2	—	—
12.	Least breadth of premaxillae opposite anterior nares	91	12.6	—	—
13.	Breadth of premaxillae opposite premaxillary foramina	81	11.2	—	—
14.	Least distance between the posterodorsal margins of the maxillary foramina	61	8.4	—	—
15.	Least distance between premaxillary foramina	37	5.1	—	—
16.	Least distance between maxillary and premaxillary foramina	L. 14	1.9	—	—
		R. 11	1.5	—	—
17.	Distance between posterior border of maxillary foramen and anterior extremity of maxillary protuberance	L. 65	9.0	—	—
		R. 63	8.7	—	—
18.	Length of nasal suture line (anteroposterior)	14	1.9	—	—
19.	Length of nasal at the vertex of skull	L. 13	1.8	—	—
		R. 23	3.2	—	—
20.	Greatest breadth of nasals at the vertex of skull	26	3.6	—	—
21.	Breadth of anterior nares	43	5.9	—	—
22.	Breadth of posterior nares immediately behind pterigoid processes	69	9.5	—	—
23.	Length from tip of rostrum to prominential notch (median)	436	60.1	—	—
24.	Length from tip of rostrum to bottom of maxillary notches	472	65.1	—	—
25.	Length from tip of rostrum to anterior end of vomer	183	25.2	—	—
26.	Length from tip of rostrum to anterior margin of anterior nares	542	74.8	—	—
27.	Length from tip of rostrum to nasal vertex	587	81.0	—	—
28.	Length from tip of rostrum to madial suture line of posterior end of pterygoids	551	76.0	—	—
29.	Length from tip of rostrum to level of antorbital processes of maxillae	461	63.6	—	—
30.	Length from tip of rostrum to occipitofrontal vertex	607	83.7	—	—
31.	Length from tip of rostrum to posterior median end of maxillae on palate	462	63.7	—	—
32.	Length from tip of rostrum to most anterior point of palatines	333	45.9	—	—
33.	Length of premaxilla	L. 616	85.0	—	—
		R. 620	85.5	—	—
34.	Length of vomer visible on palate	94	13.0	—	—
35.	Breadth across centers of orbits	270	37.2	—	—
36.	Breadth across postorbital processes	Ca. 289	39.9	—	—

Continued . . .

TABLE 4. Continued.

		TK 256		TK 245	
	Measurements	mm	percentage of total length*	mm	percentage of total length*
37.	Breadth across zygomatic processes	276	38.1	—	—
38.	Breadth across posterior margins of temporal fossae	186	25.7	—	—
39.	Diameter of orbit (antero-posterior)	R. 95	13.1	—	—
40.	Length of temporal fossa	L. 80	11.0	—	—
		R. 83	11.4	—	—
41.	Depth of temporal fossa	L. 62	8.6	—	—
		R. 64	8.8	—	—
42.	Length of tympanic bone	R. 54	7.0	—	—
43.	Greatest breadth of tympanic bone	R. 40	5.5	—	—
44.	Breadth of occipital condyles	83	11.4	—	—
45.	Length of occipital condyle	L. 63	8.7	—	—
		R. 61	8.8	—	—
46.	Breadth of foramen magnum	33	4.6	—	—
47.	Height vertex to inferior border of pterygoids	248	33.8	—	—
48.	Length of mandible (median)	615	84.8	—	—
49.	Length of mandibular ramus	L. 625	100.0	—	—
		R. 623	100.0	681	100.0
50.	Length of mandibular symphysis	L. 159	25.4	—	—
		R. 160	25.7	206	30.2
51.	Distance from anterior end of mandible to coronoid process	L. 604	96.6	—	—
		R. 607	97.4	664	97.5
52.	Distance from anterior end of mandible to angle	L. 629	100.6	—	—
		R. 632	101.4	—	—
53.	Distance from anterior end of mandible to anterior lip of alveolus	L. 253	40.5	299	43.9
		R. 252	40.4	296	43.5
54.	Distance from anterior end of mandible to posterior lip of alveolus	L. 278	44.5	326	47.9
		R. 278	44.6	325	47.7
55.	Depth of mandible at posterior lip of alveolus	L. 73	11.7	86	12.6
		R. 73	11.7	87	12.8
56.	Depth between angle and coronoid process	L. 114	18.2	—	—
		R. 113	18.1	—	—
57.	Breadth across mandibular condyles	240	33.1	—	—
58.	Length of tooth	L. 51	8.2	L. 57	8.4
59.	Breadth of tooth (antero-posterior)	39	6.2	L. 48	7.0
60.	Breadth of tooth (transverse)	10	1.6	L. 12	1.8

* Measurements of mandibles are shown in the percentage of length of mandible

ACKNOWLEDGEMENT

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EXPLANATION OF PLATES

PLATE I

Fig. 1. Throat region of *M. densirostris*, TK 256.
Fig. 2. Ventral aspect of thoracic region of the same specimen.
Fig. 3. Ventral aspect of tail region of the same specimen.

PLATE II

Fig. 1. Lateral aspect of head region of *M. densirostris*, TK 256.
Fig. 2. Ventral aspect of tail flukes of the same specimen.
Fig. 3. Dorsal fin of the same specimen seen from the right side. A wound slightly below the base of dorsal fin will have been caused by hand harpoon.
Fig. 4. Ventral aspect of left flipper of the same specimen.

PLATE III

Dorsal, lateral, ventral and posterior (top to bottom) aspects of the skull of *M. densirostris*, TK 256.

