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–W S W	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

Size (whales)	North Pacific				Antarctic	
			Pelagic ground			
	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.

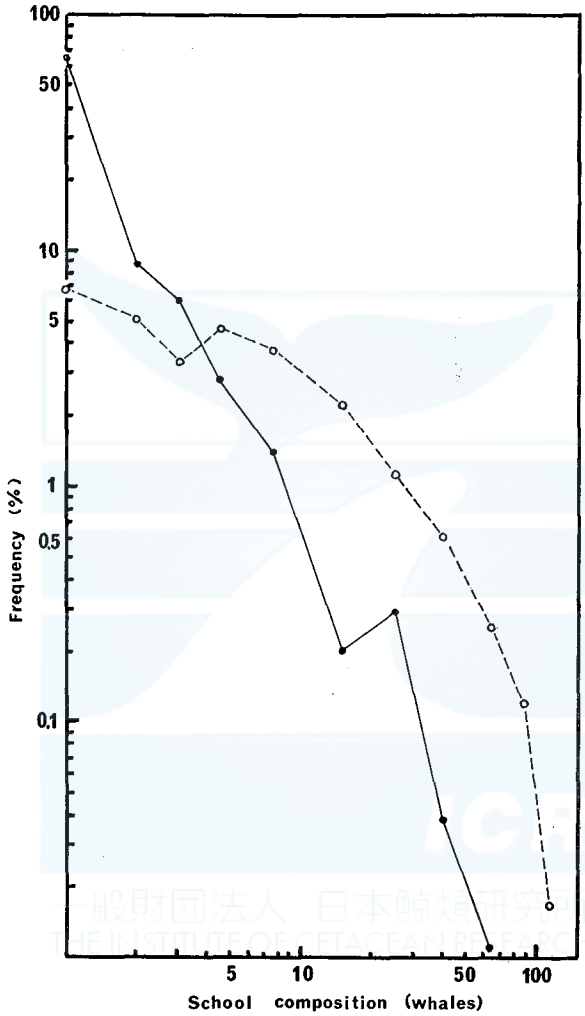


Fig. 1. Frequency distribution of school composition (number of whales in a school) in the sperm whale.
Open circle and broken line: Japanese coastal waters,
Closed circle and solid line: northern part of the North Pacific (north of 50°N).

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 South	50°N North	Total	North	South	Total
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

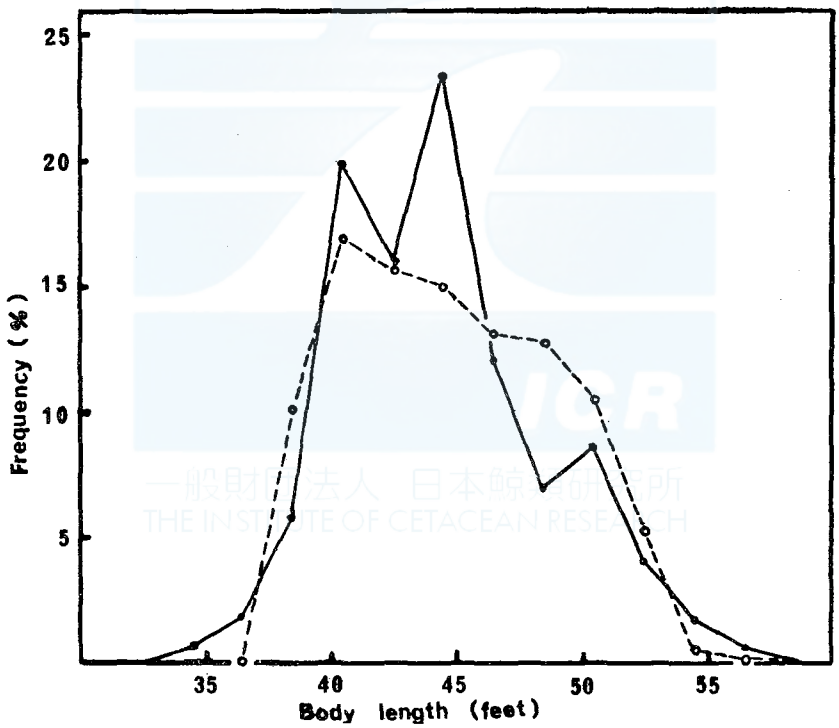


Fig. 2. Estimated size distribution of solitary sperm whales and size distribution of male sperm whales caught in the northern part of the North Pacific in 1957. Closed circle and solid line: solitary whales, Open circle and broken line: males caught.