PLATE IV

Fig. 1. Dorsal and lateral aspects of the mandible of *M. densirostris*, TK 256. White mark indicates the position of the tip of the mandibular tooth.
Fig. 2. Dorsal and lateral aspects of the mandible of *M. densirostris*, TK 245. White mark indicates the same with Fig. 1.

PLATE V

Fig. 1. Outer, ventral and posterior (top to bottom) aspects of the left mandibular tooth of *M. densirostris*, TK 256.
Fig. 2. Outer, ventral and posterior (top to bottom) aspects of the left mandibular tooth of *M. densirostris*, TK 245.

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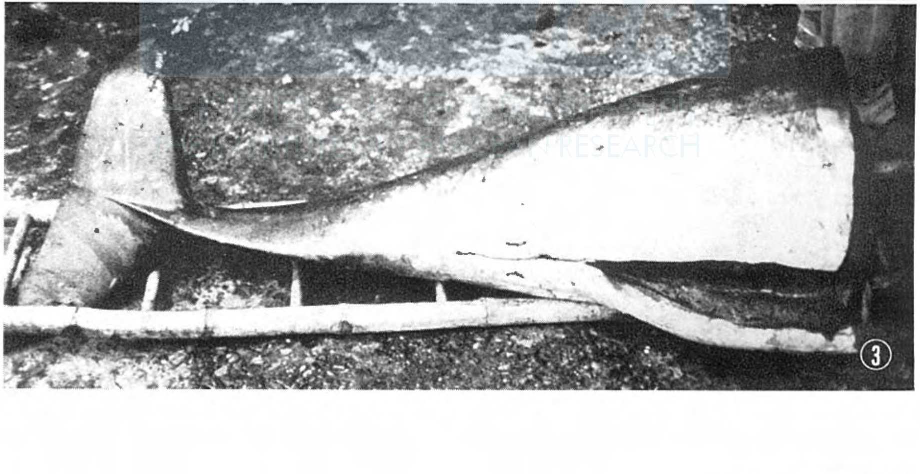

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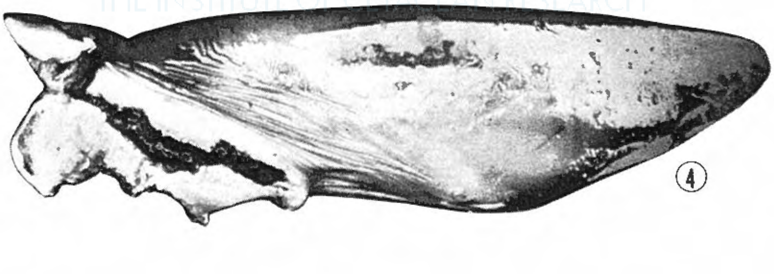

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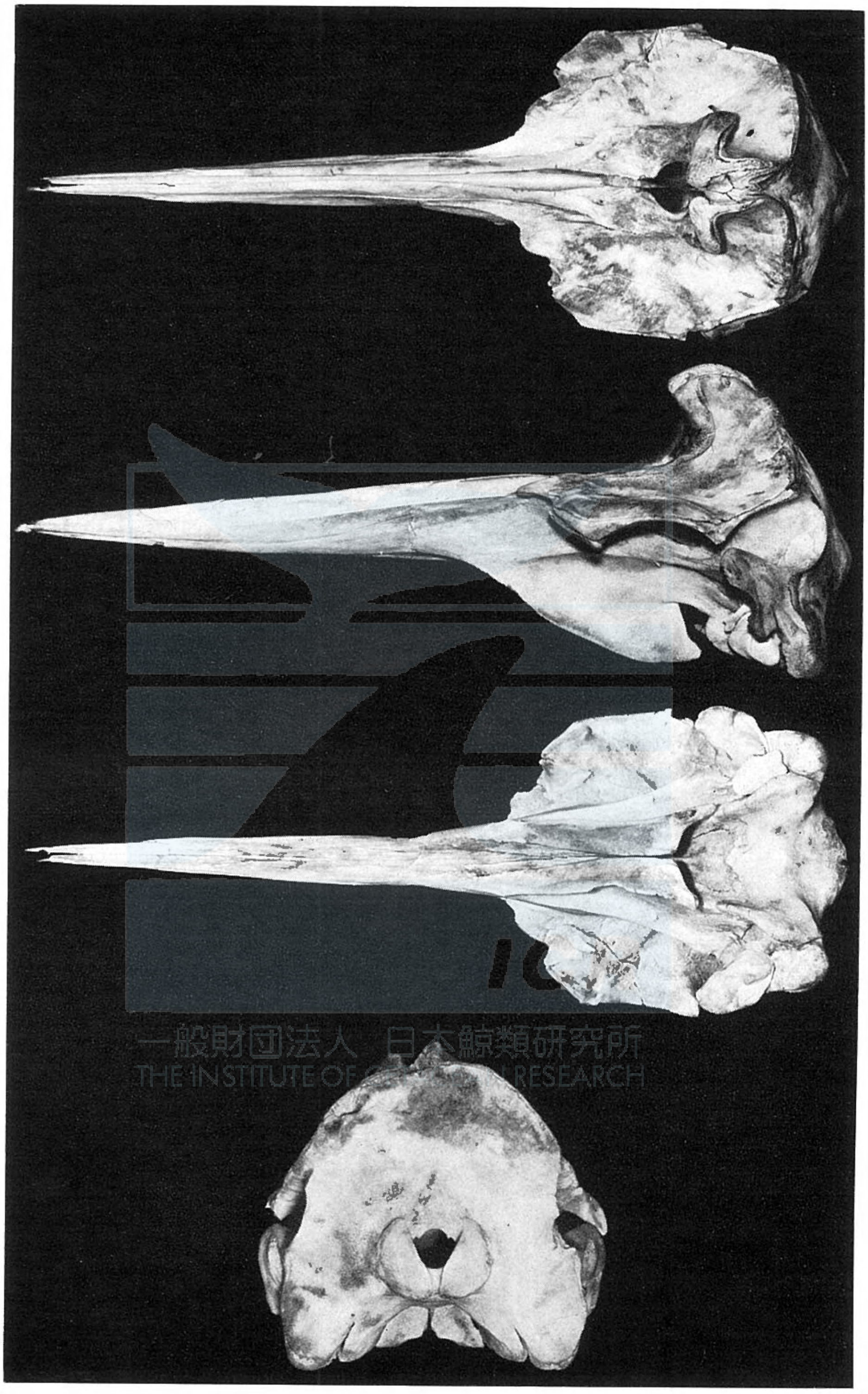

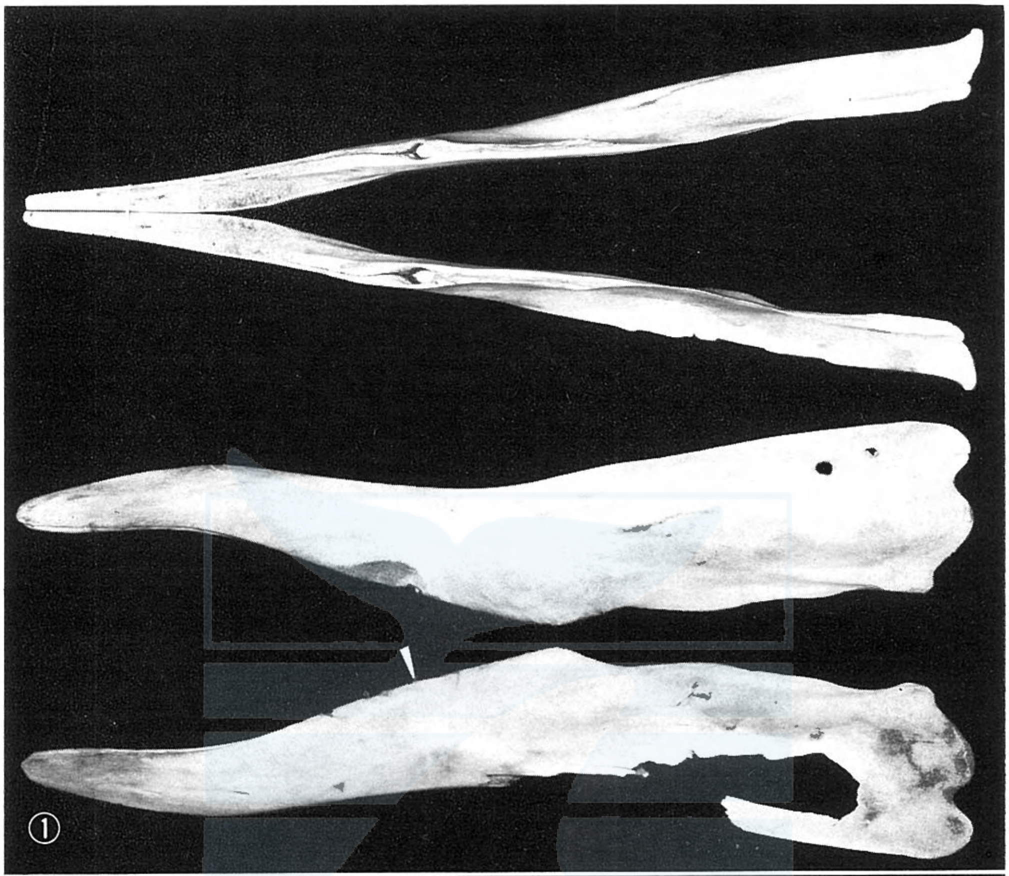

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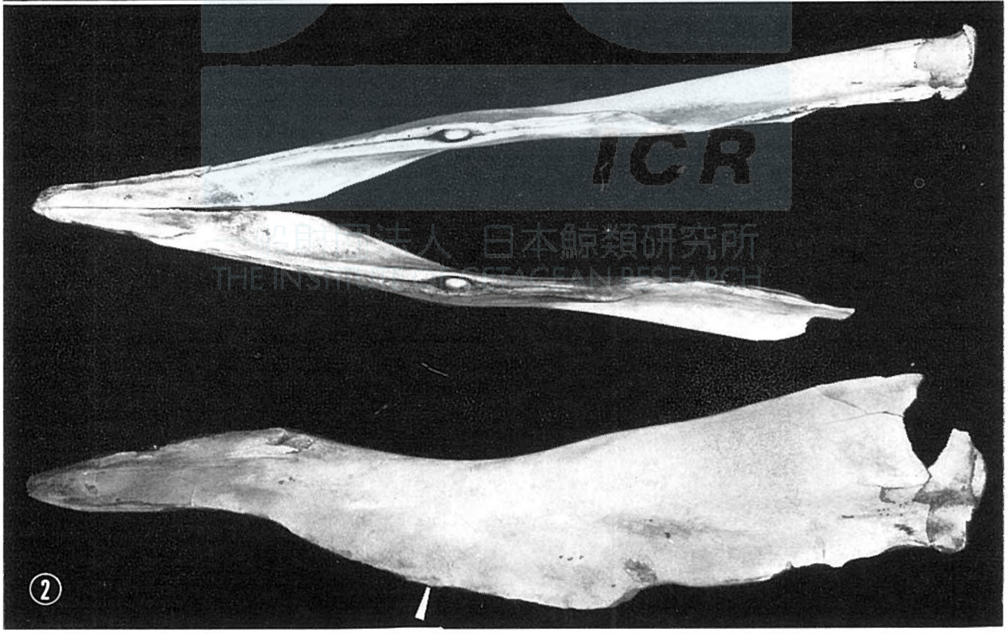