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

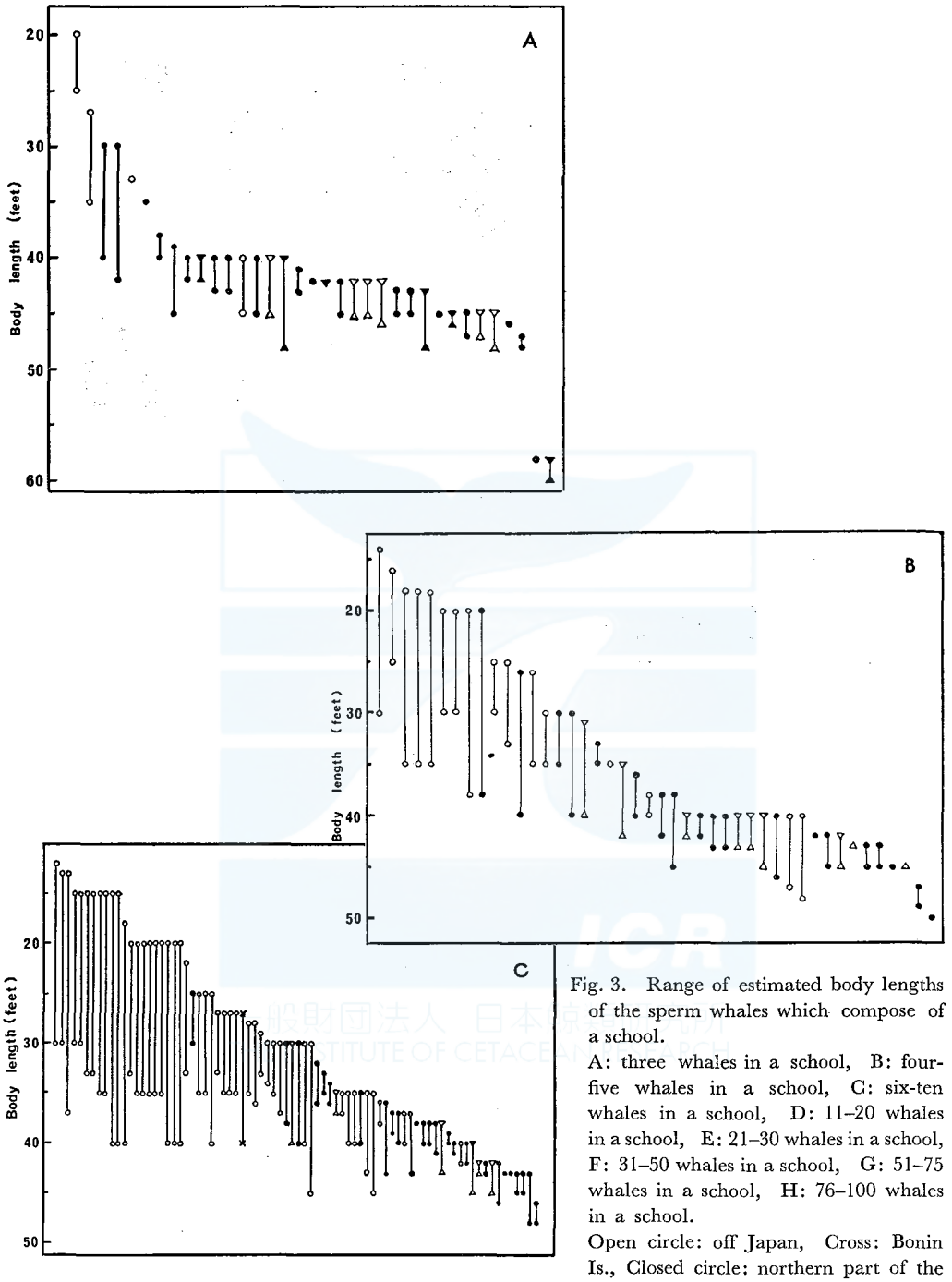
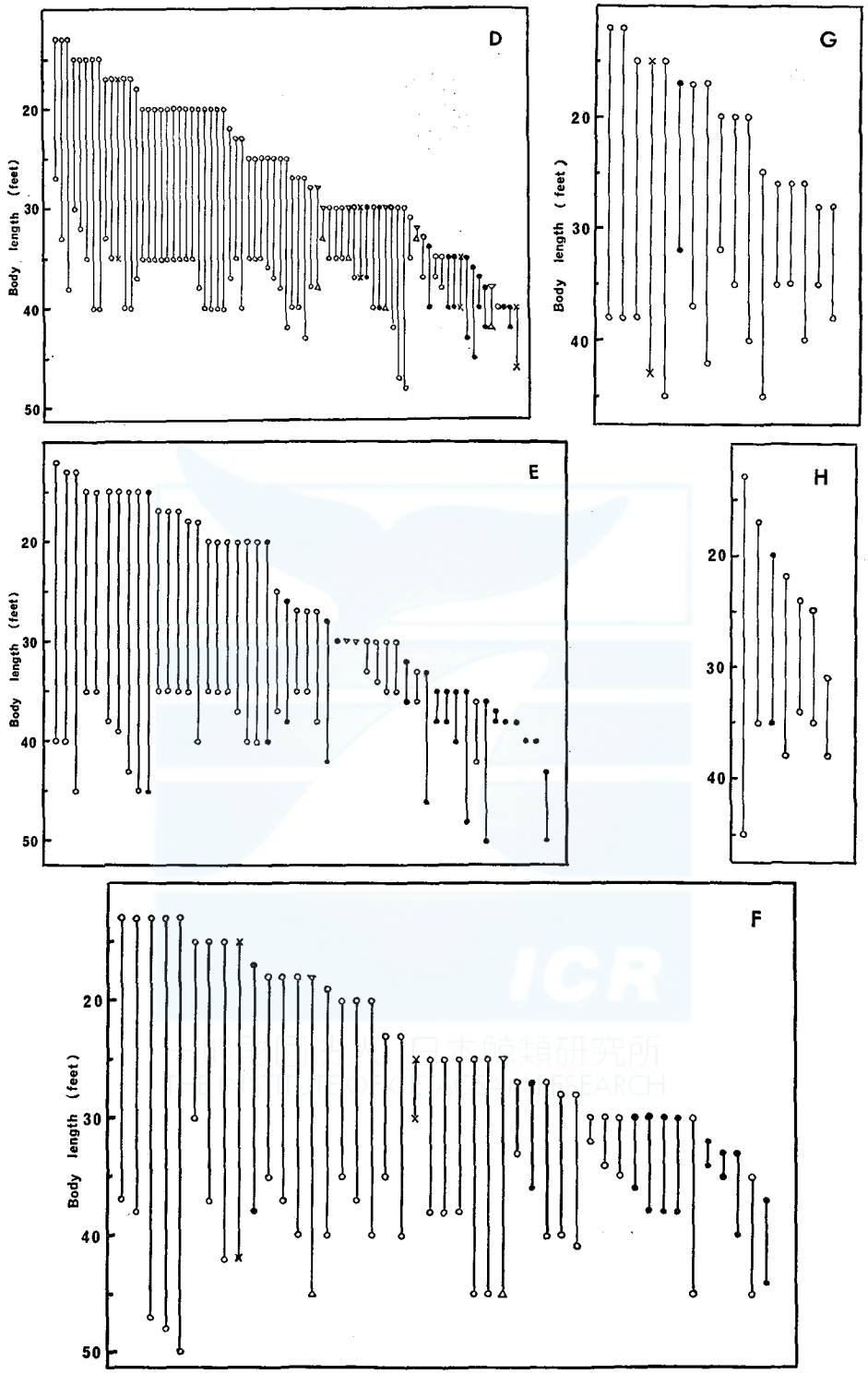