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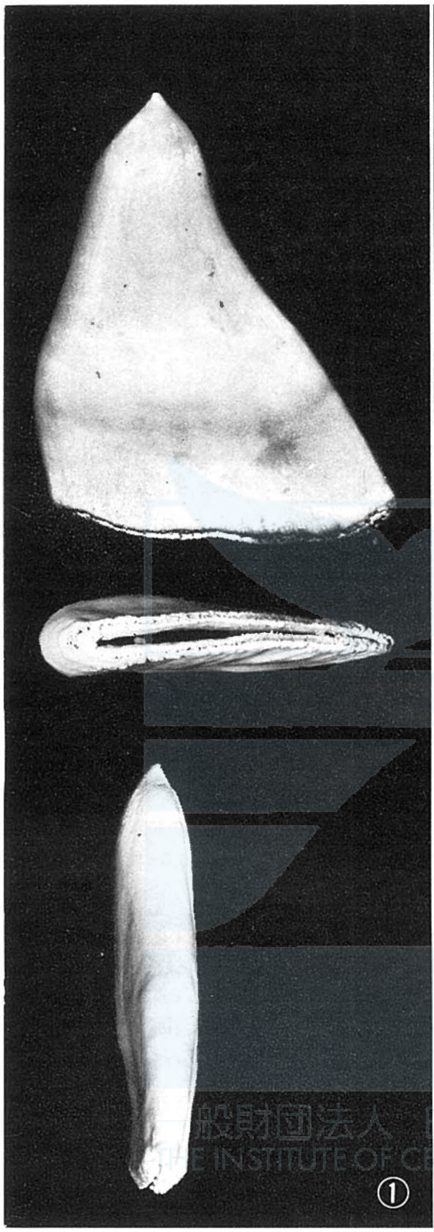

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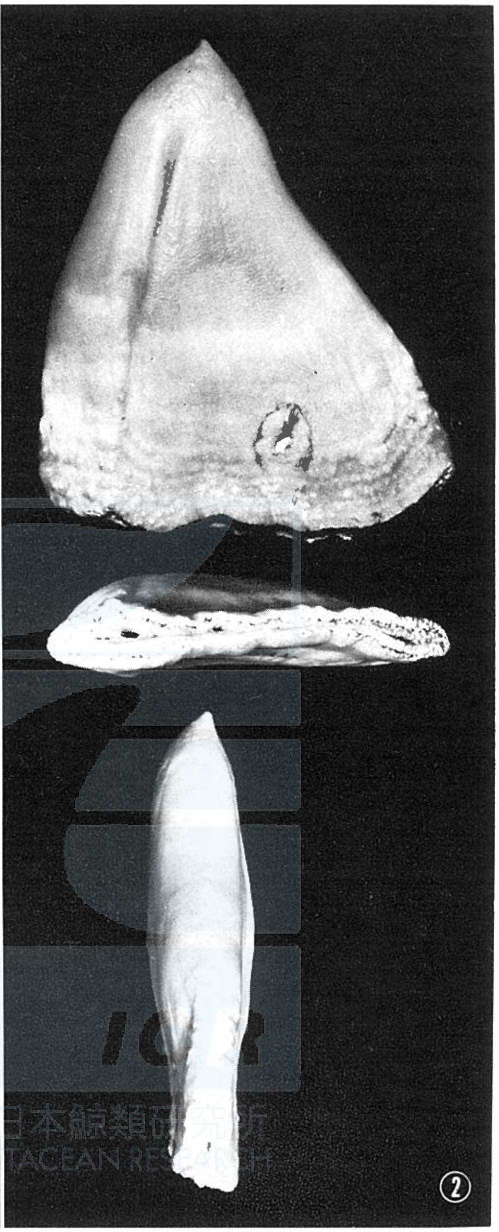

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A RARE DOUBLE MONSTER OF DOLPHIN, *STENELLA CAERULEOALBA*

AKITO KAWAMURA AND KYOJI KASHITA*

Kawana, a village on the east coast of Izu Peninsula and located some 90 km southwest from Tokyo, is famous with dolphin hunting where several thousands of small cetaceans are caught every year by means of ' Oikomi-driving '. This whaling method is somewhat alike to that followed by Malaitan natives of Solomon Islands (Dawbin, 1966). Almost all the cetaceans caught there are used exclusively for local consumption in Kawana and its environs.

During the course of examining whale body of *S. caeruleoalba* in the field at Kawana village on November 26, 1970, one of the authors (Kashita) found very small but an abnormaly shaped foetuses among many normal ones. On closer examination it was proved later to be a kind of double monster which was apparently attributable to monovulation. The foetuses have one head with two body trunks below the shoulder (Plate I).

A fairly big swarms of the dolphins had been driven into the Kawana Port on November 22, and kept alive there, and this foetuses were found among the one-day-catch of November 26. The number of dolphins caught on that day was 1,532 animals in total which were consisted of 1,262 larger sized individuals and 270 smaller ones. The composition of those animals by their state of maturity was not known. It could, however, be reasonably approximated from the previous study that both pregnant and lactating females occupy more than 40 percent among whole animals caught in mid-November of 1968 (Tobayama, 1970). The mother of this foetuses was 195 cm in total length, and showed no unusual appearance or charactors both in the outside look and internal organs. The features of ovaries, the number of corpus albicans and corpus luteum were not observed. The estiated age of the mother would be about 3 years from the body length by applying it to growth curve obtained previously (Kasuya, 1970).

The general characters observed in this double monster were as follows: The body lengths along transverse axis are 16.8 and 17.2 mm respectively. The facial region in ventral view is much broader at the eye level than normal foetuses of about same length. The breadth is 5.6 mm in the former and 4.2 mm in the latter while the distance between eyes is 3.1 and 3.4 mm respectively. The eyes are clearly visible, and the external nasal pits, *Fovea nasalis*, are distinctly seen on a level slightly below the eyes. There is mouth cleft just below the nasal pits. External ear opening is obscure. Maxillary process, lower jaw are distinguishable. Distance between nasal pits and mouth cleft is considerable. A slight neck-flexure is visible, which seems as one of the distinct differences from that of normal foetuses. Two pairs of fore-limbs and rudimental processes of hind-limbs on the side of genital

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member are distinct. Tails are conical in shape with obscure constrictions of muscle plates. Umbilical cords are quite massive and distinct so as to fill the cavity formed by confronting two bodies along with the dark brown colored evaginations of internal organs such as heart and liver. Pigmentation in the skin is not developed yet.

Comparing these characters with those of normal foetuses collected on the same day at Kawana, and with another species of dolphins, *Lagenorhynchus acutus* or *Phocaena communis* (Guldberg and Nansen, 1894), there seems no distinct differences between them except lateral appearance ; the double monster twins showed much slighter neck-flexure than the normal ones although it would be almost usual when the double monster was seen dorsi-lateraly. It therefore seems that those unusual appearance is supposedly caused by the fusing due to twisting of the bodies at their shoulder.

There have been reported at least two instances of Siamese twins and one double monster in cetaceans : the first report is a double monster of 3 feet foetus of 72 feet fin whale which was caught and found in Leith Harbor, South Georgia in 1946 (Intern. Whal. Statis., 1949; Vangstein, 1971, *person. com.*), the second one is southern sei whale (Kawamura, 1969), and then humpback whale very recently (Zemsky and Budylenko, 1970). The instances of sei and humpback whales are complete Siamese twins so-called equal conjoined twins of thoracopagus, and those of fin whale seems to be a kind of hemididymus or double monster, viz., two headed twins with one body trunk. All the twins having been reported were the only cases of baleen whales. The double monster reported here would be the first record in toothed whales, and double monster of cephalopagus, the type of this foetuses which have two dody trunks with one head, must be also the first instance throughout the order cetacea.

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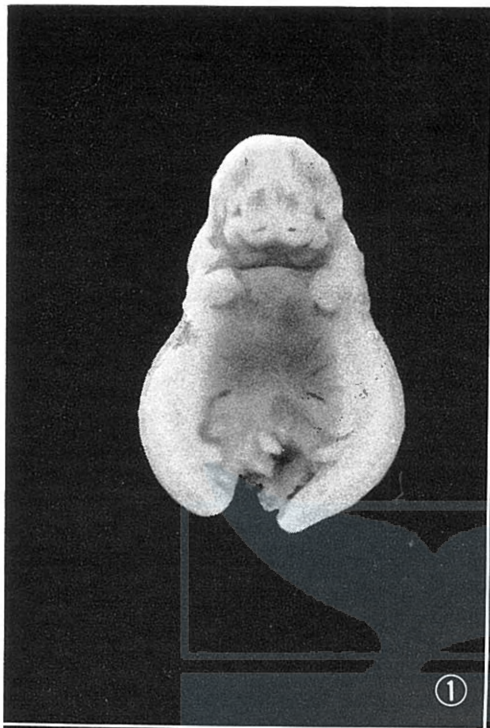
EXPLANATION OF PLATE