Fig. 3. Range of estimated body lengths of the sperm whales which compose of a school.
A: three whales in a school, B: four-five whales in a school, C: six-ten whales in a school, D: 11–20 whales in a school, E: 21–30 whales in a school, F: 31–50 whales in a school, G: 51–75 whales in a school, H: 76–100 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
G
E
H
F
Body length (feet)
20
30
40
50

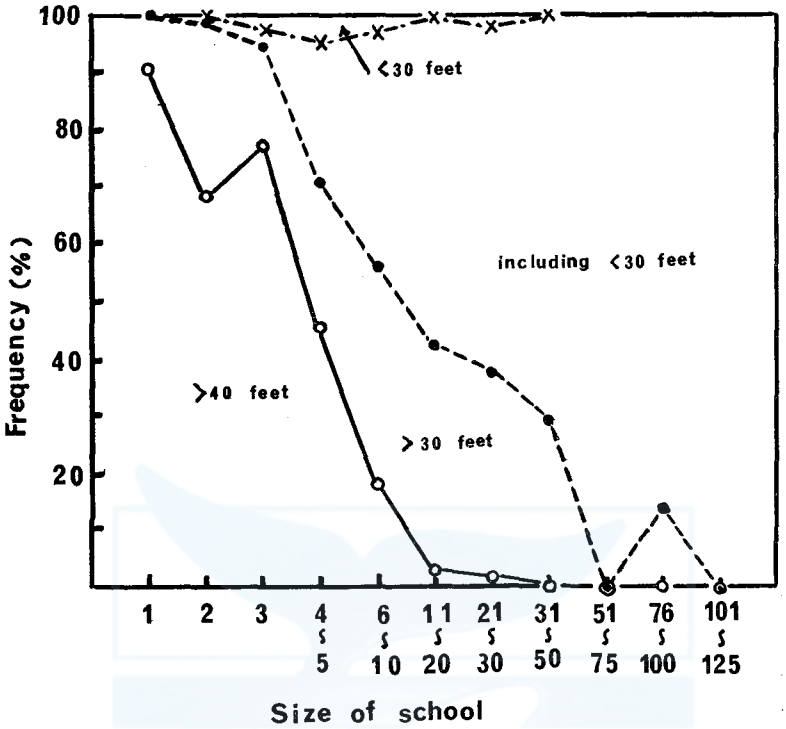


Fig. 4. Change in ratio of frequency occurrence of sperm whale schools classified by range of body length according with the size of school.
+40 feet: Schools composed with individuals over 40 feet in body length, +30 feet: Schools composed with individuals over 30 feet in body length, Including +30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

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

Mark No.	Sex	Body length (feet): 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								Grand Total
	Male	Female			Total	Male	Female			Total	Male			Female				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								Grand Total
	Male	Female			Total	Male	Female			Total	Male			Female				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		7	4	
Puberal	—	1	—	2	—		2	1	
Pregnant		5[a)]			2	26		3	9
Lactating		5	1[c)]		1			14[b)]	
Resting		—			5			6[b)]	
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		8	
Lactating	19	33	16	32
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 ".

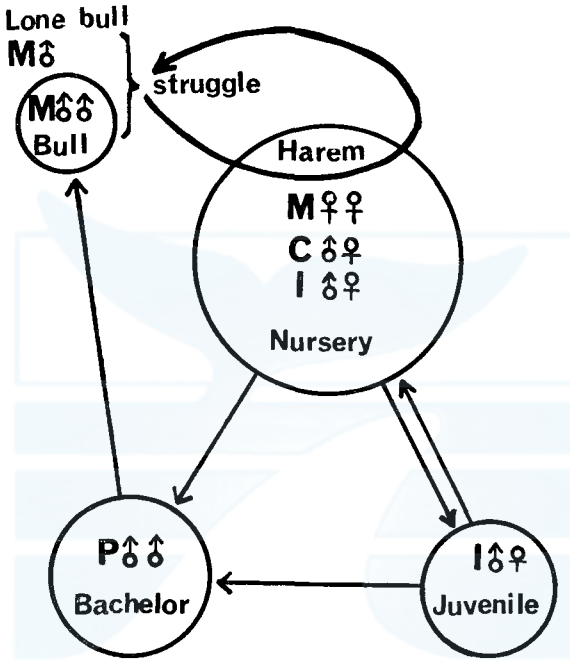


Fig. 5. Types and their relationship of social organization in the sperm whale.
M: mature, I: immature, C: suckling, P: puberal.