The foetal double monster of *Stenella caeruleoalba*

Fig. 1. Ventral view (ca. × 3.1)
Fig. 2. Dorsal view (ca. × 3.1)
Fig. 3. Ventro-lateral view (ca. × 3.1)
Fig. 4. Lateral views of the double monster (left) and the mormal foetus of about same body length (right). (ca. × 2.9)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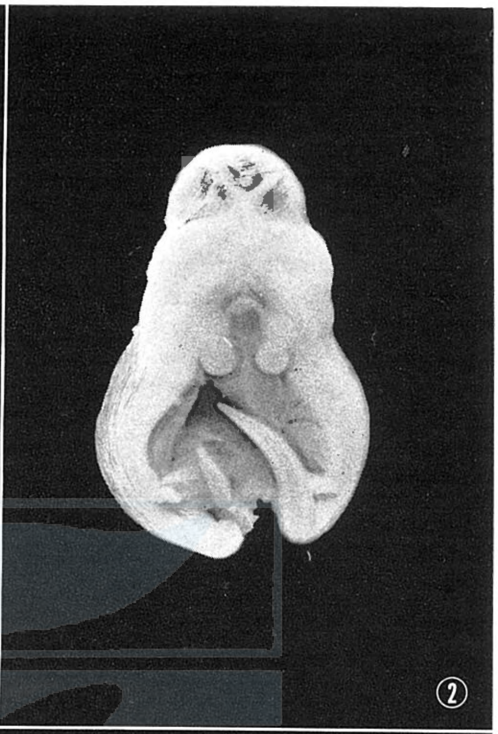
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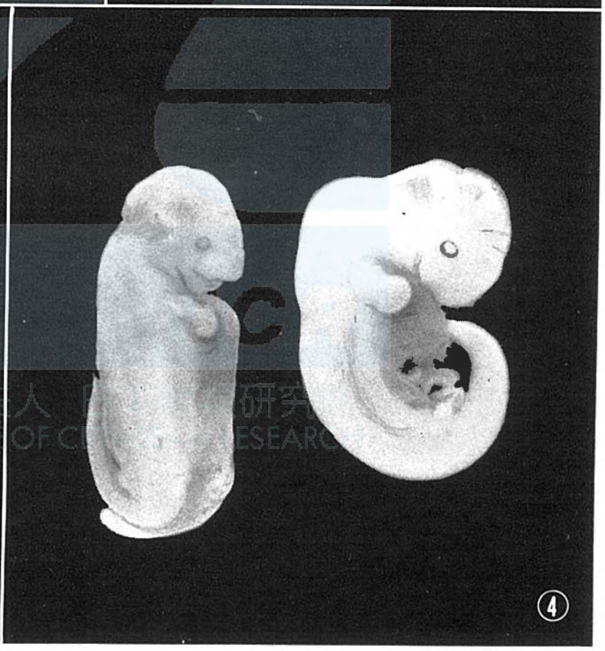
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FATTY ACID COMPONENTS OF GANGES RIVER DOLPHIN OIL

HIDEO TSUYUKI[*] AND SHINGO ITOH[*]

ABSTRACT

The purpose of the present work is an examination of chemical components of Ganges river dolphin oil by TLC, CC, and GLC.

The analysis by TLC and CC showed the presence of triglycerides, phospholipids, sterol esters, diglycerides, hydrocarbons, monoglycerides, sterols and free fatty acids. A substantial part in all fractions was 80.6% of triglycerides fraction contained a small amount of free fatty acids.

The analysis by GLC showed the presence of fatty acids with chain lengths from 10 to 22 carbon atoms and with zero to six double bonds. The Ganges river dolphin oil was found to be rich in unsaturated fatty acids (72.73%), particularly octadecamonoenoic (32.30%) and hexadecamonoenoic (24.47%). On the other hand, saturated fatty acids were contained in small amounts (27.27%) in Ganges river dolphin oil.

INTRODUCTION

Although we have reported on the fatty acid composition of the oil of Finless porpoise (Tsuyuki and Itoh, 1969a) and Many-toothed pilot whale (Tsuyuki and Itoh, 1969b) which are cetaceans in salt-water, the literatures on the oil of fresh-water cetaceans are few.

Expedition of the Ganges river dolphin (*Platanista gangetica*) was done in East Pakistan on the various field of study from Oct. 1969 through March 1970 organized by Prof. M. Nishiwaki of the Ocean Research Institute, University of Tokyo. The materials were brought us through Prof. M. Nishiwaki.

This study is reported as a part of the examination of Platanistidae which has been continuing to date by organized Japanese scientists.

It was a pleasure for us to join in the study.

MATERIAL AND METHODS

Material

Ganges river dolphin used in the present investigation was caught at the Ganges River in East Pakistan, in January 1970 by Prof. Dr. Nishiwaki. Then sample oil was extracted by boiling the blubber of Ganges river dolphin with water. The chemical properties of sample oil are shown in Table 1.

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TABLE 1. PROPERTIES OF GANGES RIVER DOLPHIN OIL

n_D^{20}	1.4635
Acid value	1.3
Iodine value (Wijs)	104.4
Saponification value	195.3
Unsaponifiable matter (%)	1.01

Thin-layer chromatography

TLC was carried out qualitatively according to the method of Doizaki and Zieve (1962). Commercially available silica gel (Wakogel B-5, Wako Pure Chemical Industries, Ltd. in Tokyo) was applied in 0.25 mm thickness on 5 × 20 cm glass plate. The plate was dried in air for 15 min after spreading, and activated for 1 hr at 110° just before use. The sample oil was applied on 1.5 cm place from the bottom of the plate with a capillary tube. The chromatograms were developed in the glass chamber saturated with petroleum ether-ethyl ether-glacial acetic acid, 90: 10: 1 (v/v/v). The developed plate was sprayed with 50% solution of sulfuric acid in water, and the separated spots were identified by comparison with the each standard mixture which was developed by the same procedure.

Silicic acid column chromatography

To separate Ganges river dolphin oil quantitatively, silicic acid column chromatography was carried out according to the modified method of Barron and Hanahan (1958). A glass column (height 70 cm, ID 20 mm) was packed with 60 g silicic acid (Wakogel C-200, Wako Pure Chemical Industries, Ltd. in Tokyo) prepared by activation at 120° for 1 hr and washing with hexane. 0.526 g of sample oil was placed on the column as 10% solution in hexane, and constituents in sample oil were eluted. Also the flow rate was adjusted to 1.5–1.8 ml/min, and then each fraction was respectively collected in amount of 20 ml. The solvent mixture was replenished from a reservoir filled consecutively with 120 ml of hexane, 180 ml of 15% benzen in hexane, 660 ml of 5% ether in hexane, 320 ml of 15% ether in hexane, 280 ml of 30% ether in hexane, 240 ml of 90% ether in hexane and 320 ml of 20% methanol in ether. Each fraction was identified by chromatographed known compounds on silicic acid column by the same procedure.

Preparation of methyl ester

Fatty acid methyl ester was prepared with boron trifluoride-methanol reagent according to Duron and Nowotny (1963). 100 mg of Ganges river dolphin oil was added 10 ml of boron trifluoride-methanol reagent (140 g BF_3 per liter of methanol) under nitrogen atmosphere, and the conical beaker was closed with the screw cap. Then, the beaker was heated in a boiling water bath for 45 min. After the reaction, the ester was extracted by adding 2 volumes of ethyl ether, so 1 volume of water and shaking. The ethyl ether solution was dehydrated with anhydrous sodium sulfate and then evaporated. Finally the methyl ester was obtained in amount of 92 mg.

Gas-liquid chromatography

GLC was analyzed with a Shimadzu Gas Chromatograph Model GC-1C using a flame ionization attachment. A 180 cm long, 3 mm ID, U shaped stainless steel column was packed with Shimalite W (60–80 mesh), coated with 10% diethylene glycol succinate (commercially available DEGS made by Shimadzu Seisakusho Ltd, in Kyoto). Column temperature was kept constantly at 200°, and temperature at injection port and detector block were respectively 275° and 240°. Flow rates for air, nitrogen as carrier and hydrogen were 600, 70 and 75 ml/min respectively.

Chromatographic peaks were identified either by comparison of retention times with those of standards or from a graph representing the relationship between log retention time and the number of carbon atoms by applying the methods of Ackman (1963), Nelson and Freeman (1960).

Each peak was quantitated by the method of Ettre and Kabot (1963). All fatty acids were calculated as weight percentages of the total known fatty acids present.

RESULTS AND DISCUSSION

Fig. 1 shows the fractionation of Ganges river dolphin oil by a TLC plate qualitatively. The obtained fractions were from above, as follows: hydrocarbons, sterol esters, triglycerides, free fatty acids, sterols, diglycerides, monoglycerides and phos-

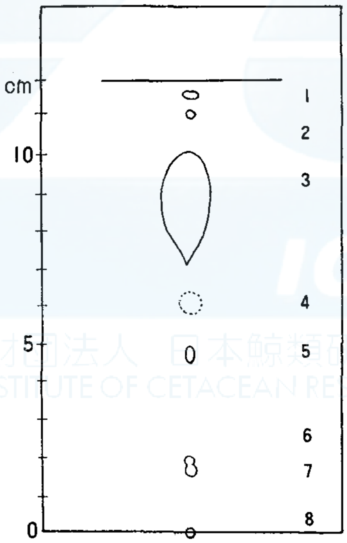

Fig. 1. Thin-layer chromatogram of Ganges river dolphin oil.
1. Hydrocarbons
2. Sterol esters
3. Triglycerides
4. Free fatty acids
5. Sterols
6. Diglycerides
7. Monoglycerides
8. Phospholipids

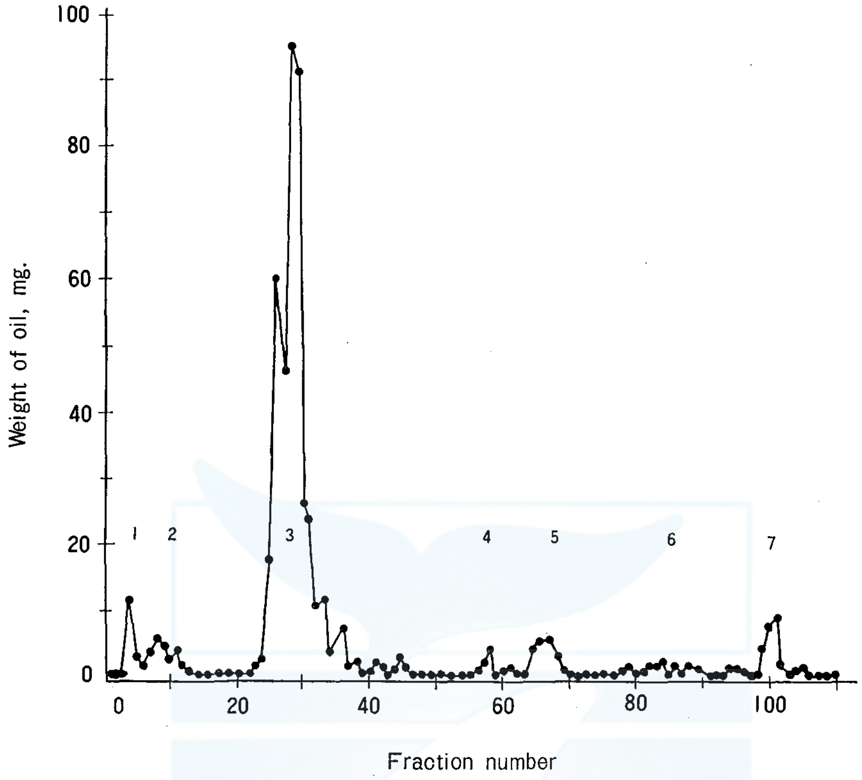

Fig. 2. Separation of Ganges river dolphin oil by silicic acid column.