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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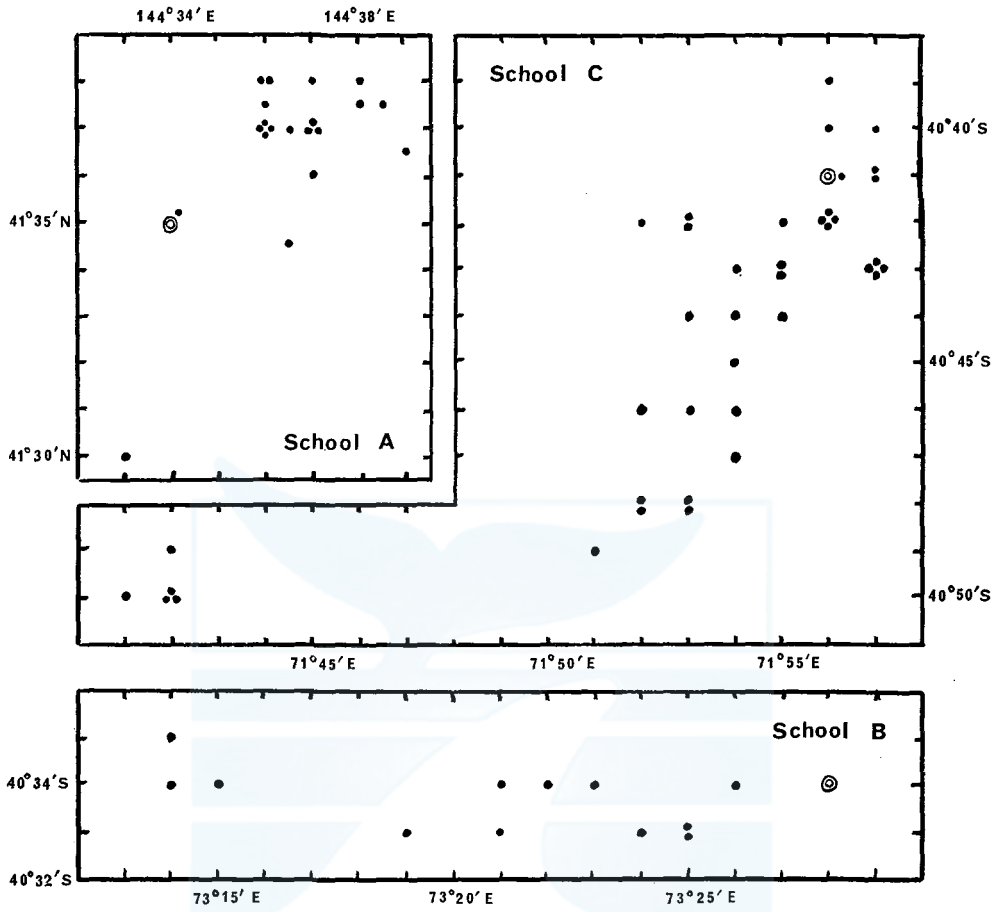

Appendix-fig. 1. Positions found and caught of the sperm whales in the special investigations of school catch.
Double circle: position found, Closed circle: position caught.

APPENDIX TABLE 1. BIOLOGICAL DATA ON THE

Samp. No.	Sex	Body length (m)	Age (years)	Mammary gland: Thickness (cm)	Mammary gland: Condition[a]	Breadth of uterine cornu (cm): Left	Breadth of uterine cornu (cm): Right	Foetus: Sex	Foetus: Length (cm)	Gonad[b]: Left	Gonad[b]: Right	V.[c]
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 Left	Lower Right	Upper		
8.0		0		—	+	—	22	22	L 13	12 : 10	
9.0	Sq	r	f	—	—	—	27	28	L 15	13 : 05	
10.5		0		—	+	—	20	20	R 12	12 : 20	
8.0	Sq	r	f	B	—	—	25	25	R 10+	12 : 50	
7.0	Sq	r	f	A	—	—	25	26	R 14	15 : 30	
11.5	Sq	r	f	B	+	+	22	22	R 13	12 : 20	Mother
10.0	Sq	r	f	B	—	—	27	27	R 11+	12 : 55	
10.5	Sq	r	f	B	+	—	22	24	R 15	12 : 00	
10.0		0		C	+	—	26	26	L 16	12 : 20	Mother
8.5		0		C	—	—	21	21	L 10+	13 : 10	Large scar on top of head
10.0	Sq	r	ff	A	+	—	Broken		L 12	10 : 35	Mother
9.5		0		C	+	+	Broken		R 13+	12 : 00	
10.0		0		B	+	—	23	23	L 13+	12 : 30	
8.0		0		C	—	—	24	25	R 13	14 : 35	
9.0	Sq	r	f	D	—	—	23	23	R 15	14 : 25	
9.0	Sq	r	f	CD	±	—	22	22	R 14+	13 : 10	
8.5		0		D	±	—	23	22	R 14	12 : 45	
7.5	Sq	r	f	A	—	—	22	22	L 11	12 : 25	
10.0		0		C	+	+	21	21	R 14	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 Sex	Foetus Length (cm)	Gonad	Thickness of blubber (cm)	Stomach contents Species	Stomach contents Quantity	Ossification of vertebrae	Time caught	Remarks
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	
B10	M	9.2	10				0.8, 0.8	9.0		0	n	19:05	
B11	F	9.5	12	R	F	300	1–3, 0–1	7.0	Sq	rr	N	18:30	
B12	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 Sex	Foetus Length (cm)	Gonad	Thickness of blubber (cm)	Stomach contents Species	Stomach contents Quantity	Ossification of vertebrae	Time caught	Remarks
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.