No.	Fraction	Eluting solvent
1	Hydrocarbons	Hexane
2	Sterol esters	15% benzen in hexane
3	Triglicerides & free fatty acids	5% ether in hexane
4	Sterols	15% ether in hexane
5	Diglycerides	30% ether in hexane
6	Monoglycerides	90% ether in hexane
7	Phospholipids	20% methanol in ether

pholipids. It was seemed that triglycerides fraction was contained in sample oil at the largest quantity as compared to other fractions, because of the spot color was darker than others. The seven fractions except triglycerides seem to be contained respectively only trace amount as compared to triglycerides fraction.

Fig. 2 shows the fractionation of Ganges river dolphin oil by a silicic acid column quantitatively. The seven fractions were eluted as follows: hydrocarbons, sterol esters, triglycerides and free fatty acids, sterols, diglycerides, monoglycerides, and phospholipids. The largest proportion was 80.6% as triglycerides and free fatty acids fraction, and other proportions were as follows: 4.9% phospholipids, 4.1% sterol esters, 3.2% diglycerides, 2.8% hydrocarbons, 2.5% monoglycerides and 1.9% sterols.

TABLE 2. FATTY ACID COMPONENTS OF GANGES RIVER DOLPHIN OIL

No. of carbon atoms	No. of double bonds	Weight per cent	No. of carbon atoms	No. of double bond	Weight per cent
12	0	0.39	18	3	0.43
12	1	0.09	18	4	0.24
14	0	4.89	20	0	2.51
14	1	2.35	20	1	0.54
14	2	1.40	20	2	0.11
16	0	18.11	20	3	0.29
16	1	24.47	20	4	0.98
16	2	1.32	20	5	0.42
16	3	1.71	22	0	0.10
18	0	1.27	22	4	0.53
18	1	32.30	22	5	0.41
18	2	4.65	22	6	0.49

TABLE 3. A COMPARISON OF SATURATED AND UNSATURATED FATTY ACIDS OF GANGES RIVER DOLPHIN OIL

No. of carbon atoms	Weight per cent of total fatty acids		
	Saturated	Unsaturated	Total
12	0.39	0.09	0.48
14	4.89	3.75	8.64
16	18.11	27.50	45.61
18	1.27	37.62	38.89
20	2.51	2.34	4.85
22	0.10	1.43	1.53
Total	27.27	72.73	100.00

From the results of thin layer chromatogram and column chromatogram, it was found that Ganges river dolphin oil was approximately consisted of triglycerides.

Table 2 shows the fatty acid components of Ganges river dolphin oil by quantitative GLC analysis. There were 24 kinds of fatty acids, having from 12 to 22 carbon atoms. The majority were hexadecanoic, hexadecamonoenoic and octadecamonoenoic fatty acids, because of the total of the above three fatty acids held really 74.88% of the total fatty acids. The next prominents were tetradecanoic, tetradecamonoenoic and octadecadienoic fatty acids. On the other hand, the total proportion of other fatty acids was slightly 9.72%. In comparison with saturated and unsaturated fatty acids, the proportion of total saturated fatty acids was 27.27%, and those of total unsaturated fatty acids was 72.73%, as shown in Table 3. Moreover, to compare with the proportion of each carbon numbers, the most prominent was 45.61% of 16 carbon atoms fatty acids, and the next was 38.89% of 18 carbon atoms fatty acids. The rest were as follows: 8.64% 14 carbon atoms, 4.85% 20 carbon atoms, 1.53% 22 carbon atoms and 0.48% 12 carbon atoms.

Finally, the principal ingredient of Ganges river dolphin oil was triglycerides, and main fatty acid components of sample oil were hexadecanoic, hexadecamonoenoic and octadecamonoenoic.

SUMMARY

1. The fractionation of Ganges river dolphin oil was done by thin layer chromatography and silicic acid chromatography. The largest fraction was triglycerides and free fatty acids, and its proportion was 80.6%. The other proportions were as follows: phospholipids 4.9%, sterol esters 4.1%, diglycerides 3.2%, hydrocarbons 2.8%, monoglycerides 2.5%, and sterols 1.9%.

2. Fatty acid components of Ganges river dolphin oil were analyzed by gas-liquid chromatography.

The results obtained were as follows:

Total saturated fatty acids	27.27%;
dodecanoic	0.39%
tetradecanoic	4.89%
hexadecanoic	18.11%
octadecanoic	1.27%
eicosanoic	2.51%
docosanoic	0.10%
Total unsaturated fatty acids	72.73%;
dodecamonoenoic	0.09%
tetradecamonoenoic	2.35%
tetradecadienoic	1.40%
hexadecamonoenoic	24.47%
hexadecadienoic	1.32%
hexadecatrienoic	1.71%
octadecamonoenoic	32.30%
octadecadienoic	4.65%
octadecatrienoic	0.43%
octadecatetraenoic	0.24%
eicosamonoenoic	0.54%
eicosadienoic	0.11%
eicosatrienoic	0.29%
eicosatetraenoic	0.98%
eicosapentaenoic	0.42%
docosatetraenoic	0.53%
docosapentaenoic	0.41%
docosahexaenoic	0.49%

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